MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

Global Changes

Summer 2013 | In this Issue

MIT JOINT PROGRAM SCIENCE POLICY GLOBAL CHANGE

MISSION AND OBJECTIVES

Integrating natural and social science to further the international dialogue toward a global response to climate change

- Discover new interactions between natural and human climate system components
- Objectively assess uncertainty in economic and climate projections
- Critically and quantitatively analyze environmental management and policy proposals
- Improve methods to model, monitor and verify greenhouse gas emissions and climate impacts
- Understand the complex connections among the many forces that will shape our future

IN THIS ISSUE:

Climate Change and Food Security

Central to our program is discovering what impacts climate change may have on society—and there is no sector more exposed to changes in climate than farming. This summer, farmers in the Midwest had flooded fields after seeing snow in May, and record heat and drought last year. Meanwhile, farmers in the southwest continue to suffer from one of the worst droughts in decades. How will we confront climate changes like these while trying to feed the world's growing population? At the Joint Program, we know there is no simple answer to this question. The system is complex and interactive, and so is our approach—food security isn't separate from water challenges, which isn't separate from energy needs.

To help analyze these interactions, we've developed a model for predicting crop yield changes in the world's breadbasket regions—areas where major crops like corn, wheat, rice and soy beans are grown. We've found the effects of climate change on agriculture are likely to be mixed. Generally speaking, colder regions should expect longer growing seasons and higher yields, while in warmer regions heat may exceed critical thresholds resulting in lower yields. In fact, in some areas, crop yields could be cut in half.

These changes could in turn affect food prices. But if regions near the equator that are currently productive suffer significant yield losses, those losses could balance out with gains in colder areas—keeping the global price of food largely unchanged. In this case, even though global food supply may be adequate, regional economies could be disrupted, especially if those countries accustomed to depending on local agriculture can't generate other economic activity. Or if yield losses are more widespread such that the cost of food increases, these conditions could contribute to political instability and "environmental refugees." Some have pointed to high food prices as being a contributing factor to the Arab Spring. Adaptation and robust trade in food could allow us to take advantage of ups and downs in yields around the world, but a big problem is the lack of predictability of what will happen in local growing regions from year-to-year.

Climate change affects agriculture. But how does agriculture affect climate change? There are five key ways. First, the agricultural sector uses fossil energy—though such emissions from tractors and water pumping adds a percent or two of CO_2-equivalent global greenhouse gas emissions. Second, agriculture adds an additional 10 to 12 percent of emissions from methane from rice and livestock production and nitrous oxide resulting from fertilizers. Third, land-use changes such as deforestation contribute an estimated 12 percent of greenhouse gases. There is considerable uncertainty in these estimates, but it adds up to around one quarter of emissions from a sector that makes up only about 3 percent of the world economy.

Agriculture also affects climate change in other ways. Particularly in developing countries, regular burning of fields and forest clearing produces ozone smog—a greenhouse gas—and aerosols that affect climate in a variety of ways and may have especially strong effects on precipitation patterns. Then changing the planet's surface from forest to grass or crop land can also change the hydrology and radiative balance of the planet. For example, while cutting down CO_2–absorbing forests for food or biofuels would lead to higher emissions the added warming could be balanced by the more reflective open land that would have a cooling effect (see page 4 to learn more).

Even as agriculture is a major cause of greenhouse gas emissions and other climate changes, it could also play a role in mitigating climate change. Our studies show that an aggressive global reforestation policy could avoid about a half-degree Celsius of warming by 2100. The key would be putting a price on changes in carbon stored in agro-ecosystems. Such a price would create an incentive for landholders to reforest their land to sequester carbon. But more land for forests means less land to grow food—raising the price of food (see page 12 to learn more).

This is the "trilemma" we face when trying to decide what to do with land in the 21st century. Do we use it to produce food? Do we use it to preserve biodiversity and store carbon? Do we use it to produce biofuels as a substitute for fossil fuels? These are the questions we will explore in a symposium on food this fall. But one factor is clear: there are no clean–cut answers or easy solutions when it comes to climate change and food security. No matter what the decision, there will be unavoidable trade-offs. Still, the worst "solution" would be continued inaction in the face of the overwhelming evidence that climate change has real and growing effects on so many aspects of our society—what's on the dinner table included.

— John Reilly

MIT GLOBAL CHANGE JOINT PROGRAM FOOD SYMPOSIUM

Join us at our Food Symposium on Tuesday, November 5th. Learn more on page 25.

Cleaner Energy, Warmer Climate?

Researchers explore possible consequences of greater biofuel use.

The growing global demand for energy, combined with a need to reduce emissions and lessen the effects of climate change, has increased focus on cleaner energy sources. But what unintended consequences could these cleaner sources have on the changing climate?

Researchers at MIT now have some answers to that question, using biofuels as a test case. Their study, recently released in *Geophysical Research Letters*, found that land-use changes caused by a major ramp-up in biofuel crops—enough to meet about 10 percent of the world's energy needs—could make some regions even warmer.

"Because all actions have consequences, it's important to consider that even well-intentioned actions can have unintended negative consequences," says Willow Hallgren, the lead author of the study and a research associate at MIT's Joint Program on the Science and Policy of Global Change. "It's easy to look at a new, cleaner energy source, see how it will directly improve the climate, and stop there without ever considering all the ramifications. But when attempting to mitigate climate change, there's more to consider than simply substituting out fossil fuels for a cleaner source of energy."

Hallgren and her colleagues explored some of those consequences in considering two scenarios: one where more forests are cleared to grow biofuel crops, and one where forests are maintained and cropland productivity is intensified through the use of fertilizers and irrigation.

In both cases, the researchers found that at a global scale, greenhouse gas emissions increase—in the form of more CO_2 when CO_2–absorbing forests are cut, and in the form of more nitrous oxide from fertilizers when land use is intensified. But this global warming is counterbalanced when the additional cropland reflects more sunlight, causing some cooling. Additionally, an increase in biofuels would replace some fossil fuel-based energy sources, further countering the warming.

While the effects of large-scale expansion of biofuels seem to cancel each other out globally, the study does point to significant regional impacts—in some cases, far from where the biofuel crops are grown. In the tropics, for example, clearing of rainforests would likely dry the climate and increase warming, with the Amazon Basin and central Africa potentially warming by 1.5 °C .

This tropical warming is made worse with more deforestation, which also causes a release of CO_2, further contributing to the warming of the planet. Meanwhile, Arctic regions might generally experience cooling caused by an increase in reflectivity from deforestation.

"Emphasizing changes not only globally, but also regionally, is vitally important when considering the impacts of future energy sources," Hallgren says. "We've found the greatest impacts occur at a regional level."

From these results, the researchers found that land-use policies that permit more extensive deforestation would have a larger impact on regional emissions and temperatures. Policies that protect forests would likely provide more tolerable future environmental conditions, especially in the tropics.

David McGuire, Professor of Ecology at University of Alaska Fairbanks, says these findings are important for those trying to implement mitigation policies to consider.

"Hallgren et al. caution that society needs to further consider how biofuels policies influence ecosystem services to society as understanding the full dimension of these effects should be taken into consideration before deciding on policies that lead to the implementation of biofuels programs," McGuire says.

He finds Hallgren's incorporation of reflectivity and energy feedbacks unique compared to similar studies on the climate impacts of biofuels.

Beyond the climate

While Hallgren focuses specifically on the climate implications of expanded use of biofuels, she admits there are many other possible consequences—such as impacts on food supplies and prices.

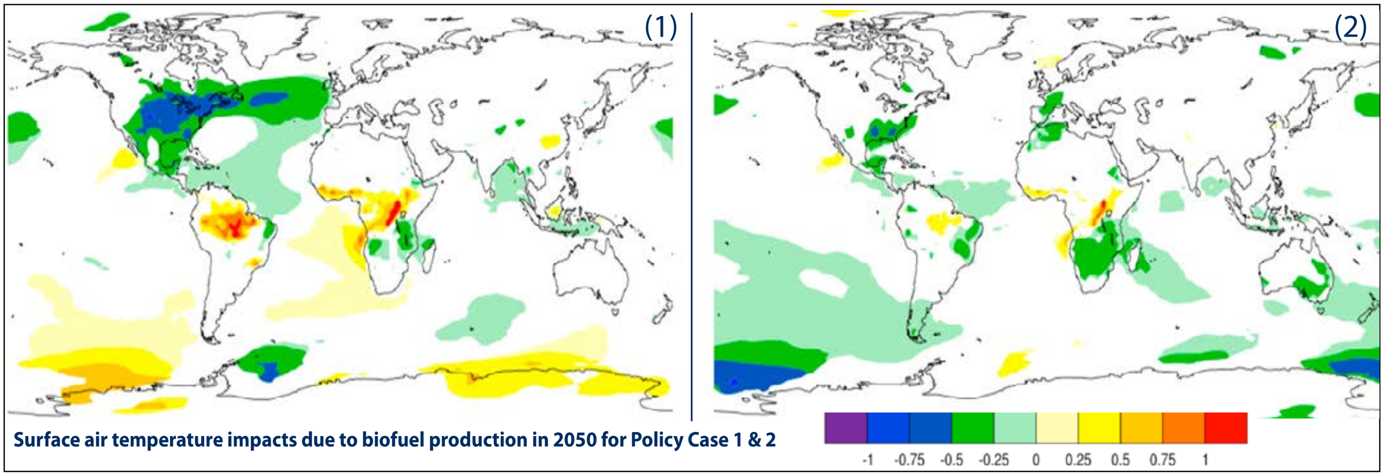
A group of her colleagues explored the economic side of biofuel expansion as part of a study released last year in *Environmental Science & Technology* (see page 12). The team, led by Joint Program co-director John Reilly, modeled feedbacks among the atmosphere, ecosystems and the global economy. They found that the combination of a carbon tax, incentives for reforestation and the addition of biofuels could nearly stabilize the climate by the end of the century; increased biofuels production alone could cut fossil-fuel use in half by 2100.

But just as Hallgren found trade-offs when she dug deeper, so did Reilly and his team of researchers.

"The environmental change avoided by reducing greenhouse gas emissions is substantial and actually means less land used for crops," Reilly says. This leads to substantial rises in food and forestry prices, he explains, with food prices possibly rising by more than 80 percent.

Hallgren says, "There is clearly no one simple cause and effect when it comes to our climate. The impacts we see—both to the environment and the economy—from adding a large supply of biofuels to our energy system illustrate why it is so important to consider all factors so that we'll know what we're heading into before making a change." ■

Hallgren, W., C.A. Schlosser, E. Monier, D. Kicklighter, A. Sokolov and J. Melillo, Climate impacts of a large-scale biofuels expansion, *Geophysical Research Letters*, 40(8): 1624–1630, 2013.



Surface air temperature impacts due to biofuel production in 2050 for Policy Case 1 & 2

RECENT EVENT

Co-Director John Reilly participated in a Siemens Energy panel on the future of affordable and sustainable energy as part of a series of panels ahead of the World Energy Conference. Watch the panel: http://mitsha.re/12XPuIw

Winners and Losers in a Warming Ocean

MIT researchers build a marine ecosystem model to explore the effects of climate change on phytoplankton.

Phytoplankton—small plant-like organisms that serve as the base of the marine ecosystem—play a crucial role in maintaining the health of our oceans by consuming CO_2 and fueling the food web. But with a changing climate, which of these vital organisms will survive, and what impact will their demise have on fish higher up the chain?

Stephanie Dutkiewicz, Principal Research Scientist with the MIT Joint Program on the Science and Policy of Global Change, and her colleagues developed a model that investigates the potential effects of climate change on phytoplankton.

"Our model is unique because we were able to include 100 different species of phytoplankton, where almost all other models include just three or four," Dutkiewicz explains. "This diversity of species allows us to analyze the ecological effects of climate change and how species will shift, adapt, thrive or die off."

Once Dutkiewicz and her team built their phytoplankton model, they integrated it with a 3-D model of the global ocean system that is part of the Joint Program's Integrated Global System Model (IGSM) 2.3. This comprehensive model allows the researchers to study temperature, light and circulation in terms of both the large consequences to the ocean system as a whole and the local responses individual phytoplankton species have with each other.

"This model gives a nice demonstration of the complexity of the system and how you can't just look at one piece of it to see what's going to happen," Dutkiewicz says.

Dutkiewicz gives an example: If a researcher just looks at the effects from a change in temperature, they would find that phytoplankton would be more productive. But when studying the whole picture, that is not the case.

On a global scale, and in the most extreme climate scenario, Dutkiewicz finds that by the end of the century half the population of phytoplankton that existed at the beginning of the century will have disappeared and been replaced by entirely new phytoplankton species.

"There will still be phytoplankton in any part of the ocean, they'll just be different and that is going to have impacts up the food chain," Dutkiewicz says.

Globally ocean productivity may not change much, as different impacts of changing climate might balance each other out, Dutkiewicz' s research shows. But looking regionally paints an entirely different picture. In the tropics and higher latitudes, a decrease in the nutrients these small organisms need to survive will limit phytoplankton growth. Meanwhile, in the upper latitudes, the ocean temperatures are expected to rise, spurring phytoplankton growth.

"The take home message is, studying these complex climate interactions is not simple and trying to make it simple will give you the wrong answer," Dutkiewicz says.

Now that Dutkiewicz has built this complex marine ecosystem model, she is planning to apply it to new research. In fact, she has already added an additional type of phytoplankton that's a nitrogen fixer, meaning it converts nitrogen into a useable form to help feed other organisms. She plans to assess how this species has changed over time. Dutkiewicz is also assessing the impacts of iron, an important nutrient in absorbing CO_2, on phytoplankton populations. ■

Dutkiewicz, S., J.R. Scott, M.J. Follows, Winners and Losers: Ecological and Biogeochemical Changes in a Warming Ocean, *Global Biogeochemical Cycles*, 2013.

Creating a Low-Carbon, Non-Nuclear Economy: The Case of Taiwan

After the 2011 Fukushima nuclear disaster, energy experts and policymakers around the world began to reassess the future of nuclear power. Countries, including Japan and Germany, have since scaled back or plan to shut down their nuclear power, sparking a global debate on how nations will replace nuclear.

Taiwan is just one country where this intense debate is unfolding. Yen–Heng Henry Chen, a Taiwan native and research scientist at MIT's Joint Program on the Science and Policy of Global Change, decided to look at how the nation's economy and emissions reduction strategies might be affected by future changes to Taiwanese nuclear energy policies.

"There has been little research on the interactions between non-nuclear and low-carbon policies," Chen says. "Taiwan has a small economy and limited natural resources, making it an interesting case study for other countries looking for ways to cut carbon emissions with or without nuclear power."

The Taiwanese government aims to cut its CO_2 emissions in half (from 2000 levels) by 2050. Taiwan currently has three nuclear power plants, with plans to bring a fourth plant, the Longmen Nuclear Power Station, online in 2015. This tightly populated country has more than nine million residents within 50 miles of its three existing nuclear reactors. Because Taiwan is similar in topography and fault lines to Japan, the prospect of the new plant has raised public concerns about the safety of nuclear power.

"After the Fukushima accident, more than 60 percent of the Taiwanese population was against the construction of a new nuclear power plant according to a recent poll," Chen says. "I wanted to know what it would mean for the Taiwanese economy and the government's emissions reduction targets if they were to eliminate or reduce nuclear power."

Taiwan currently imports 99 percent of its energy, which includes oil, natural gas, coal and nuclear. Chen conducted an economy-wide analysis that explored other ways to reduce carbon emissions: nuclear power, a carbon tax, and carbon capture and storage (CCS) technology.

When implementing a low-carbon and non-nuclear policy, without the availability of CCS, Chen finds that by 2050 GDP would drop by about 20 percent. If CCS were to become more cost-effective and could be added to the low-carbon strategy, GDP would drop by less than 10 percent. Chen finds the least expensive way to pursue a low-carbon policy would be to expand nuclear capacity in addition to CCS. If nuclear capacity was tripled and CCS was feasible, by 2050 GDP loss would be reduced to around five percent.

Absent nuclear power and CCS, "Taiwan needs to convert its industrial structure into a much less energy intensive one if the country is serious about achieving a low-carbon environment," Chen says. Taiwan's industrial sector accounts for almost half of the country's energy demands.

Costs could be lowered for industry and consumers if Taiwan were able to join an international emissions trading system. Until such an international trading system exists, "This case study can help policymakers better understand the costs of cutting CO_2 emissions without nuclear energy," Chen says, "as nuclear power becomes a less viable energy solution in Taiwan and around the world." ■

Chen, Y.-H.H., Non-nuclear, low-carbon, or both? The case of Taiwan, *Energy Economics*, 39: 53–65, 2013.

Putting a Price on Adaptation

If you know how much something costs, you can budget and plan ahead. With this in mind, a team of researchers from MIT, the World Bank and the International Food Policy Research Institute recently developed a country-level method of estimating the impacts of climate change and the costs of adaptation. This new method models sector-wide and economy-wide estimates to help policymakers prepare and plan for the future.

"Previous country-level research assessing climate change impacts and adaptation either focused on economy-wide estimates or sector-by-sector analysis, without looking at the bigger picture," says Kenneth Strzepek, one of the lead authors of the study and a research scientist at MIT's Joint Program on the Science and Policy of Global Change. "By looking at the interplay between different sectors and within the economy, we are able to evaluate the indirect effects and interactions that can occur that are often not captured."

As a case study, the researchers apply their technique to Ethiopia—the second most populated country in Sub-Saharan Africa. They look at three key sectors: agriculture, road infrastructure and hydropower.

"These sectors were selected because of their strategic role in the country's current economic structure and its future development plans," Strzepek says.

Agriculture accounts for about 46 percent of the GDP in Ethiopia and is almost entirely rainfed. Variability in temperature and rainfall will have major impacts on this crucial industry. The researchers found that with a temperature increase of 2 °C , more intense drought and floods will cause a drop in crop production—triggering reductions in income, employment and investments.

Frequent and intense flooding will also damage Ethiopia's road infrastructure—the backbone of the country's transportation system and a needed link in the agricultural supply chain.

Researchers use new method to calculate the impacts and adaptation costs of climate change.

The researchers found that flooding brought on by climate change will increase maintenance costs by as much as $14 million per year for the existing road network, which is expected to grow dramatically in the next 40 years. The intense variability of precipitation will also greatly impact the country's hydropower and associated reservoir storage, which could provide energy, irrigation and flood mitigation.

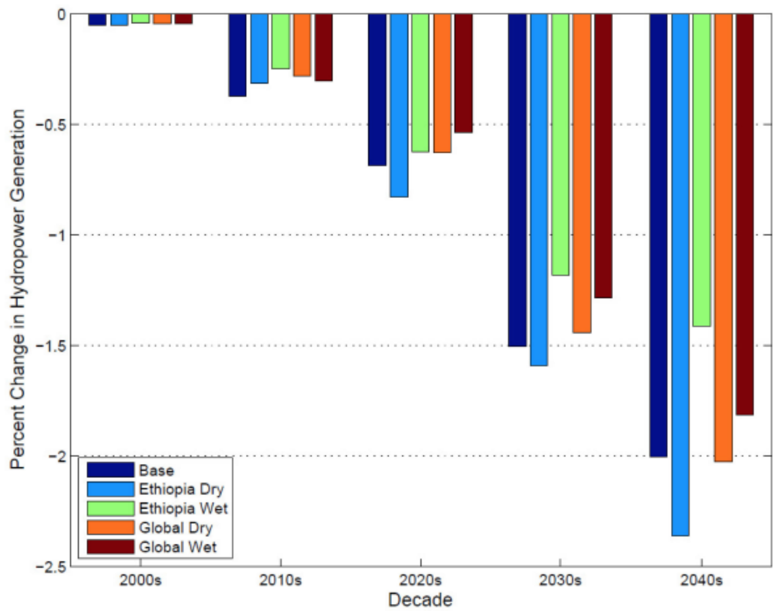
Because there is currently little installed hydro capacity in Ethiopia, the model showed few climate change impacts. But in the coming years, the government plans to invest heavily in hydropower, potentially creating significant future impacts to this sector.

Additionally, the researchers found that there would be an increased demand for water across sectors and create challenges for policymakers to effectively distribute this important resource. For example, Ethiopia plans to expand irrigated agriculture by 30 percent by 2050. The researchers found that some of the irrigation demands will be unmet, placing demands on other sectors requiring water resources.

"This research makes clear the impact droughts, floods, and other effects brought on by climate change can have on major financial sectors and infrastructure," Strzepek says. "For Ethiopia, we find that one of the best defenses against climate change is investment in infrastructure for transportation, energy and agriculture. By building up these sectors, the government will be able to enhance the country's resiliency."

He continued, "In predicting the outcomes of future water, infrastructure and agriculture projects, we were able to test the effectiveness of policies. This gives decision-makers in these countries, as well as international organizations, the information they need to continue to grow, develop and plan for the future with climate change in mind."

Planning for climate change is essential, Raffaello Cervigni, a co-author of the study and lead environmental economist at the World Bank, writes in a recent blog post.



Mean decadal changes in hydropower production given increasing municipal and industrial demands and irrigation demands, relative to a no-demand scenario.

"Addressing climate change is first and foremost a development priority for Africa … If no action is taken to adapt to climate change, it threatens to dissipate the gains made by many African countries in terms of economic growth and poverty reduction over the past ten years."

But, he continues, "a harsher climate need not be an impediment for Africa's development," if we can come together to address these challenges.

The integrated approach used by the authors is now being applied to studies on the costs of adapting to climate change in Ghana and Mozambique, as well as Vietnam. Others have replicated the approach to help other countries calculate the costs of adaptation. ■

Robinson, S., K. Strzepek and R. Cervigni, The Cost of Adapting to Climate Change in Ethiopia, *Ethiopia Strategy Support Program II Working Paper 53*, IFPRI ESSP WP 53, 2013.

MEET A RESEARCHER

In addition to studying adaptation strategies throughout Africa, MIT researchers are also setting up a new climate observatory in Rwanda. Research Scientist Katherine Potter is leading the effort to create an observatory, which she hopes will become part of the Advanced Global Atmospheric Gases Experiment (AGAGE) network—a worldwide monitoring network led by Joint Program Co-Director Ron Prinn that measures the composition of the global atmosphere. Learn more here: http://mitsha.re/12XPUOZ

400+ ppm: What are the Implications?

The NOAA-operated Mauna Loa Observatory shows that the atmospheric CO_2 concentration hovers around 400 ppm, a level not seen in more than 3 million years when sea levels were as much as 80 feet higher than today. Oceans at MIT's Genevieve Wanucha interviewed the Joint Program's Co-Director Ron Prinn, on the subject.

Wanucha: What is so significant about this 400-ppm reading?

Prinn: This isn't the first time that the reading of 400 parts per million (ppm) of atmospheric CO_2 was obtained. It was recorded at NOAA's observatory station in Barrow, Alaska, in May 2012. But the recent 400-ppm reading at Mauna Loa, Hawaii got into the news because that station produced the famous "Keeling Curve," which is the longest continuous record of CO_2 in the world, going back to 1958.

'400' is just a round number. It's more of a symbol than a true threshold of climate doom. The real issue is that CO_2 keeps going up and up at about 2.1 ppm a year. Even though there was a global recession in which emissions were lower in most fully-developed countries, China, and to lesser extent India and Indonesia, blew right through and continued to increase their emissions.

Wanucha: Has anything gone unappreciated in the news coverage of this event?

Prinn: Yes. What's not appreciated is that there are a whole lot of other greenhouse gases (GHGs) that have fundamentally changed the composition of our atmosphere since preindustrial times: methane, nitrous oxide, chlorofluorocarbons (CFCs), and hydrofluorocarbons (HFCs). The screen of your laptop is probably manufactured in Taiwan, Japan, and Eastern China by a process that releases nitrogen trifluoride—release of 1 ton of nitrogen trifluoride is equivalent to 16,800 tons of CO_2. But there is a fix to that—the contaminated air in the factory could be incinerated to destroy the nitrogen trifluoride before it's released into the environment.

Many of these other gases are increasing, percentage-wise, faster than CO_2. In the Advanced Global Atmospheric Gases Experiment (AGAGE), we continuously measure over 40 of these other GHGs in real time over the globe. If you convert these other GHGs into their equivalent amounts of CO_2 that will have the same effect on climate, and add them to the NOAA measurements of CO_2, you find that we are actually at 478 ppm of CO_2 equivalents right now. In fact, we passed the 400 ppm back in about 1985. So, 478 not 400 is the real number to watch. That's the number people should be talking about when it comes to climate change.

Wanucha: What has Advanced Global Atmospheric Gases Experiment (AGAGE) revealed about this greenhouse gas problem?

Prinn: The non-CO_2 GHGs are very powerful. One example is sulfur hexafluoride, which used to be in Nike shoes, and is now most widely used in the step-down transformers in long-distance electrical power grids. But sulfur hexafluoride leaks a lot, with 1 ton equivalent to 22,800 tons of CO_2, and it's increasing in our measurements. Another example is methane. We have been measuring methane for almost 30 years now, and it actually didn't increase for almost 8 years from 1998 onwards, but we discovered in our network that it began to increase again in 2006. We published this finding in 2008, and ever since, methane has been rising at a rapid rate. Nitrous oxide, the third most important GHG, has been going up almost linearly since we started measuring it in 1978.

The worrisome thing is that almost all of these gases keep rising and, per ton, they are very powerful drivers of warming. Many of these GHGs have lifetimes of hundreds to thousands to tens of thousands of years, so they are essentially in our atmosphere forever. There is almost nothing practical we can do to vacuum these gases out again.

Wanucha: Is it possible to decrease the atmospheric CO_2?

Prinn: One well-understood method of removing CO_2 from the atmosphere is carbon sequestration, in which you remove the CO_2 from the biomass burnt in an electrical utility, and then bury it in subsurface saline aquifers or in the deep ocean. There are people here at MIT, Rob van der Hilst and Brad Hager and others, who study the question of just how permanent is this deep burial on land.

Carbon sequestration can also lower CO_2 emissions from coal-fired power plants. It looks like the Department of Energy will reactivate a couple of these projects in Wisconsin and Texas to better understand this technology, with the goal of lowering the emissions from power plants to say 10 percent or less of what they were.

At the end of the day, the smart thing would be not to resort to vacuuming CO_2 out of the atmosphere and putting it down deep underground. It would be better to develop new and affordable zero- or very low-emission energy technologies such as biofuels, nuclear, solar and wind.

Wanucha: Will switching to "fracked" natural gas reduce warming?

Prinn: We have run our Integrated Global System Model (IGSM) presuming that hydraulically fractured gas from shale deposits in the U.S. and elsewhere around the world could begin to be used at large scale. We've looked at the question of if we did convert all oil usage to fracked gas usage over the next 20–30 years, would it lower the rate of warming? And the answer is yes, because you get about twice as much energy per ton of CO_2 emitted from burning methane as you get from coal.

There are some serious issues about the water used to pump down and split the shale. In the fracking process, trace chemicals are added into the water to make it slippery so the water can force itself in between the layers of shale. The problem is, shale is filled with mucky stuff such as salts and heavy organics, which all ends up in the frack water and comes back up to the surface. So what do you do with that very polluted water? Then there is the concern that the water could travel horizontally and vertically through the shale layers and end up in ground water. And that's an environmental issue that has to be addressed.

However, chemical companies are already investing in technologies that can take the frack water that's pumped back out and literally clean out the hydrocarbons and reuse it again for fracking. So, there is an answer to the frack water problem, but there must be a strong push to make sure fracking is environmentally sound.

We did find that if you increase the use of fracked gas and didn't repair the existing natural gas pipelines, they could leak several percent of the transferred volume because it's old city and intercity infrastructure. It's leaking now in all major pipeline systems in the U.S. and Europe, which is a problem because the leaked methane is a much more powerful GHG per ton than CO_2. So, repairing or replacing old gas pipelines will be a big requirement.

Addressing all these environmental concerns will add somewhat to the cost of energy. But most who study the climate issue in detail and in depth understand that the damages that are going to result from continued warming will far exceed the cost of any policy that we put together to lower GHG emissions. Yet, as you know, the politics of climate in Washington is impossible right now because a minority of senators can block any legislation. It doesn't look like anything will happen soon on a national emissions reduction policy. Politics trumps science on these issues. But the EPA has the power to treat CO_2 as an air pollutant so maybe that's what will happen near term.

The bottom line is if we switched from using oil and coal globally to running everything on shale gas, there probably is enough gas there. But with this alone, you would still get about a 3.5 °C warming by 2100. With no policy at all, our model estimates a 5 °C or higher warming. So replacing coal and oil with fracked gas is a sensible pathway for the U.S. to go over the next few decades, with the additional advantage of gaining more energy independence. But it won't remove the global warming threat beyond that.

Wanucha: What are the implications of the 478-ppm measurement to human life?

Prinn: According to the paleoclimatological ice core record, if our planet warms more than 2 °C globally (4 °C at the Poles), we are in trouble. That's about 6 meters or 20 feet of sea level rise. Most of the world's valuable infrastructure and high populations are along the coasts. So, the damage and cost of sea level rise alone is potentially very high. Other risky phenomena we face are shifting rainfall patterns that may move the locations of arable farmland out of the U.S and into Canada. Mexico could grow drier and drier, and there's concern in the Department of Defense about potential challenges to the security at the southern U.S. border. Other similarly vulnerable areas around the world could face desperate large-scale migrations of people seeking to find places to grow food.

These damages are likely to exceed significantly the costs associated with an efficient and fair GHG policy such as an emission tax whose revenues are used to offset income taxes. ■

MIT SPOTLIGHT

A new study by Kerry Emanuel finds that with global warming, tropical cyclones may become more frequent and intense. Read more: http://mitsha.re/12XQagU

Cooling Down Climate Change, While Heating Up Grocery Bills

Study Named Top Policy Paper by Environmental Science & Technology.

By: Janet Pelley, Science Writer for ES&T
http://mitsha.re/15Lwdfk

By 2100, the world population will pass 10 billion people. How can we sustain that population, while throttling back climate change? Some scientists think part of the answer is to plant forests and grow biofuel crops, allowing us to use land to sequester carbon. But those changes in land use also could crowd out food crops, raising the cost of food. In ES&T's Best Policy Analysis Paper of 2012, researchers model the feedback between the atmosphere, Earth's ecosystems, and the global economy to show that a fossil fuel tax plus incentives for reforestation and biofuels nearly stabilizes the climate by 2100. Unfortunately, the team reports that the trade-off is a hefty rise in food prices.

John Reilly, an energy economist at MIT, and his team realized that any analysis of climate policies, such as a carbon tax or incentives for reforestation, is complicated by the fact that land use policy, climate, and the economy are tightly linked. For example, as the climate warms, plant productivity changes, which in turn affects people's decisions about land use, he says. "Thinking of that complex set of interactions and trying to understand what was going on was the motivation for the study," Reilly says.

Previous studies have narrowly focused on one land use at a time, such as finding the best policies to sequester more carbon in forests but ignoring spillover impacts on cropland. Also these studies did not take into account the interactive and downstream effects of a worldwide carbon tax." Reducing greenhouse gases with a carbon tax will increase energy costs, and energy is a big input in agricultural production," Reilly says.

His team decided to study a combination of policies—a carbon tax and incentives for reforestation and biofuels—and ask what the effects would be on the climate, food prices, and land use.

To do so, they developed a set of three models that feed data among one another. First, a global economic model, provided by the MIT team, predicts food prices, land use, and greenhouse gas emissions every five years. Next, those emissions estimates drive a climate model that simulates future climate conditions. These climate outputs, such as CO_2 and ozone concentrations, then feed into an ecosystem model, developed by Jerry M. Melillo and his team at the [Marine Biological Institute at] Woods Hole Oceanographic Institution. The ecosystem model generates changes in crop and forest productivity. The economic model then uses these productivity changes, along with expected demand for products produced from the land, to reassess land and energy use, which then determines the next set of greenhouse gas emissions estimates. And the cycle continues.

The team members ran their models through the year 2100 under several different policy scenarios. They found that if humanity sticks with the status quo and attempts no change in climate policy, CO_2 concentrations reach 900 ppm by 2100, and global mean temperature hits 5.8 °C above preindustrial levels. However, a worldwide tax on fossil fuel emissions limits the CO_2 concentration to 520 ppm and holds temperature rise to 2.7 °C. These metrics are still above the targets set by the 2009 Copenhagen Accord, which are a 2 °C temperature increase and CO_2 levels around 450 ppm CO_2.

When the team added incentives for reforestation and biofuels to a tax on energy, CO_2 concentrations reach only 490 ppm and global temperature increases 2.2 °C over preindustrial levels by the end of the century. But Reilly says these better climate statistics come at a price: Competition for agricultural land from reforestation and biofuels boosts food prices by 80 percent.

Stephen Polasky, an environmental economist at the University of Minnesota, Twin Cities, says that this paper reveals that policy makers cannot think of energy and food policies as independent.

Even though the scenarios in the paper are far more aggressive than any proposed policies suggested right now, fossil fuel use in the models never drops to levels scientists say we need to stabilize the climate, says Steve Running, a terrestrial carbon scientist at the University of Montana. He also says the paper highlights how any solution to the climate problem requires choices and trade-offs when it comes to land use.

Reilly hopes that others will adopt his team's modeling practices to find sensible polices to improve the climate. ■

IN THE NEWS!
Cargill talked with John Reilly about this topic and more: http://mitsha.re/12XQ0Gt

MIT and UC Berkeley Launch Energy-Efficiency Research Project

Energy efficiency promises to cut emissions, reduce dependence on foreign fuel, and mitigate climate change. As such, governments around the world are spending tens of billions of dollars to support energy-efficiency regulations, technologies and policies.

But are these programs realizing their potential? Researchers from the MIT Energy Initiative and University of California at Berkeley's Haas School of Business have collaborated to find out.

The researchers' energy-efficiency research project, dubbed "E2e," is a new interdisciplinary effort that aims to evaluate and improve energy-efficiency policies and technologies. Its goal is to support and conduct rigorous and objective research, communicate the results and give decision-makers the real–world analysis they need to make smart choices.

The E2e Project is a joint initiative of the Energy Institute at Haas and MIT's Center for Energy and Environmental Policy Research (CEEPR), an affiliate of MITEI—two recognized leaders in energy research.

The project's name, E2e, captures its mission, the researchers say: to find the best way to go from using a large amount of energy ("E") to a small amount of energy ("e"), by bringing together a range of experts—from engineers to economists—from MIT and UC Berkeley. This collaboration uniquely positions the E2e Project to leverage cutting-edge scientific and economic insights on energy efficiency.

"Cutting energy has lots of potential to help us save money and fight climate change," says Michael Greenstone, MIT's 3M Professor of Environmental Economics. "It's critical to find the local, national and global policies with the biggest bang for the buck to use governments', industry's and consumers' money wisely while slowing climate change."

Greenstone is leading the project with Christopher Knittel, Director of CEEPR, and Catherine Wolfram, associate professor and co-director of the Energy Institute at Haas.

The group's motivations for studying energy efficiency are derived, in part, from the McKinsey Curve—a cost curve that shows that abating emissions actually pays for itself.

"Our goal is to better understand what the costs and benefits of energy-efficient investments are—where the low-hanging fruit is, as well as how high that fruit is up the tree," says Knittel, MIT's William Barton Rogers Professor of Energy Economics. "The McKinsey curve would suggest the fruit's already on the ground. If this is true, we want to figure out why no one is picking it up."

The E2e Project seeks to answer questions such as: Are consumers and businesses bypassing profitable opportunities to reduce their energy consumption? What are the most effective ways to encourage individuals and businesses to invest in energy efficiency? Are current energy-efficiency programs providing the most savings?

Initial projects include tracking consumers' vehicle purchasing decisions, evaluating the Federal Weatherization Assistance Program, and determining why households invest in energy efficiency and the returns to those investments. ■

Learn more at **http://e2e.mit.edu/**

MIT SPOTLIGHT

Along with launching E2e, Michael Greenstone unveiled a new study on the health impact of air pollution in China. The study attracted much attention globally to the important issue. Read it here: http://mitsha.re/12XQ7Sm

China Energy and Climate Project

Second Annual Meeting Explores the Future of China's Energy and Climate Policy

Chinese policymakers, senior academics, and more than 100 researchers, scientists and industry leaders gathered in June for the Second Annual Stakeholders Meeting of the Tsinghua-MIT China Energy and Climate Project (CECP). At the yearly gathering, participants reflected on the state of climate policy in China and the progress of the multi-disciplinary partnership, which launched last year to develop new tools to solve China's most challenging climate and energy policy questions.

"In light of the recent agreement between Presidents Obama and Xi to limit hydrofluorocarbons—a potent greenhouse gas—we hope that close work between the two countries continues," said Henry "Jake" Jacoby, co-director emeritus of the MIT Joint Program on the Science and Policy of Global Change, during his keynote address. "In this context, the work of the CECP becomes ever more important."

Jointly hosted by CECP's parent research groups—the Tsinghua University Institute for Energy, Environment, and Economy and the MIT Joint Program on the Science and Policy of Global Change—the meeting creates a platform for a diverse group of policymakers to interact with researchers and explore future paths for China's energy and climate policy. The number of external attendees more than quadrupled from last year's conference, indicating the high level of interest in the Tsinghua-MIT collaboration and China's energy and climate policy more broadly. Senior officials from China's National Development and Reform Commission, National Energy Administration, Ministry of Industry and Information Technology and Ministry of Science and Technology, as well as leading Chinese academics, formed a panel of experts that responded to the findings of the joint research team.

SPONSORSHIP
To gain access to the research before it's released publicly, become a sponsor! More: http://globalchange.mit.edu/CECP/

Over 150 stakeholders representing industries, governments, and academic institutions in China and abroad attended the meeting, reflecting CECP's goal of sharing project insights with a broad range of global leaders on energy and climate topics.

The meeting's main dialogue between CECP researchers and policymakers focused on future drivers of energy use and the design of a carbon emissions trading schemes (ETS) in China, a subset of the CECP's ongoing work. CECP researchers compared China's current climate policy—provincial carbon intensity targets—to national emissions trading system designs that varied in terms of sector and regional coverage. CECP researchers underscored the need for broad sector and geographic coverage to enhance ETS cost effectiveness, as well as the potential to achieve equity goals through the initial allocation of emissions permits.

In the afternoon, a panel of policy advisors representing planned pilot emissions trading systems in Beijing, Guangdong, Shanghai, Tianjin, and Hubei described the design and progress toward implementation, which is expected to be complete by the end of 2013. Panel participants emphasized that pilot schemes build familiarity with emissions trading and help policymakers evaluate the feasibility of a national ETS.

The CECP's leaders, Dr. Valerie Karplus of MIT and Professor Zhang Xiliang of Tsinghua, explained these findings based on two models they developed over the last year: the China-Global Energy Model (C-GEM) and the China-Regional Energy Model (C-REM). While the C-REM model allowed the researchers to uncover their ETS findings, the C-GEM model provided analysis on China's "economic transformation"—the effort to move from an energy and emissions intensive economy focused on manufacturing for export to one that is more services and technology oriented.

Prof. Zhang highlighted the importance of the MIT-Tsinghua relationship in bringing about these results. "The regular exchange of Tsinghua students working at MIT, and MIT students and researchers visiting Tsinghua, makes for a very productive working relationship," Prof. Zhang said, acknowledging the support of sponsors on both the MIT and Tsinghua sides. MIT founding sponsors include French Development Agency, Eni, ICF International (a consultancy), and Shell, while the collaboration receives support at Tsinghua from the Ministry of Science and Technology, National Development and Reform Commission and the National Energy Administration.

Alongside government representatives, a number of senior academics from China's top universities in a variety of disciplines offered their input on the CECP's ongoing research efforts. The experts identified key ramifications from the results and called attention to future topics of interest.

"An important goal of this meeting is to bring the key stakeholders together in the same room," said Karplus, "This helps to foster a shared awareness of the wide range of views on policy options that reflect the diverse circumstances facing China's localities and industries." ■

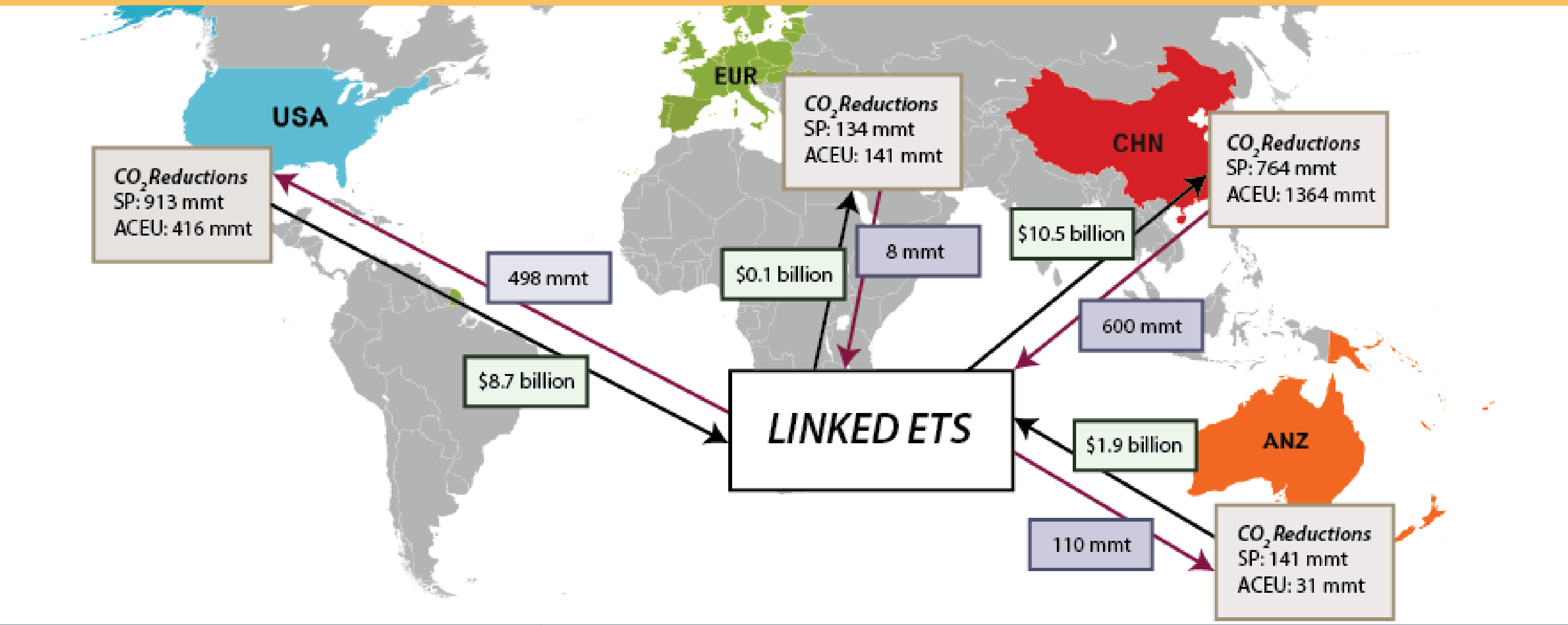
COMMENTARY

Carbon Emissions in China's Trade
Nature News & Views

A large share of China's carbon emissions is linked to consumption that takes place in its most developed provinces and overseas. A new study highlights the implications of considering those emissions in the country's climate policy. The CECP's Valerie Karplus gives her take on the study.

Transforming China's Grid
The Energy Collective

The CECP's Michael Davidson critically examines China's efforts to reinvent and decarbonize its power sector and related energy goals. This is a series Davidson will write for *Energy Collective*, as part of the site's new column: "East Winds, With Michael Davidson."
Read it here: http://mitsha.re/137CHmZ



The Energy and Economic Impacts of Expanding International Emissions Trading

What is China's relationship to the EU and Australia Trading Systems?

China is currently piloting regional Emissions Trading System (ETS) designs, and recently announced plans for a national trading market. It has also indicated that it would consider participating in an international carbon market. Meanwhile, Australia plans to establish an ETS that will link to the EU-ETS as early as 2015, and is interested in linking with the New Zealand ETS. Given that a single global market for greenhouse gas emissions is widely accepted as a cost-effective path to climate change mitigation, we simulated the impact of expanding the global carbon market to include China, the EU-ETS, Australia and New Zealand, and the United States.

What are the effects of including China and the United States in a global Emissions Trading System?

Expanding a global ETS to include China and the United States has several effects. First, it decreases the carbon price in every participating market except for China and the EU. Second, it lowers the amount by which the U.S., Australia and New Zealand need to reduce their emissions. Third, although there is no change in global emissions, it results in an 80 perecent greater reduction in emissions from China and a small decrease in EU emissions, relative to when carbon markets operate independently. There are smaller reductions in emissions in the U.S. and Australia-New Zealand as these nations purchase permits internationally, primarily from China.

IN THE NEWS!
Co-Director John Reilly talks about China's challenge of controlling the costs of reducing emissions in *Quartz*.
Read the story: http://mitsha.re/12XQn3I

What is the likelihood of this happening?

There are still many hurdles to overcome in China before a global trading market becomes reality. China is in the early stages of establishing domestic emissions trading, and has just begun experimenting with provincial-level pilots. Officials in China may be hesitant to fully link with other regions without assurance that China will benefit from the linkages. Economic benefits aside, much remains to be done to develop the institutions that would support a trading system. However, China is taking action to tackle these obstacles. In talks with Australia in March 2013, China released the details of its planned nationwide emissions trading market. Above all, including China in an international emissions trading market is an important step toward implementing more ambitious emissions reduction targets globally.

Tianyu, Q., N. Winchester, X. Zhang and V. J. Karplus, The Energy and Economic Impacts of Expanding International Emissions Trading, *JP Report*, August 2013.

Analysis on Energy-Water Nexus: The Case of Beijing

The energy-water nexus—the complex relationship between water supply and energy generation—will play a central role in sustaining economic growth in China. Yet, little quantitative analysis focuses on this issue. This study visualizes water use in Beijing using a Sankey diagram, a tool that describes energy flows by visually mapping the source and destination of each kind of energy at each stage of the energy system. The resulting map visualizes the energy-water challenges facing Beijing. For example, the city's water resources are highly constrained, and it relies heavily on water that is energy-intensive to supply, such as underground water or water that must be conveyed over long distances.

The study finds that the electricity required by Beijing's water system comprised about 5–7 percent of total electricity consumption in Beijing in 2009. Water used in energy production accounted for about one-fourth of the water used in the whole industrial sector and about of 3 percent of the total fresh water used in Beijing in 2009. These rates of water use in energy production rival those seen in the U.S. Further, if totals are expanded to include water used outside of Beijing that is associated with supplying its electricity, the rate of water use compared to electricity generation is larger than that in the U.S. ■

Hu, G., X. Ou, Q. Zhang and V.J. Karplus, Analysis on energy-water nexus by Sankey diagram: the case of Beijing, *Desalination and Water Treatment,* 2013: 1-11, 2013.

Forthcoming CECP Reports

The China-in-Global Energy Model

Modeling Regional Transportation Demand in China and the Impacts of a Natural Carbon Constraint

Synergy between Pollution and Carbon Emissions Control: Comparing China and the United States

An Integrated Assessment of China's Wind Energy Potential

Bridging the Gap

Atmospheric Chemist Colette Heald combines observations and models to uncover lessons from the gases and particles in our atmosphere.

Colette Heald has always been a problem solver. But uninspired by the theoretical approach of engineering physics—her major as an undergraduate at Queen's University in Canada—Heald began studying atmospheric chemistry to tackle problems that directly impact society. Specifically, she studies gases and particles in the lower atmosphere—black carbon from fires, sulfate from power generation, dust from deserts—and how they impact air pollution, climate change and the Earth's ecosystems.

"Working on an earth system problem that links to air pollution, climate change, as well as a variety of other important environmental problems, is a real societal driver behind my research," Heald, Associate Professor in the Department of Civil and Environmental Engineering and Earth, Atmospheric and Planetary Sciences, says. "While I don't actually work in the policy world myself, it underpins my research, and that's a very motivating connection."

Heald is reminded of this human connection to her work every day by reading the news—from heavy air pollution in China to soot from wildfires in Colorado. It also spurs ideas for new research.

In the Western U.S., for example, bark beetles are now present in greater numbers because increasingly warmer weather has allowed them to survive winters. The beetles then attack forests, creating dead wood on the ground and leading to the rapid spread of fires—and poor air quality from the resulting smoke. But do the beetles contribute more directly to the poor air quality? Heald and her team dug deeper.

Leaves and other types of vegetation emit gases and particles into the atmosphere. So when vegetation is decreased, such as through a beetle infestation, one would think there would be a decline in these particle emissions. But Heald's team found that the increase in emission that occurs when these trees are stressed by an insect attack actually outweighs this effect. This increase in atmospheric particles can degrade visibility in pristine forests and also play a role in climate change.

Building Better Models

Much of Heald's work focuses on a challenge that is wracking the brains of atmospheric researchers throughout the world: bridging the gap between observations and models.

"I always tell my students not to have too much faith in models. By definition, a model is wrong, because it's just a simplified description of what we know now. But it's important to think about what we can learn from these imperfect models," Heald says.

Heald and her colleagues didn't realize just how wrong the models were in the case of organic aerosols until almost a decade ago when the measurements and the models began painting very different pictures.

"The whole community got turned on its head and realized that there was a lot of chemical complexity that we did not understand and that we are not treating in models. That leads us to the question: what are we going to do about it?" Heald says.

Heald, her research group, and the whole atmospheric research community are answering that question by looking at more measurements, studying more satellite images, and doing more lab experiments to include factors they didn't originally think to include. Then, they're trying to use all of this information to better inform models.

"So we're using whatever we can get our hands on to try to reveal where the gaps are between what we see in these snapshot observations and what models would tell us based on what we think is happening."

To give an example, Heald is waiting for more data from observations on aerosols in the Southeastern United States. Climate records show that this region has actually been cooling over the last 50 years. Some researchers have suggested that this cooling may be associated with aerosol particles. Given that the region has a lot of vegetation, Heald and her team know that the particular types of trees growing there substantially emit a compound that can form these aerosol particles. So they wanted to investigate whether this was a likely explanation.

They used satellite observations to show that there are indeed a lot more aerosols in that region in the summer time which could scatter radiation and cool the climate. But even when considering the smog from the South's big urban centers, the satellites are showing aerosol levels higher than what the trees and cities combined would produce, according to her models.

Heald thinks there has to be another source. Colleagues have hypothesized that there is an unknown chemistry occurring where the smog from urban areas is working together with emissions from trees—causing them to produce higher levels of aerosols. Or there might be some other source or process that is just not well understood. To investigate this, Heald and her team are waiting for data from a field campaign launched by the U.S. Environmental Protection Agency and National Science Foundation in the region this summer.

This example demonstrates the extreme complexity of the work. But this is just one example of one type of particle in one place. Atmospheric particles come from many different sources. They form many different types and sizes. And they travel in many different patterns over different lengths of time—though generally they last in the atmosphere for about a week before latching onto precipitation and raining down to earth.

"What that means is that when you make a measurement in one location, it doesn't tell you about anything other than what that one location is experiencing. It doesn't give you a sense of any large scale," Heald says. "So it is really tough to go from a single point measurement of particles to understanding what is happening in terms of their global budgets."

Problem Solving at a Global Scale

Understanding these "global budgets" is especially important when determining the climate impacts of the gases in our atmosphere.

"When it comes to thinking about our climate, it's not just about how many of these particles there are in the atmosphere," Heald says. "It's about what are the properties of these particles. Do they mix together? Do they chemically change form? Do they scatter or absorb radiation? These are really critical questions to ask to better understand the Earth's radiation balance. But they're really open questions."

While Heald and her colleagues work to learn more about the properties and impacts of many different pollutants, they're also working to build simple models that may not include all the details, but will provide an overall description of the behavior of particles that matches more closely with what they are observing in the atmosphere.

"We're doing this with the idea that if we can come up with something simple, we can use it in climate models for future and past predictions." ■

UPCOMING WEBINAR

As part of the sponsors-only webinar series, Erwan Monier will hold a presentation on "Uncertainty in Regional Climate Projections" on September 26th.
Learn more: http://mitsha.re/11g5x76

Student Spotlights

Bilhuda Rasheed: Mapping the Future of Water in Pakistan

Born and raised in Pakistan, Bilhuda Rasheed studied astronomy as an undergraduate at Princeton University. But when the IPCC Fourth Assessment on the impacts of climate change predicted the glaciers of the Himalayas—which her country depends on to fuel their rivers, crops and many associated industries—would shrink by half by 2035, Rasheed was inspired to pursue a different path.

"I was terrified because my country depends on the Himalayas for so much," Rasheed says. When the predictions about the Himalayas turned out to be a typo, Rasheed felt even stronger about studying climate science. "It just showed me that there was a real gap, and work needed to be done in this area."

Rasheed decided if she wanted to contribute, why not start at home. So she returned to Pakistan, where the country was undergoing a significant energy crisis. For a year and a half, Rasheed worked in Pakistan's Ministry of Water and Power. Her boss in the Ministry—an MIT Technology and Policy Program (TPP) graduate—thought Rasheed was a good fit for the program and encouraged her to attend.

"It turns out he was right. The TPP program, and the Joint Program, is a great fit for me because it allows me to answer policy questions from a technical perspective and consider important economic implications. I like this interdisciplinary approach," Rasheed says.

Knowing she wanted to explore the water challenges of Pakistan, Rasheed joined the Joint Program's water team and started working with Adam Schlosser, Ken Strzepek and Elodie Blanc. She arrived at the Program right as the researchers were starting to develop a global Water

Resource System (WRS) model, and her thesis would add important components to the model as she narrowed down to explore Pakistan's hydrological system.

"In the WRS Global, Pakistan is one of 282 river basins, which is okay for a global model," Rasheed says. "But if you want to study the inner workings of Pakistan, you can't just study one big unit. The data would be too crude. So, I have split Pakistan into five different basins."

The basins each reflect unique attributes and the wide diversity of climates throughout Pakistan—from the northern glaciers to the Indus River running through the country to the Arabian Sea in the south.

"The basins are different in the crops that are grown, the water demands, the topography and even the climate. Each of them has to be programed differently in the model," Rasheed says.

"The TPP Program, and the Joint Program, is a great fit for me because it allows me to answer policy questions from a technical perspective and consider important economic implications. I like this interdisciplinary approach."

Building on her relationships with government officials in Pakistan, Rasheed gathered additional hydrology data, irrigation information and water flow rates to add to the model. In particular, Rasheed added glacial melt, the absence of which had distorted previous measurements key to determining river flow and sea level rise.

After gathering all of this data, Rasheed was able to predict future temperature rise, river flows, glacier melting and the interactions between these changes.

She finds that temperature in the Indus glaciers will rise between 1 and 2.5 °C by 2050, causing increased glacial melt and a conversion of more snow to rain. Eventually the glaciers will disappear, greatly affecting water flows, but there is a great deal of uncertainty around the rate of glacier retreat.

Food security, particularly wheat, is a key consideration for water managers. Pakistan has two major dams on the Indus River that help distribute water. But Rasheed believes there should be a third to help store and release water during dry seasons.

"Effective management of water is vital to help mitigate limited precipitation and manage national priorities," Rasheed says. "This third dam would help water managers adapt, manage and control flows, allowing Pakistan to introduce more flexibility into the water infrastructure. So, by the end of the summer, you have enough water to get you through the winter, while also helping to control flooding."

After completing her research, Rasheed plans to share this model with her colleagues in the Pakistani Ministry of Water and Power to help planners and water managers better understand current water demands and predict future water stresses.

"I would like water to enter the general discourse in Pakistan in a more informed way," Rasheed says. "People in Pakistan understand that water is important, but the conversation is more visceral and emotional than data driven."

Rasheed believes that once this information is available, people in Pakistan will embrace it because they tend to be more worried about climate change than the rest of the developed world, she says.

"When you discuss climate change and glaciers, Pakistanis pay attention because they want to know what's going on. They have a stake in the challenges because of the effects of the glaciers in the Himalayas," Rasheed says. "I think there is going to really be an audience for my work."

Beyond Pakistan, Rasheed hopes her contributions to the model will help other researchers apply the information to other countries that face severe water challenges, such as India and Egypt.

Rasheed will complete her Masters thesis at the end of August and pursue a position in the climate change field. ■

Ioanna Karkatsouli: The Cost of Wind in Europe

Ioanna Karkatsouli knew heading into college in her native Greece that engineering was a perfect fit for her. She quickly focused on electrical engineering and worked in the industry for several years before realizing she needed to gain a more comprehensive view of the energy sector.

"Engineers have a very focused way of thinking and approaching problems. I found I very much have that 'get it done' mentality. I also saw in the news, in classes and in my everyday life, how important power and energy is for the future," says Karkatsouli. "But the power sector is so heavily influenced by economics and regulations that I found I really needed to know more about these areas before moving forward in my career."

Karkatsouli just completed her Masters in MIT's Technology and Policy Program (TPP), where she was immediately drawn to the Joint Program's Emissions Prediction and Policy Analysis (EPPA) model because of the way it integrated the energy, economic and emissions factors. Under the guidance of her advisors, Sergey Paltsev and Ignacio Pérez-Arriaga, she enhanced EPPA through her analysis of the cost of expanding wind power at large scale.

"I really wanted to explore how the power sector could be more sustainable and low cost," Karkatsouli said. "Wind was a great example to use because it—like solar—is so intermittent. Wind power works well when the wind is blowing, but might require a backup power supply, and additional costs when it's not blowing."

Karkatsouli's research focuses specifically on wind power in Europe, where the European Union committed to reduce greenhouse gas emissions by 20 percent in comparison to 1990 levels by 2020. One key way they are planning to reduce these emissions is through wind power.

By adding to the observed data on wind patterns in EPPA, and integrating a detailed electricity model of the effects of large wind penetration, Karkatsouli improved the way wind power is currently represented in the model. With it, she calculated the increased costs of infrastructure, flexible backup power sources and integration of power systems between countries.

"I have found that when regions or countries have grids that are interconnected, they can share their wind resources and their backup power. This saves money, reduces intermittency and requires less backup power."

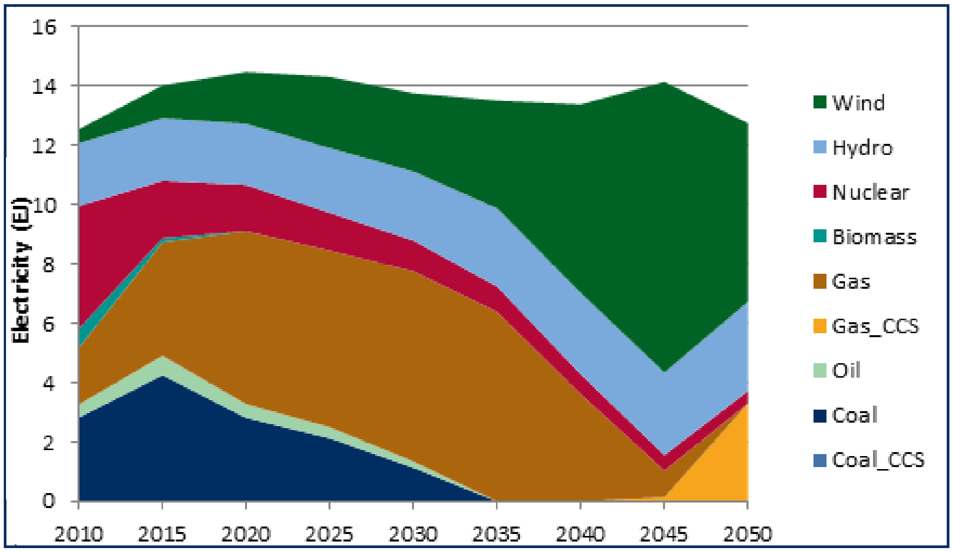
After adding all of the information to the model, Karkatsouli tested 40 percent and 80 percent greenhouse gas emissions reduction scenarios for Europe—relative to 1990 levels. She found that small-scale wind penetration does not result in much additional cost. But when wind is introduced at a large-scale, the cost of the power system may increase. These costs are due to reserve requirements, additional capacity and integration into exisiting infrastructure.

She also found that the additional backup power generation would have to be provided mainly by natural gas because the plants have been built to operate in a more flexible manner.

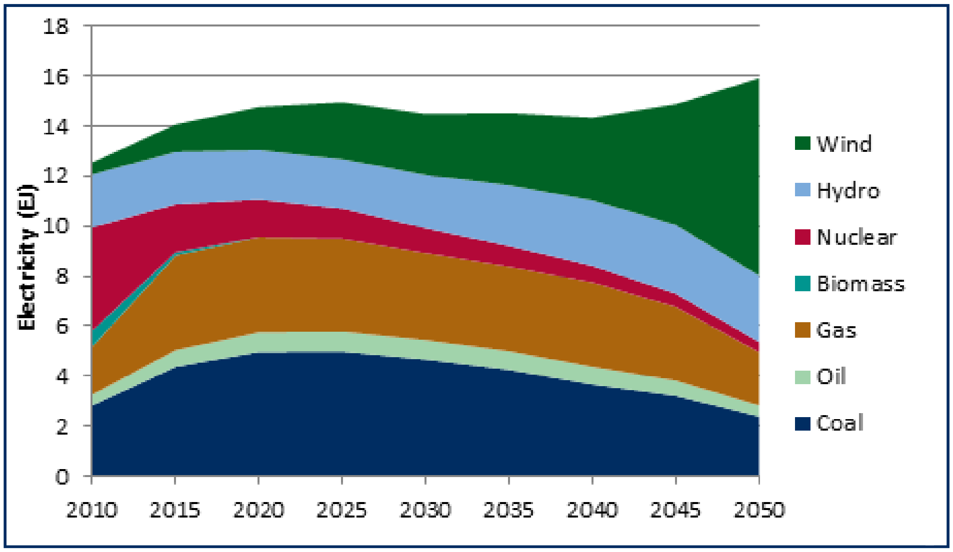
Overall, Karkatsouli's research shows that, "wind power will play an important role in Europe's future," she says. "But countries and utilities will need to invest in backup power supply availability, infrastructure, storage and additional capacity if they plan to use large-scale wind power to meet their low-carbon energy goals."

By providing cost information to better understand the feasibility of expanding wind power in Europe, Karkatsouli hopes her research can help policymakers and utilities plan their investments in wind power in the future —in Europe, and through additional research, elsewhere.

"I was able to find the exact effects of large wind penetration in Europe. This information will be useful for future researchers using the EPPA model, and it should give more accurate results of the costs of different policies in other countries," says Karkatsouli.



Electricity generation in Europe for 40 percent greenhouse gas emissions reduction by 2050 relative to 1990 levels. Karkatsouli, I., *Masters Thesis,* May 2013.



Electricity generation in Europe for 80 percent greenhouse gas emissions reduction by 2050 relative to 1990 levels. Karkatsouli, I., *Masters Thesis,* May 2013.

Karkatsouli credits the Joint Program and TPP with helping her think about the big picture when it comes to electric power. Through her work at MIT, she gained experience in policy, modeling, research and economics to compliment her background as an engineer.

After graduation, Karkatsouli plans to stay in Boston and ideally work in the renewable energy industry. She eventually plans to return home to Greece and apply the lessons she learned to the energy needs of her country. ■

The Environment @ MIT

Renewable Energy Futures to 2050: Current Thinking

The Joint Program hosted Professor Eric Martinot, the senior research director with the Institute for Sustainable Energy Policies in Tokyo, at a lecture on April 18. At the talk, he told students and faculty that renewables have become “mainstream” and are “a major part of our energy system.” Martinot just completed a two-year project entitled the Renewables Global Futures Report—a compilation of 170 face-to-face interviews conducted with industry executives, CEOs of renewable energy companies, utility leaders, government officials and researchers. Martinot gave an overview of various projections and scenarios from the oil industry, the International Energy Agency (IEA) and environmental groups. The data shows that investment in renewables is a key example of the current growth and expected trajectory. “Renewable energy investment is predicted to double if not by 2020, then by 2040,” explains Martinot. More: **http://mitsha.re/12XQxrQ**

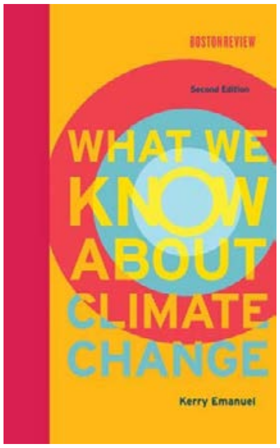
Securing our Clean Energy Future in Massachusetts

In honor of Earth Day, the MIT Energy Initiative hosted Governor Deval Patrick at an event on April 25. Governor Patrick described a series of successes in achieving his goals to significantly reduce greenhouse gas emissions and create businesses and jobs based on clean-energy solutions. Patrick also outlined a next crucial area of environmental sustainability. “We see water innovation as the next opportunity for Massachusetts to seize,” he said. “The same concentration of brainpower in this and other world-class universities and research facilities that spawned and feeds the life sciences and high-tech revolution in Massachusetts is at the center of this next big push in water innovation.”

More: **http://mitsha.re/12XQsEz**

What We Know About Climate Change

MIT professor Kerry Emanuel talked about his new book, “What We Know About Climate Change,” on May 3. In the book, Emanuel outlines the basic science of global warming and how the current consensus has emerged. “Although it is impossible to predict exactly when the most dramatic effects of global warming will be felt,” he argues, “we can be confident that we face real dangers.” More: **http://mitsha.re/14iuWjr**



GEOENGINEERING: SCIENCE & GOVERNANCE

Sponsored by the MIT Joint Program and the Harvard University Center for the Environment

The Physical Science of Solar Geoengineering

On May 1, at Harvard University, Ken Caldeira, a senior climate scientist in Carnegie Institution's Department of Global Ecology, spoke about the science behind solar geoengineering. This event was a part of the Joint Program's ongoing speakers series with Harvard. Stay tuned for future geoengineering lectures in the fall. More: **http://mitsha.re/14itPAc**

Energy-Water-Land Nexus

Select Joint Program researchers spoke at a two-day workshop in Washington, D.C. on May 6–7 sponsored by the MIT Energy Initiative and the Center for Strategic and International Studies. The workshop explored various aspects of the energy-water-land nexus and included talks on climate change's impact on regional water resources and land availability, the challenge of supporting a growing planet, and defining the future research agenda. The outcomes of the workshop will be assembled into a whitepaper in the coming months. More: **http://mitsha.re/14iuNwg**

Climate Change Impacts and Risk Analysis

The U.S. Environmental Protection Agency has assembled a team of researchers to evaluate the risks and uncertainties of climate change impacts as part of their Climate Change Impacts and Risk Analysis (CIRA) project. Several Joint Program researchers are leading the efforts to simulate future climate change and are using the MIT Integrated Global System Modeling (IGSM) framework to address these challenges. Here is a snapshot of their results so far:

Future Effects of Climate Policy: To better understand the climate benefits of given mitigation strategies, we studied two global policy scenarios. We found that both policies we tested result in lower temperatures than if there were no policy. This clearly shows that the long-term risks of climate change can be strongly influenced by policy choices. These will have relatively little effect in the nearer term, but will be the most important factor affecting climate by the second half of the century. Of course, this is a receding window—if we don't start to significantly change the current emissions path until 2030 or 2040, then we will not see the effect of policy until very late in the century. If we delay and make a choice only when we see the effects of climate change, we may find we are on a path that will take us into dangerous territory with little we can do to stop it.

Evaluating Uncertainty: When it comes to simulating future climate change, there are four major sources of uncertainty: 1) the details of future climate policies and how they will affect emissions, 2) how sensitive the climate is to increased greenhouse gas concentrations, 3) year-to-year or longer-scale changes caused by natural climate variations, such as el Niño and 4) differences between climate models. We conducted more than 100 climate simulations from 1980 through 2115—using three emissions policies, multiple models, different initial conditions and different climate sensitivities—and found a large range of warming over the U.S., from 1 °C to 10 °C, and a range of precipitation changes, from a decrease of 0.1 mm/day to an increase of 0.7 mm/day. Policy emerged as the largest source of uncertainty for temperature change, with climate sensitivity being the second largest source. The uncertainty associated with natural variability and different models is mostly seen in the location of the largest changes, but less so in the overall magnitude of these changes. By 2100, the spread in temperature changes caused by differences in policy is more than twice that caused by differences in climate sensitivity. So it appears the largest source of uncertainty in future projections of climate change is also the only source that society has control over—the emissions policy.

Climate Change Impacts on Extreme Events: In the last decades, the occurrence of extreme weather events such as heat waves, droughts, hurricanes and blizzards has changed significantly. But there is much uncertainty about future changes, especially at the regional level. We analyzed the range of possible changes in the U.S. using three emissions scenarios, four climate sensitivity scenarios, and five sets of initial conditions. Although the simulations produce a wide range of outcomes, in general the results show an intensification of hot days—causing the frost-free zone to expand northward, and an increase in the most extreme precipitation events. Even though the simulations were conducted with a single climate model, the magnitude of change in extreme events differs greatly from one scenario to another, underlining the large uncertainty in the future of extreme events. Generally, implementation of a policy that stabilizes emissions drastically reduces the changes in extremes, even for the highest climate sensitivity considered.

Project Leaders: *Monier, E., X. Gao, J. Scott, A. Sokolov A. Schlosser, S. Paltsev, J. Reilly*

IN THE NEWS!
NPR talks with John Reilly and Henry "Jake" Jacoby in their piece "Economists have a One-Page Solution to Climate Change."
Listen to it: http://mitsha.re/14iv96d

Coming and Going

Élodie Blanc was promoted to research scientist.

Alexandra Cosseron from Ecole Polytechnique will be a visiting student starting in September.

Chas Fant, Anita Ganesan, **Diane Ivy,** and **Laura Meredith** completed their PhD dissertations and accepted postdoctoral appointments at MIT.

Xavier Gitiaux from University of Colorado and **Pascal Kriesche** from École Polytechnique in France were visiting researchers for the summer.

Jennifer Morris graduates in August and will stay on as research scientist.

Tony Tran replaced CEEPR's program administrator, **Joni Bubluski**, who retired in June.

Newly-Released Joint Program Reports

Report 247: What GHG Concentration Targets are Reachable in this Century?

Report 246: Probabilistic Projections of 21st Century Climate Change over Northern Eurasia

Report 245: Climate Change Impacts on Extreme Events in the United States: An Uncertainty Analysis

Report 244: A Framework for Modeling Uncertainty in Regional Climate Change

Report 243: Integrated Economic and Climate Projections for Impact Assessment

Forthcoming Joint Program Reports

The China-in-Global Energy Model

Limited Sectoral Trading between the EU-ETS and China

The potential wind power resource in Australia

Climate Change and Crop Productivity in the United States: An Uncertainty Analysis

Global Change Impacts on Global Water Stress

The Energy and Economic Impacts of Expanding International Emissions Trading

Peer-Review Studies/ Pending Reprints

Nonlinear effects of coexisiting surface and atmospheric forcing by anthropogenic aerosols, *J. Climate*

Iron, phosphorous and nitrogen supply ratios define the biogeography of nitrogen fixation, *Limnology and Oceanography*

Permafrost Degradation and Methane: Low Risk of Biogeochemical Climate -Warming Feedback, *Geophysical Research Letters*

Challenges for Implementing a Global Mercury Treaty, *Environmental Toxicology and Chemistry*

Market versus Regulation: The Efficiency and Distributional Impacts of U.S. Climate Policy Proposals, *Energy Journal*

Optimal Urban Population Size: National vs. Local Economic Efficiency, *Urban Studies*

Ocean eddies and disperal maintain phytoplankton diversity, *Limnology and Oceanography: Fluids and Environment*

The Efficiency and Distributional Impacts of U.S. Climate Policy Proposals, *The Energy Journal*

Is small better? A comparison of the effect of large versus small dams on cropland productivity in South Africa, *World Bank Economic Review*

Crop supply in Sub-Saharan Africa and Climate Change Impacts, *Journal of Development and Agricultural Economics*

A Numerical Examination of the Potential for Negative Leakage, American, *Economic Review Papers and Proceedings*

A stochastic minimum principle and meshfree method for stochastic optimal control, *Automatica*

Newly-Released Joint Program Reprints

Reprint 2013-9: Correction to "Sensitivity of distributions of climate system properties to the surface temperature data set", and Sensitivity of distributions of climate system properties to the surface temperature data set

Reprint 2013-8: Historical and idealized model experiments: an intercomparison of Earth system models of intermediate complexity

Reprint 2013-7: The Cost of Adapting to Climate Change in Ethiopia

Reprint 2013-6: Non-nuclear, low-carbon, or both? The case of Taiwan

Reprint 2013-5: Climate impacts of a large-scale biofuels expansion

Reprint 2013-4: Should a vehicle fuel economy standard be combined with an economy-wide greenhouse gas emissions constraint? Implications for energy and climate policy in the United States

Joint Program In the News

http://globalchange.mit.edu/news-events/news

July 17, *Forbes,* Escalating Fear of Disintermediation Fuels Utility Backlash Against Distributed Energy

July 15, *Financial Times,* Pollution: Under a Cloud

July 15, *Wall Street Journal,* 1,600 Die Prematurely in Hong Kong as Smog Spikes

July 10 & 11, *Nature World News,* MIT Study Claims Stronger, More Frequent Hurricanes in the Future; *CBS News,* Storms will be more intense, more frequent MIT climatologist

July 9, *Time,* Climate Change Could Make Hurricanes Stronger—and More Frequent. Also covered by: *USA Today*

July 9-12, *New York Times,* Pollution Leads to Drop in Life Span in Northern China, Study Finds. Also covered by: *Wall Street Journal, Washington Post, Associated Press, Reuters, Bloomberg, BBC, USA Today, CNN, Discover Magazine, LA Times, National Geographic, Nature, Guardian, Sky News, International Business Times, Financial Times, The Telegraph, Daily Mail, China.org, Agence France-Presse, CBS News, CNBC, Nature World News.*

June 18, *Washington Post,* Saving energy is great. But how much is actually possible?

June 17, *ClimateWire,* Model helps developing nations budget for climate change

June 12, *Reuters,* Shale wells and methane emission

June 12, *Tech Review,* Cheaper Ways to Capture Carbon Dioxide

June 6, *Washington Post,* Want to boost fuel economy? Stop thinking about miles per gallon.

June 6, *Climate Wire,* Researchers develop tool to set cost and emissions targets for energy sources

May 30, *Tech Review,* Grasping for Ways to Capture Carbon Dioxide on the Cheap

May 23, *Bloomberg,* With U.S. Awash in Oil, Keystone Argument Weakens

May 9, *National Journal,* The Coming GOP Civil War Over Climate Change

April 24, *The Atlantic,* What If We Never Run Out Of Oil

April 15, *WBUR,* The Future of Food

March 14, *Washington Post,* Could Republicans ever support a carbon tax? Bob Inglis thinks so.

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