Air Pollution’s Invisible Toll

Two decades later, pivotal Harvard School of Public Health Six Cities Study key in fight for clean air

By Alvin Powell

Years before Janice Nolen began keeping tabs on the nation’s air quality for the American Lung Association, her mother used to tell her about air pollution in her native Nashville that was so bad that people brought an extra shirt to work so they’d have a clean one to change into. By 1993, those days seemed to be in the past. The major amendments to the U.S. Clean Air Act that passed in 1970 had been at work for decades, and the air was visibly cleaner. So it was a shock to Nolen — today the Lung Association’s assistant vice president of national policy and advocacy — when Harvard School of Public Health researchers highlighted still deadly air pollution in the small city of Harriman, Tennessee that was taking years from people’s lives.

“It was not one of those places you’d think of as having a pollution problem,” Nolen said. Nolen, who joined the Lung Association the year after the study was published and who authors its annual State of the Air report, has followed the far-reaching effects of the Harvard Six Cities Study, including a new suite of U.S. air pollution regulations that has seen the nation’s air grow cleaner, political controversy over those regulations that continues today, and a new generation of studies investigating avenues opened by Six Cities’ findings.

“It’s a landmark, no question about it,” Nolen said of the Harvard study. “[It has] just absolutely been fundamental to the work we’ve been doing over the last 20 years to reduce particle pollution across the country…Because of this work showing an association, it was easier to convince people that this wasn’t just an arbitrary health effect, it was lives lost.”

HSPH Professor Douglas Dockery, pictured taking air pollution measurements in South Boston in 1999, joined the Six Cities Study in the 1970s as a graduate student and later became its principal investigator.
2.5 microns in diameter—one fourth the size in the air pollution standards at the time. It linked pollution from those particles not only to ill health, as other studies had before, but directly to deaths, which were 26 percent higher in the most polluted city—Steubenville—than in the least.

The nature of those deaths was a surprise as well. The biggest cause was not respiratory disease, as seemed logical, but rather stroke, heart attack, and other coronary conditions.

Perhaps most important for federal regulatory officials, Six Cities also illustrated that some 23 years after the modern regulatory scheme was adopted in the Clean Air Act amendments of 1970, air pollution was still killing thousands of Americans annually.

“We were surprised by this very strong unexpected effect on mortality,” said Douglas Dockery, chair of the Harvard School of Public Health’s Department of Environmental Health. Dockery, a faculty associate of the Harvard University Center for the Environment (HUCE), joined Six Cities as a graduate student in the 1970s and later became the study’s principal investigator. “There’d been lots of papers on respiratory illness and asthma and chronic obstructive pulmonary disease and lung function and so forth, but it was the mortality paper that got the most attention and really galvanized the political debate.

“When you think about the routes of exposure, you expect a respiratory problem and the biggest effect to be on the lungs,” Dockery continued. “It has become apparent that the lungs and heart are so intimately connected that if air pollution is straining the lungs, it puts a strain on the heart also. The most important effects we see are cardiovascular.”

**From killer smoke to concerted action**

Six Cities got its start in 1974, four years after the Clean Air Act of 1970 and at a time when public pressure was building and action was already beginning to clean up skies over the U.S. That pressure resulted from a shift in the public’s attitude toward air pollution and economic development. But in the early decades of the 20th century, a different kind of pressure was on: to innovate and modernize. Ever bigger factories churned out new products resulting from wave after wave of innovation. New cars packed the roads, adding their own emissions to the air. Radios and televisions, washing machines, and a dizzying array of goods were demanded by the burgeoning consumer society. The fumes that poured from smokestacks, darkening the skies, made people cough and wheeze, but many just shrugged at their ailments, believing their sniffles were the cost of progress.

It soon became apparent, however, that progress’ price wasn’t just ill health, but potentially life itself. In 1948, an atmospheric inversion over the industrial town of Donora, Pennsylvania trapped the emissions, killing 20 residents and causing respiratory issues in countless more.

As industrialization took hold in the early 20th century, factories—including this wire mill in Donora, PA—churned harmful pollutants into the air. In 1948, an atmospheric inversion in Donora trapped the emissions, killing 20 residents and causing respiratory issues in countless more.

A few years later, in 1952, a December fog settled over London, the still air brewing toxic emissions into a deadly stew, causing the worst air pollution disaster on record. Some 4,000 deaths were immediately attributed to the episode and its aftermath. A 2004 analysis examined excess deaths later that winter and put the number several times higher, at about 12,000.

Even as public concern was mounting over industrial pollution in the East, another problem arose in the clear skies of Los Angeles. Though little coal was burned in L.A., residents were periodically afflicted by an eye-burning haze, first noticed in 1943. Investigations found a new kind of pollution, ozone, which was not emitted directly from smokestacks, but instead was produced in the atmosphere by the reaction of auto exhaust, industrial emissions, and sun-shine, trapped and simmering in the Los Angeles basin.

Frank Speizer, professor of environmental science at the Harvard School of Public Health, Kass distinguished professor of medicine at Harvard Medical School (HMS), and principal investigator of the Six Cities Study, worked on early air pollution studies in the 1950s...
in Los Angeles. He recalls being halted at a stop sign and someone banging on the window and asking when something was going to be done about the air pollution.

Though momentum toward change was slowly building, effective action was still decades away, at least in part because so little was actually known about how air pollution affected health.

As a student in Los Angeles in the late 1950s, Speizer worked on an early study of ozone pollution’s effects on lung function of patients at a veterans hospital. He spoke of the crude measures they used to gather data at the time.

“You could see the mountain or you could not see the mountain,” said Speizer, a HUCE faculty associate. “It actually turned out to be a very good measure, but that’s how qualitative it was.”

Early federal legislation included the Clean Air Act of 1963, amendments in 1966, initial restrictions on auto exhaust in 1965, additional legislation in 1967, and the Clean Air Act of 1970, which established the regulatory structures in effect today.

Despite the legislation, change was slow. Michael McElroy, Harvard’s Butler professor of environmental studies and faculty associate of HUCE, remembers growing up in Belfast in the 1940s and 1950s and how the white handkerchief he put in his pocket each morning became black by the end of the day from his repeated blowing. By the time he visited Pittsburgh in the 1960s, the problem hadn’t changed.

“The problems of that time were pretty
Richard Vietor

As a young schoolteacher on Long Island, Richard Vietor recalls taking part in the first Earth Day by riding his bike to work wearing a gas mask. These days, Vietor, the Cherington professor of business administration and senior associate dean of the Harvard Business School, is still committed to environmental causes as a leading expert on the business of renewable energies—particularly wind power.

Vietor’s academic interest in the nexus of business, politics and the environment can be traced back decades, to his work as a doctoral student at the University of Pittsburgh. Working under environmental historian Samuel P. Hays, Vietor wrote his dissertation on environmental politics and coal, and later wrote a book that examined stationary source air pollution and coal strip mining.

“After I completed my doctoral dissertation on coal, I realized that coal-related air pollution and water pollution were big deals and kill people,” he said. “But it wasn’t until later, when I became aware of climate change, that I understood how great the problem is.”

The path that brought Vietor to Harvard began when he received a year-long fellowship. Though he intended to use the time solely for his dissertation, Vietor soon found himself drafted into classroom duty, as one of nine professors teaching a course called “Business, Government and International Economy,” more popularly known as “BGIE.”

When the Working Group on Environment was created in the early 1990s, Vietor—by then the author of several books on environmental politics and countless HBS cases that addressed environmental issues—was invited to join.

When asked about the future of the renewable energy industry, Vietor said he expects the next several years will bring a tipping point as technology continues to drive costs down. “It is happening, but it requires oil prices to stay high,” Vietor said. “The cost of solar has come down drastically—about three years ago, solar cost about 18 cents per kilowatt hour, and it’s now down near 14 cents. That still doesn’t compete in the U.S., but prices are continuing to drop.”

With renewable technologies becoming increasingly viable, Vietor said a number of nations have begun to turn to them as a way to supplement their power needs. “Iceland, for example, not only has enough geothermal energy to power themselves, but they can actually generate electricity to build an undersea cable all the way to Europe,” he said. “They’re considering doing that…because if they can deliver electricity in England or Ireland for ten cents per kilowatt hour, that would be comparable to their cost.”

Other nations, like Ireland and Denmark, have turned to wind power, and today generate 20 percent or more of their energy using wind turbines. “That has freed them up from having to import so much natural gas,” Vietor said. “It’s also an alternative to nuclear power for countries that choose not to have it. However, it’s variable, so they can’t do it all with wind—you need to have base load from other energy sources.”

Speizer told of how carbon monoxide limits in Boston’s Sumner Tunnel were established at the time, among officials at a restaurant over dinner, with guesswork playing an uncomfortably large role in the process.

“Nobody knew what levels to set, that was the problem,” Speizer said. “We knew carbon monoxide was bad for you—there were studies done in the ’20s that showed cognitive decline and acute poisoning. But the question was what should the level be in the Sumner Tunnel for workers and drivers?”

From Steubenville to Topeka

Shortly after the 1970 Clean Air Act, Speizer and Ben Ferris, both professors at HSPH, appeared before a federal commission investigating the health impacts of burning coal. Commissioners asked how the two would go about assessing those impacts. In response, Speizer drafted a document detailing a
study of sulfur dioxide and total suspended particles, which would later be refined to examine particles of different sizes. Shortly after, the two were asked to submit the proposal, which would become the Six Cities Study, for funding.

The first city to be enrolled in Six Cities was nearby Watertown in 1974. Watertown was selected because of its proximity so that the researchers could work out kinks in their procedures before the study spread to more distant locations. Harriman, Tennessee and St. Louis were enrolled in 1975. Steubenville, Ohio—the most polluted city—was enrolled in 1976, along with Portage, Wisconsin, which had the cleanest air. Topeka, Kansas, which rivaled Portage for cleanliness, was the last to join, in 1977.

The study enrolled 8,111 adults between age 25 and 74 who were followed up annually, as well as some 14,000 children in grades one through four, who were followed through high school. Researchers set up instruments in each city and gathered air quality data. After conducting initial physical examinations and detailed questionnaires, researchers returned every third year and tracked down participants, taking basic health measurements and asking about smoking habits, health history, and occupational history. In the years between, researchers sent annual post cards that served to alert researchers when a study participant died, after which researchers tracked down cause-of-death information.

“We were in Steubenville, a steelmaking community, and periodically they’d have bad air pollution episodes,” Dockery recalled. “We set up the study to monitor the kids, measure lung function, and then, when the air pollution was going to get bad, re-tested some kids. We measured lung function before, during and after air pollution events. We could see their lung volumes dropped during these events.

“It was the first study I was involved in that directly showed the effect of air pollution with obvious physiological measures,” Dockery said. “We were taking these clinical measures into the field and providing objective measures of the health of the kids—that was one of the innovations.”

Another innovation was provided by John Spengler, today the Yamaguchi professor of environmental health and human habitation at HSPH, who joined Six Cities as a postdoctoral fellow shortly after it began and designed instruments to measure particles of different sizes. This allowed the study to shift from the crude measure of total suspended particles to measuring and analyzing particles of different sizes, which would be key in the landmark 1993 paper.

Called an “impactor,” the device sucked air through a nozzle and directed it around an impactor sheet and then through a filter paper. By tuning the air flow, the greater momentum of the larger, heavier particles would cause them to hit the impactor sheet, where they could be measured, while the lighter, smaller particles remained entrained in the air flow and collected on filter paper deeper inside the instrument. Developed together with an aerosol physicist from the University of Minnesota and a research team at the U.S. Environmental Protection Agency (EPA), the instrument could be tuned by changing the size of the

Mortality adjusted for age, sex, cigarette smoking, occupation, education, obesity, and chronic disease. Dockery et al., 1993
opening and the speed of the air flow, to separate particles of different sizes, which could then be measured and analyzed.

Particles larger than 10 microns were gathered, along with particles smaller than 10 and smaller than 2.5 microns. Once the samples were gathered, Spengler said, they could be sent to the EPA lab, where they were analyzed for metals.

“That was a big advance, because from the metals, we could tell the sources [of the emissions],” said Spengler, today a faculty associate at the Harvard University Center for the Environment. “Vanadium and nickel were from oil, sulfur and selenium were from coal, Earth crustals and iron were from steel plants.”

In addition to the hundreds of research papers spawned by the study itself, the instruments themselves have also had an enduring impact, Spengler said, and have been duplicated and used around the world. The work also launched two generations of academic careers—Spengler tallied four professorships resulting from the first generation of research, including his own, and several among the numerous fellows who worked under those faculty members’ auspices.

The study’s most far-reaching effects, however, stemmed from that 1993 mortality paper, published in December in the *New England Journal of Medicine*.

The results were shocking enough—even to the researchers—that Speizer, the paper’s senior author, refused to submit them for publication until they had been validated. The difference in mortality between the cleanest and most polluted cities was much larger than anticipated,

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ported in 2003 that they were in “almost complete agreement” with the original study’s conclusions.

The study’s political opponents haven’t given up, however. As recently as last fall, congressional Republicans subpoenaed the Six Cities data, much of which is protected by the confidentiality restrictions that guard all human studies, in an effort to bring to light what they term “secret science” underpinning emissions standards.

Dockery, who received the subpoena, declined comment. But Spengler pointed out that the science has not only proven sound, the cleaner air has been shown to save the U.S. economy far more than it cost, with one study estimating that the economic benefits of improved health for millions of Americans—in reduced sick days and extended working lives—outweigh the cost of air pollution controls by 18 to 1.

“You’d think it’d be asked and answered,” Spengler said. “In spite of all that, the pressure’s still on.”

Though primary data collection ceased in 1991, Six Cities continues to inform. Mortality statistics are still collected, using the federal government’s National Death Index, and in 2006, HSPH Associate Professor Francine Laden was the lead author of a paper that again confirmed the association between air pollution and mortality, albeit using a happier trend. Her analysis showed that mortality fell along with levels of the 2.5 micron particles, with three percent fewer deaths for every microgram reduction in a cubic meter of air. The observed reduction equaled approximately 75,000 lives each year in the U.S., Laden said.

In 2012, an extended follow-up of Six Cities by Laden, Dockery, Johanna Lepeule, a visiting scientist at HSPH, and Joel Schwartz, HSPH professor of environmental epidemiology, confirmed the initial findings with 11 years of additional data. Specifically, they found that every 10 microgram increase of PM-2.5 per cubic meter of air was associated with a 14 percent increased risk of death from all causes, a 26 percent increased risk of death from cardiovascular causes, and a 37 percent increased risk of death from lung cancer.

Though the nation’s air has gotten cleaner in the years since the new particle pollution standards were implemented in 1997, work remains to be done, according to the American Lung Association’s annual State of the Air report.

“It [the particle pollution standards] saves lives, but we’re not where we need to be. Last year’s report showed we still have 140 million people who lived in areas that were unhealthy. Part of that is understanding better what unhealthy is, and that’s what studies like the Six Cities Study helped us to see,” Nolen said. “It wasn’t just [removing] the soot—the worst of the haze was invisible soot—we had to get cleaner and cleaner and cleaner…We haven’t solved the problem by any means, but it’s less burdensome on people’s health.”

In many places around the world, the lessons from Six Cities remain to be applied. Some 3.7 million people died in 2012 from outdoor air pollution—more than 80 percent in low- and middle-income countries, according to a March 2014 report by the World Health Organization (WHO), and millions more died from indoor air pollution, much of it generated by smoky indoor cookstoves.

As it once was in industrialized nations, the stench from burning forests and coal-fueled plants is still thought to be the price of progress in many places, progress that national leaders are loath to curb. The result is that some 20 years after the Six Cities Study dramatically highlighted the danger, air pollution is the world’s single largest environmental health risk.

Harvard researchers are working with collaborators at universities around the world to understand air pollution’s local dynamics and explore approaches that would help millions breathe easier.

An eye on Asia
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Harvard researchers are working with collaborators at universities around the world to both understand air pollution’s local dynamics and explore approaches that would help millions breathe easier. The choking smog that wreathes China’s major cities is the focus of Harvard’s China Project, begun by Mike McElroy
Wildfires in the West Set to Worsen

The effect of burning forests on human health is not a problem solely for distant governments contemplating the future of virgin rainforests.

Recent research by Loretta Mickley, senior research fellow in chemistry-climate interactions at the Harvard School of Engineering and Applied Sciences (SEAS), together with collaborators at Harvard and the Ecole Polytechnique Federale de Lausanne in Switzerland, shows that one effect of climate change may be a wildfire season in the western U.S. that is three weeks longer and up to twice as smoky, including as much as a quadrupling of the extent of August fires in the Rockies.

The work, released in August 2013 and published in the October issue of Atmospheric Environment, checked the extent and severity of historical Western fires against past weather conditions and created computer models that explained past wildfire behavior. It then used those models and predictions about changing future climate to look at what might be in store. The answer is bad news for the air quality of major cities across the American West.

The study, led by former SEAS senior research fellow Jennifer Logan and conducted by Mickley, former doctoral student Xu Yue, and Jed Kaplan, a professor at Ecole Polytechnique Federale de Lausanne, found that across the majority of the West, hotter and drier conditions in forested regions in a given year would lead to a greater number of larger fires that would spread more easily. According to their model projections, by 2050, the Pacific Northwest would see a 65 percent increase in the area burned in the month of August alone, the eastern Rocky Mountains/Great Plains region would see the burnt area nearly double, and the Rocky Mountain forest region would see it quadruple. The research also indicated that the probability of large fires would increase by a factor of two to three, and that the lengthened fire season would start in April instead of May and end in mid-October instead of the beginning of that month.

As a consequence of the findings, Mickley said air pollution can be expected to get worse in Denver, Salt Lake City and other major metropolises.

“We find fire activity is very likely to increase in the future,” Mickley said. “Moisture parameters, rainfall and relative humidity may not change as much as temperature in the West. Still, it’s going to be hot, and high temperatures will dry out fuel. Fire activity is expected to increase, and we find a longer fire season by three weeks.”

“The government has done a tremendous job cutting back emissions from power plants, cars. It’s really remarkable what the Clean Air Act has accomplished, but … when we look at the future, it seems wildfires could really ramp up our pollution problem in the western U.S. That’s the message we’re most confident about.”

— Alvin Powell

in the early 1990s. Despite his boyhood in industrial Belfast, McElroy recalls being nearly bowled over by the choking smells experienced during an early trip, in 1995, to Chongqing, a city of about 20 million on the Yangtze River.

“We arrived late at night. I’ve experienced air pollution in my life, but this was 95 to 100 degrees at night, people were working in the streets, pouring tar, with no shirts on,” McElroy said. “The place just smelled awful, awful, awful.”

McElroy was later escorted to one of the city’s iron and steel factories by an environmental official.

“I have never seen anything like this in my life,” McElroy said. “There were coal trains coming through that place continually dumping off the coal, just an astounding flow of coal. There were high smoke stacks and one in the middle, about a quarter mile back. It was like standing behind a jet plane taking off, like a supersonic blast. You could see the dirty smoke coming out of these stacks.

“I turned to my guide and asked, ‘Is this place consistent with clean air standards your ministry is imposing?’ He smiled and said, ‘Of course not. If this place had to meet international standards, it would have to be closed down.’”

The China Project, based in Harvard’s School of Engineering and Applied Sciences, today provides a focus for faculty and fellows from across Harvard and partner institutions in China who are interested in China’s energy, economy, and atmospheric environment. It works to understand what is happening in China’s skies from an interdisciplinary point of view, encompassing atmospheric chemistry, economics, and human health, and suggesting viable solutions. A book published in November, Clearer Skies over China, brings together economists and natural, applied, and health scientists from the U.S. and China to examine a successful Chinese effort to regulate sulfur dioxide and explores the potential impact of a carbon tax. McElroy’s own research, meanwhile, has focused on the potential for renewable alternatives to burning dirty coal. In fact, in a 2009 study of China’s wind power potential, McElroy found that China could potentially meet all of its power needs through wind alone.

Air that is unhealthy to breathe is just half of the Asian giant’s air pollution concerns. In recent years, it surpassed
the United States to become the world’s biggest emitter of carbon dioxide, the greenhouse gas largely responsible for human-caused climate change.

If there is a silver lining for China’s air pollution problems, McElroy said, it is that actions to improve air quality will also address climate change, since both have roots in burning coal for power. Despite the Chinese government’s efforts to improve air quality, McElroy said he believes that significant change may depend on breakthrough innovations pioneered in the industrialized West.

An ill wind over Singapore
One day in late September 2013, an interdisciplinary group of researchers gathered in a conference room on the third floor of Harvard’s Hoffman Laboratory. On a screen at the front of the room played a time lapse clip showing the intensity of smoke from burning forests in Sumatra blowing across the narrow Strait of Malacca toward Singapore, with darker colors representing higher aerosol concentrations. A black plume representing the worst smoke appeared, lengthened, and reached across the strait as the date crawled toward the smoke’s peak, on June 21, the day Singapore’s air quality dipped to the worst levels in its history.

“They experienced a pollution standards index of 401, which is higher than has ever been recorded in history in the region,” said Samuel Myers, a research scientist at the HSPH and HUCE faculty associate.

“The episode...probably is associated with a 10 percent to 30 percent increase in all-cause mortality. There were billions of dollars lost in morbidity and mortality.”

A team led by Myers has embarked on a project to understand burning on the Indonesian island of Sumatra, its health impacts on nearby cities, and to create computer-generated scenarios to help policymakers make informed decisions on whether, where, and when to burn.

That the fires have a health impact is beyond doubt. In addition to the data from Six Cities and subsequent studies, HSPH’s Spengler was an eyewitness to the effects while attending meetings at the University of Singapore when the fires reached their peak.

“Even across the quad, you just saw this veil of smoke that started to obscure the buildings on the other side. And forget about seeing the city.”

Despite the smoke’s dramatic effect, the fact that Sumatra was burning was not unusual. Subsistence farmers burn forests each year to clear land for their home gardens and burn scrub on previously cleared land to make room for crops. Larger farms burn too, clearing bigger tracts for cash crops, while industrial plantations burn forests to make room for oil palm trees.

“The public health costs of those fires are staggering,” Daniel Jacob, McCoy Family professor of atmospheric chemistry and environmental engineering and HUCE faculty associate, said later. “When you look at the kind of particulate levels Singapore was exposed to in June of this year, this is a smog that takes years from your lifetime.”

Jacob is part of the Myers-led study of Sumatra’s burning. The project also involves Senior Research Fellow in Chemistry-Climate Interactions Loretta Mickley, Professor of Environmental Epidemiology Joel Schwartz, and colleagues from Ruth DeFries’ lab at Columbia.

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In June 2013, NASA satellites captured smoke billowing from illegal wildfires on Sumatra. The smoke blew east toward Malaysia and Singapore, creating thick haze and pushing pollution to record levels.
University. Using satellite imagery, newly developed analytical tools, and publicly available data, this interdisciplinary group is applying the expertise from atmospheric science, public health, and ecology and environmental biology in order to understand what’s happening in Sumatra. They’re looking at everything from the economic drivers of burning practices to the health impacts on city residents downwind.

“Our goal in using these new tools is to really characterize this system so we fully understand how certain kinds of land cover are associated with certain kinds of fires and how these fires are associated with certain kinds of emissions—and how these emissions are transported in predictable ways to reach specific concentrations of pollutants at the population level,” Myers said. “Then, what we really want to do is understand how land management decisions being made today will alter exposures in the future.”

Though the project’s primary focus is improving human health, it also serves an underlying conservation cause, Myers said. It’s not a coincidence that major health effects from burning forests are being felt in a part of the world undergoing rapid deforestation. Those forests are home to a significant part of the world’s biodiversity and include many species found no place else. In part, the project is intended to help policymakers understand the hard-to-quantify costs associated with the benefits provided by intact forests—clean water, a home for wildlife, and a purer “airshed,” as Myers terms it—compared with the costs and benefits if the forests are burned and converted to other uses.

“What’s happened [since 1985] is that essentially half of Sumatra has been burned down,” Myers said. “And the predictions are that by 2100, Southeast Asia could lose three-quarters of its forests, up to 42 percent of its biodiversity, including over half the mammals, amphibians and reptiles. Oh, and over half of the mammals, amphibians and reptiles are endemic and don’t exist in other places. That’s the conservation challenge.”

Researchers are also sorting out how to handle ozone, Jacob said. Ozone is generated by the fires but may not have the same health impact as fine particles.

“It’s a toxic gas, the number one pollutant in the U.S.,” Jacob said. “It’s produced in the fire plume, but we don’t really understand the mechanism by which it is produced. We don’t have observations from the ground, so that means our models are pretty uncertain.”

Together, the researchers are seeking to develop computer models that can generate a series of different scenarios that could be used as tools for policymakers in the region. The scenarios will project the ultimate impact of a “business-as-usual” approach to the forests, of varying levels of development, and of a “green vision” where greater emphasis is placed on conservation and in
which the improved health of the region’s residents is considered.

Such a prediction tool has drawn initial interest from Singapore’s government and should enable policymakers to fully evaluate the costs, including human health, versus the economic benefits of new oil palm plantations, for example. And, if policymakers let plantations move ahead, the work could help determine where they should be located to minimize human health impacts.

“If we want to plan our fires, let’s plan them in regions that don’t affect the big cities,” Mickley said. “This is a nice tool for policymakers who want to put in rice paddies or oil palms.”

Though much work remains until such a tool is in policymakers hands, the group’s preliminary work has already suggested a geographical focus for action. The peat forests of southeastern Sumatra, where a lot of burning is going on now, are the source of a lot of the smoke that hits Singapore. Indonesian government officials have made it clear they won’t curb development, but perhaps land could be cleared on the western part of the island instead, to spare Singapore. Another tack could be taken by Singapore’s government, since many of the companies operating in Sumatra are based in Singapore. Perhaps a tax would encourage the companies to clean up their act.

“We want to quantify for the first time ever, what are the public health implications of land management decisions in Southeast Asia,” Myers said. “To date those health implications have always been a vague externality: If you grow more palm oil, maybe more people will die, but we don’t know how many or where. We want to quantify that.

“We want to…produce a tool to allow policymakers in the region to calculate and argue that conservation strategies will have important public health dividends, and make that case in a scientific way,” he said.

Ultimately, Myers said, such a tool could also be used elsewhere, since there are many other places around the world that, like Sumatra, are experiencing rapid deforestation and health-destroying air pollution. By providing policy-informing tools that illuminate both the value of conservation and of improved health, the researchers’ work could help more places achieve clean air goals whose roots can be traced back to findings in the Six Cities Study.

When it comes to the world of alternative energies, Laura Diaz Anadon brings an unusually broad set of skills to the table.

A chemical engineer by training, Anadon is also an assistant professor of public policy at the Harvard Kennedy School (HKS), a position that gives her unique insight into not only the science behind alternative energies but the policies that go into developing and deploying them.

“I was at Cambridge University studying multi-phase flow reactors and magnetic resonance imaging,” Anadon said. “I realized I was very interested in science, energy and environmental policy and wanted to conduct research in that area.”

That interest led Anadon to the Kennedy School, where in late 2007 she began conducting research on energy policy through the HKS Science, Technology and Public Policy program, while simultaneously working towards a master’s degree in public policy.

After receiving her degree, Anadon was appointed director of the HKS Energy, Technology Innovation Policy research group, and lectured at the Kennedy School before being hired earlier this year as an assistant professor.

While she admits that recent years have seen “a great deal of progress” in the development of alternative energy technologies, Anadon said additional government support will play a crucial role in moving new technologies out of the laboratory and into the market.

“The question is how much we should invest and how to allocate those investments,” she said. “Right now, the United States invests about $5 billion annually on energy research and development, and even very conservative estimates of the potential benefits suggest it should be investing much more, on the order of $15 billion.”

Though private investment will play a role in energy innovation, government investment has played a key role in developing technologies that are virtually indispensable in the modern world, Anadon said, and the same will likely be true for renewable energy.

“What we know is that many of the energy technologies we have today, and other non-energy technologies, like GPS, stealth technology and the Internet, have benefitted enormously from government research funding,” she said.

“Solar photovoltaics began in the 1950s in Bell Labs and were further developed in the context of the U.S. space program before government funding for R&D and deployment from the U.S. and other governments enabled its application in terrestrial settings, leading to dramatic reductions in cost. The U.S. and other nations also had a major role in the development of wind and nuclear power, among other technologies.”

Increasing funding for research, however, is only half of the equation. Given the uncertainty around the potential returns for any single technology, Anadon said the question government must answer is how to allocate their investments across various technologies. Current approaches for investment, unfortunately, take a piecemeal approach to making those decisions.

“One question I have found interesting is how governments can make those decisions using a more robust approach,” she said. “In the U.S. the current funding allocation, for example, doesn’t focus enough on storage. If you’re investing a lot in solar, but you don’t also invest in storage, you won’t get the same benefits, so you need an integrated method to make those decisions.”

Anadon is also working on other technology innovation policy questions beyond R&D decision making, such as understanding the sources of technology breakthroughs, the evolving role of publicly-funded R&D institutions, what transnational actors can do to accelerate innovation for sustainable development, and how to manage linkages between water and energy systems.

— Peter Reuell
CHARTING CHINA’S COURSE

Probing the nexus between environment, energy, & economic growth

By Jennifer Weeks

China has been the world’s most populous country for centuries, but after several decades of rapid economic growth, China has become something much more significant: a global heavyweight with a massive environmental footprint. Today, China is the world’s second-largest economy, after the United States, and the world’s number one exporter, manufacturer, and energy consumer.

This dramatic transformation increased China’s gross domestic product tenfold over 30 years, lifting more than 500 million people out of crushing poverty. But wealth came at a price. Choking urban smog, arid farmland and undrinkable water have become widely-publicized hallmarks of the country’s dizzying economic growth. In 2006, China’s greenhouse gas emissions surpassed those of the United States, and are roughly 50 percent higher than U.S. emissions today (although the average American’s carbon footprint is still roughly twice as big as that of a Chinese citizen).

Chinese leaders have pledged to fight pollution and shift to a more sustainable path, but that effort is just one aspect of a broader challenge. To become a stable and prosperous society, experts widely agree that China needs to develop a more market-based economy, foster innovation and competition, and address pressing social problems, including rising inequality and an aging work force. But China also needs to develop an economic growth strategy that is sustainable—one that is not based on heavy government spending, wasteful overuse of resources, or a skewed distribution of wealth.

To explore linkages between China’s environmental challenges and its broader economic policies, the Harvard University Center for the Environment (HUCE), together with the Harvard China Project, an interdisciplinary research project based in Harvard’s School of Engineering and Applied Sciences, launched a new lecture series in the spring of 2014, “China 2035: Energy, Climate, and Development.” “China today has about one-seventh of the world’s population, uses more coal than the rest of the world combined, and produces about 30 percent of the world’s greenhouse gas emissions… It’s impossible to think about the future of the global environment without thinking about China,” says HUCE Director Daniel Schrag.

The first three speakers in the China 2035 series brought perspectives from the worlds of academia, international organizations, and politics: Michael Spence, a Nobel laureate in economics and former dean of Harvard’s Faculty of Arts and Sciences; Robert Zoellick, former president of the World Bank; and Kevin Rudd, former prime minister of Australia and current senior fellow at the Harvard Kennedy School (HKS). Michael McElroy, Butler professor of environmental studies, former HUCE director, and chair of the Harvard China Project noted, “Harvard University has long been a center for research on all aspects of China, including its history, culture, politics, and geopolitical role. We hope that these lectures will not only bring experts to Harvard to consider China’s future choices—they will also bring Harvard faculty together from across the University for wide-ranging discussions of their own research.”

Success, at a Cost

China’s economic transformation began when Deng Xiaoping assumed leadership in 1978, two years after the death of Mao Zedong. Mao’s major attempts at transformative change—the Great Leap Forward (1958-60) and the Cultural Revolution (1966-76)—had ravaged China’s economy, leaving the nation impoverished and demoralized. Under Deng, Chinese leaders embraced a different goal: reforming the economy to stimulate growth and opening up to global trade, while preserving the Communist Party’s tight control on political power. The introduction of market-oriented reforms in agriculture, special economic zones to encourage foreign direct investment, and currency reform combined to help make China a manufacturing powerhouse, shipping textiles, electronics, toys, appliances, and other products worldwide. From
“Many of China’s problems affect particular communities, but environmental degradation affects everyone. And its a clear outcome of China’s development strategy.”

1978 through 2010, China’s economy grew at an average rate of nearly 10 percent annually, compared to typical rates of two or three percent in wealthy nations. In 2010, China surpassed Japan as the world’s second-largest economy, with a gross domestic product of nearly $5 trillion.

These shifts triggered a wave of urbanization. Millions of workers moved from the countryside to urban areas in search of manufacturing and construction jobs. In 1978, no city in China had more than 10 million people, and only two had more than five million. By 2010, six cities had populations over 10 million, and ten more had populations larger than five million.

Now China faces another dramatic transition. Developing countries can sustain high economic growth by spending heavily at home, as China’s government has done over the past several decades to build up high-priority sectors like energy and manufacturing. But eventually this approach yields diminishing returns. “High investment and exports have been the engines of growth, but this model has run its course,” said economist Michael Spence in the inaugural China 2035 lecture.

Pollution and resource scarcity are also stressing the economy. Major cities, especially in industrialized northern China, often are swathed in dense smog, caused mainly by emissions from coal and oil combustion. Water supplies in many Chinese cities are heavily polluted, and a 2014 Chinese government study concluded that one-fifth of China’s farmland is contaminated with cadmium, nickel, arsenic and other toxic materials.

These environmental problems directly threaten China’s economic development and political stability. The Ministry of Environmental Protection estimated that in 2010 pollution cost the nation about $230 billion, equal to 3.5 percent of its gross domestic product. “It’s a crucial issue for Chinese leaders,” says Anthony Saich, Daewoo professor of international affairs and director of the Ash Center for Democratic Governance and Innovation at the Harvard Kennedy School. “Many of China’s problems affect particular communities, but environmental degradation affects everyone, whether they are rich or poor, urban or rural. And it’s a clear outcome of China’s development strategy.”

Chinese citizens are becoming increasingly outspoken about environmental hazards. Riots have broken out in recent years over wastewater discharges, heavily-polluting factories, and incinerators.

The government has responded to some concerns. For example, it started releasing data on levels of fine particulate air pollution in major cities after activists obtained the same information from foreign sources—including the U.S. Embassy in Beijing—and called on their government to publish its data.

“Public opinion does play a role, and the leadership is trying to respond to people’s concerns,” says Saich.

Transition or Trap?

China has reached a stage in its development that economists call the middle-income transition. Low-income countries have advantages that enable
them to grow quickly when they start to develop. They have abundant low-cost labor, which makes their products competitive, and can sell their goods into vast global markets. And they can import knowledge and technology from abroad rather than developing industries and skilled work forces from scratch.

But as nations reach middle-income levels, these advantages fade and growth slows. As workers move from farming to industry, wages rise and the country’s goods become less competitive abroad.

To sustain growth, countries need to develop a prosperous consumer class at home that will generate economic demand. They also need to innovate instead of depending on imported technology and knowledge, and develop higher-value goods and services.

Countries that fail to evolve get stuck at this level, a pattern that some experts call the middle-income trap. To maintain growth, China will have to make far-reaching changes in many areas. China 2030, a 2013 report produced jointly by experts from the World Bank and China, outlines changes required to put China on a stable growth path. They include: economic reforms to support a more market-based economy; policies to promote innovation; incentives and regulations to spur green development; policies to reduce social far-reaching changes in many areas. China 2030, a 2013 report produced jointly by experts from the World Bank and China, outlines changes required to put China on a stable growth path. They include: economic reforms to support a more market-based economy; policies to promote innovation; incentives and regulations to spur green development; policies to reduce social and economic inequality; and fiscal reforms to ensure that government has enough resources. “These reforms affect every industry in China,” says Dale Jorgenson, Morris university professor at the Harvard Kennedy School. “I think that China will be successful, but it will be very challenging.”

One question is how China will manage urbanization. In March 2014, the Chinese government released a $6.8 trillion plan for increasing the fraction of the population living in cities from 54 percent today to 60 percent by 2020. The plan acknowledged that urban growth had been poorly managed, generating congestion and sprawl, and called for better planning and investments in mass transportation and affordable housing. “By far the most important reforms are those...
that involve integrating the urban and rural population, which will require considerably more than two decades as China continues to urbanize,” says Jorgenson. “Most economic growth will be concentrated in urban areas, which will require continued infrastructure investments on a massive scale.”

William Kirby, Spangler Family professor of business administration and Chang professor of China studies at Harvard Business School, is skeptical of promises to make urbanization more people-centered. “Urbanization has happened without a lot of central planning until now, and it has worked reasonably well up to a point, although the large numbers of migrant workers living around cities are second-class citizens without access to schools or health care,” Kirby says. “The idea that China will now move even more people to cities in a planned way terrifies me.”

“This is a government whose most catastrophic moves have been large-scale social engineering projects,” Kirby observes. “If you look at what happened to the millions of people displaced by the Three Gorges Dam project, it doesn’t make you confident.”

**Barriers to Change**

Many of the structural changes on China’s agenda will affect its energy and environmental profile directly or indirectly. For example, the Chinese economy distorts the prices of energy and natural resources—subsidies make fossil fuels, electricity and water artificially cheap, so they are overused. And their prices do not reflect social and environmental costs associated with using them, such as widespread illnesses caused by air pollution. “China needs to move toward a market-based allocation of coal, oil, and natural gas, as well as electricity,” says Jorgenson.

Another priority is reforming and restructuring state-owned enterprises (SOEs), large firms controlled by the central government or by local or regional governments. SOEs are a pillar of China’s socialist system. Many are
protected against competition and receive preferential access to capital and raw materials. Even so, they are much less productive than private businesses. They also retain a large share of their profits, although the central government announced at a plenum meeting late last year that the largest SOEs would increase their contributions to China’s developing social security system over the next several years.

Many of China’s heaviest polluters are SOEs, including large oil, coal, electricity, cement, mining and steel companies. Since these enterprises produce to meet quotas and are shielded from competition, they have little motive to modernize their processes. “All incentives over the past 25 years have pushed toward an economy that is heavily energy-dependent and inefficient,” says Kirby. “And state-owned industries have a lot of influence over government decision-making.”

In April, the Chinese legislature revised the nation’s environmental protection law to increase fines and penalties for polluting companies, and for local officials who tolerate heavy polluters. This step followed on Prime Minister Li Keqiang’s pledge in March to “declare war” on pollution. But it remains to be seen how stringently the new law will be applied.

“Enforcing environmental law is an ongoing challenge—indeed, it’s a growing issue in some parts of the country,” says William Alford, Stimson professor of law. “So long as local environmental protection bureaus and local courts depend financially and in other respects on local government—which in turn may rely for tax revenue and employment on powerful local industries that pollute—it is hard to foresee stronger enforcement.” With respect to state-owned enterprises, Alford says, “I don’t foresee a radical improvement unless Chinese authorities demonstrate by action that they value a cleaner environment as much as they value revenue generation.”

One area in which the government has pushed SOEs toward cleaner technology is renewable energy. To meet its enormous electricity needs, China has invested heavily in solar, wind, and hydropower. Today renewables generate about 8 percent of China’s electric power, and the government wants to increase their share to 15 percent by 2020. In 2012 and 2013, China invested more money in renewable energy than any other nation worldwide.

“China’s five major state-owned power companies all have institutes focusing on clean energy, and they’re trying to develop expertise,” says Chris Nielsen, executive director of the Harvard China Project (for more on the China Project, see related story on p. 8). “They’re acquiring assets worldwide. For example, the Three Gorges Company has bought into a major Portuguese utility with large renewable capacities, not only in Europe but also in the U.S. Globalization is probably helping some of these companies diver-
sify and figure out how to build more grid capacity.”

But top-down mandates have their limits. China has installed more wind generating capacity than any other nation—more than 91 gigawatts (GW) as of 2013, followed by the United States (61 GW), Germany (35 GW), and Spain (23 GW). As recently as 2010, however, up to one-third of Chinese turbines were not connected to local power grids. “They built a lot of wind power in a short period because companies were given capacity targets, so they went crazy and developed faster than the grid, which reflects the way that the government mandates changes,” says Nielsen.

Today most of those turbines are linked up, but the swift scaling up of the wind industry poses other challenges. The grid has to be managed to accommodate a growing share of intermittent power. And in winter, clean and effectively costless wind power sometimes has to be curtailed because coal-fired plants must operate to provide heat to buildings, as well as electricity.

**Green Prospects**

China’s green plans extend far beyond wind power. The 12th Five Year Plan, which runs from 2011 through 2015, set ambitious targets for reducing energy consumption in absolute terms and per unit of gross domestic product, cutting emissions of major air pollutants, using water more efficiently and increasing forest cover.

And as former Australian prime minister Kevin Rudd noted in his China 2035 lecture, China is currently preparing carbon intensity targets for the 13th Five Year Plan, which will set policy guidelines through 2020. “Now… is the time,” urged Rudd, “for both political leaders and policy leaders in the climate change policy space to engage our Chinese friends.”

Henry Lee, senior lecturer and Jaidah Family director of the Environment and Natural Resources Program at the Harvard Kennedy School, agrees with Rudd on timing and is leading an initiative to analyze the interaction of environmental and energy policies in China along with scholars from Tsinghua University and officials from Chinese government agencies. In Lee’s view, Chinese leaders are serious about reducing the nation’s greenhouse gas emissions. “They are much more sensitive to this issue than they were five years ago. I expect that their next five-year plan will include a comparatively strong climate policy,” says Lee.

To meet its enormous electricity needs, China has invested heavily in solar, wind, and hydropower. Today renewables generate about 8 percent of China’s electric power, and the government wants to increase their share to 15 percent by 2020.
Maintaining high employment is an overriding goal for China’s leaders, so environmental reforms could lose momentum if they are perceived to be slowing economic growth. But Lee does not believe the current government is worried about this scenario yet. “I think they feel that they can resolve their environmental problems and continue growing,” he says. “They also know there’s a global market for green technologies. They see South Korea and Japan doing well in it, and they would like to be competitive too.”

As China continues to urbanize, insights from the fields of green building and sustainable planning could make its new cities more livable. "Urban growth in China has put enormous pressure on natural resources and energy supplies, especially if you consider impacts from the construction industry as well as from building design,” says Ali Malkawi, professor of architectural technology and founding director of the newly-created Harvard Center for Green Buildings and Cities at the Graduate School of Design.

Neil Brenner grew up in small-town central Florida and has since lived in New Haven (CT), Berlin, Chicago, Los Angeles, New York City, and now Cambridge, but he’s wary of crediting his personal geographies with his interest in urban studies. “Obviously, if you’re an urbanist, living in dense urban areas can be a good reference point,” says Brenner, a professor of urban theory at Harvard’s Graduate School of Design (GSD). “But so much of my work has been animated by broader theoretical and conceptual concerns, rather than a place-based investigation.”

He notes the work of the French social theorist Henri Lefebvre and urban geographer David Harvey as guideposts in his academic career, leading him from an interest in historical political economy into questions about the changing geographies of capitalism, state power and urbanization. “To Lefebvre, social space is not a thing or a container, but a process,” says Brenner. His students have started producing counter-visualizations—everything from maps to three-dimensional diagrams—that show how these apparently remote, empty places are actually zones of intense socio-environmental transformation that are intimately connected to the growth and expansion of mega-cities around the world. “Suddenly, these places look like they are filled with all kinds of infrastructures,” says Brenner. “They don’t look like New York City or Mumbai or Lagos. But they don’t look remote anymore—they are parts of a planetary urban fabric.”

This is one of the major topics Brenner explores in the Urban Theory Lab, a research collective he has established at the GSD, which employs concrete research projects as a way to develop and foster new concepts on questions related to urbanization. One current project has students critically interrogate satellite images of the world taken at night, in which bright clusters of lights are commonly understood to represent the global fabric of urbanization. “Using this map, you can see what seems to be a bunch of empty spaces,” says Brenner—including dark swaths in the Amazon, the Sahara desert, Siberia and the Himalayas. But his students have started producing counter-visualizations—everything from maps to three-dimensional diagrams—that challenge this view.

Adopting carbon taxes and other market-based pricing would be a major shift for Chinese leaders...But many observers say China is willing to experiment to achieve high-priority goals.
The sheer number of buildings that will be constructed in the next several decades makes China an important focus for green design and planning. China has a few hundred buildings, mainly in large cities, that have been certified green by several rating systems, including some that are not designed for China. “There are a few showcase projects, but you don’t see the basic concepts being applied widely,” says Malkawi. And some early projects that were intended to be models failed or were never built. But in Malkawi’s view, Chinese leaders are serious about making cities more sustainable.

“They are looking at European and U.S. experiences with urban development and transportation, and are thinking about how to make systems like mass transport adequate for the coming decades,” according to Malkawi. As an example of what China is capable of accomplishing, he points to the nation’s high-speed rail system, which started running just six years ago and now carries more passengers than Chinese domestic airlines. “As new cities are being designed and built in China, a great opportunity is presented to create new models in the area of green buildings and cities that has the potential to improve upon current practices around the world,” says Malkawi.

The methods that Chinese leaders use to promote green development will be as important as the goals they set. Economist Jorgenson is encouraged that the current five-year plan discusses the possibility of pricing carbon and introducing taxes on pollution and natural resource use. In a recent article, Jorgenson and Chinese co-authors contend that China could use a carbon tax as an effective tool to reduce both greenhouse gas emissions and conventional air pollutants. If tax revenues were “recycled” back into the economy to reduce existing tax rates, the carbon tax would only reduce economic growth slightly, and this effect would be more than offset by the health benefits of reducing air pollution.

Adopting carbon taxes and other market-based pricing mechanisms would be a major shift for Chinese authorities, who rely mainly on command-and-control measures to regulate the economy. But many observers say that Chinese leaders are willing to experiment to achieve high-priority goals. “Chinese authorities are much more open than many other societies are to saying, ‘How does this work elsewhere?’” said former World Bank president Robert Zoellick in his China 2035 lecture. That may reflect an authoritarian government’s ability to impose policies from above, but it also echoes Deng Xiaoping’s pragmatic approach. Invoking a Chinese saying, Deng called the reforms that he launched without a blueprint “crossing a river by feeling the stones.”

“The entire world is struggling with the question of how you make the switch from carbon-rich fuels to something carbon-free,” says McElroy. “But one of the most important questions for the planet is: What choices will China make?”
Introducing the 2014-16 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 issues 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. These dinners introduce the Fellows to Harvard faculty while at the same time helping to build a faculty community in environmental studies across disciplinary and School lines. Visit our website, www.environment.harvard.edu, to learn more about the Environmental Fellows program, or to apply to join the 2015-17 cohort.

Marie-Abèle Bind is an environmental bio-statistician interested in health effects from environmental exposures. She earned an M.Sc. in Engineering in 2007 at one of France’s Grandes Ecoles. She then received a M.Sc. in Environmental Health in a one-year intensive program at the Cyprus Institute associated with the Harvard School of Public Health. In 2014 she received a dual doctor of science (Sc.D.) degree in Environmental Health and Biostatistics from the Harvard School of Public Health. Marie will work with Donald Rubin of the Harvard School of Public Health. In order to evaluate their impact globally on endangered species. She earned her Hon. B.Sc. in Physics and Astronomy at the University of Toronto, an M.A. at the University of Minnesota, and a Ph.D. in the Conceptual and Historical Studies of Science at the University of Chicago. Zoe will work with Sheila Jasanoff in the Program on Science, Technology and Society at the Harvard Kennedy School. Comparing conservation-oriented programs in the U.S., Australia, Britain, Canada, and Germany, the project tracks the disciplinary re-organizations of conventional ecological science in different institutional contexts to support new biodiversity objectives. Arguing that these new conservation practices are remaking not just environmental knowledge and policies but materially reshaping environments themselves, this research provides a framework for evaluating the heterogeneous and often surprising consequences of conservation interventions worldwide.

Yige Zhang is a geochemist interested in understanding how the Earth evolved chemically and using various geochemical tools to study climate change of the geological past. He earned his B.S. in geochemistry at Nanjing University, a M.S. in Marine Sciences from the University of Georgia, and his M. Phil. and Ph.D. in Geology and Geophysics from Yale University. Yige will be working with Ann Pearson from the Department of Earth and Planetary Sciences. He plans to develop improved atmospheric CO2 estimates in the Miocene, using organic geochemistry methodologies and novel approaches to isotope-ratio mass spectrometry. His goal is to resolve the Miocene CO2 climate sensitivity “paradox,” an issue confronting his field in which current reconstructions show a puzzling relationship between stable, or even increased CO2 concentrations during substantial surface seawater cooling.

Tim Cronin is a climate scientist interested in the interactions between clouds, sea ice, and severe storms in a warmer Arctic. Tim earned a B.A. in Physics from Swarthmore College in 2006, and received a Ph.D. in Climate Physics and Chemistry from MIT in June 2014. Tim will work with Eli Tziperman of the Dept. of Earth and Planetary Sciences on the interaction between clouds and sea ice in the Arctic, in climates that are warmer than present. His project has application to warmer climates of the distant past, as well as climates of the future. Tim will also explore the potential for the formation of hurricane-like storms over a warmer Arctic ocean that has lost much of its sea ice; such storms would be highly relevant to the impacts of climate change on both human and natural systems in the future Arctic.

Zoe Nyssa studies the emergence and contemporary practices of conservation biology in order to evaluate their impact globally on endangered species. She earned her Hon. B.Sc. in Physics and Astronomy at the University of Toronto, an M.A. at the University of Minnesota, and a Ph.D. in the Conceptual and Historical Studies of Science at the University of Chicago. Zoe will work with Sheila Jasanoff in the Program on Science, Technology and Society at the Harvard Kennedy School. Comparing conservation-oriented programs in the U.S., Australia, Britain, Canada, and Germany, the project tracks the disciplinary re-organizations of conventional ecological science in different institutional contexts to support new biodiversity objectives. Arguing that these new conservation practices are remaking not just environmental knowledge and policies but materially reshaping environments themselves, this research provides a framework for evaluating the heterogeneous and often surprising consequences of conservation interventions worldwide.

Outgoing 2012-14 Environmental Fellows

Four Environmental Fellows concluded their second year of the program. They are (back row, left to right): Giuseppe Torri, a theoretical physicist who worked with Ziming Kuang and Daniel Jacob; Chiara Lo Prete, an energy economist who worked with William Hogan; Jessica LaRocca, an environmental toxicologist who worked with Karin Michels; and Nathan Black, a political scientist who worked with Robert Bates. Continuing Fellows are in the back row (left to right): Pedram Hassandazeh, Nathaniel Mueller, Danielle Medek, and Charles Willis.
New Secondary Field in Energy and Environment

The Environmental Science and Public Policy (ESPP) program, in coordination with the Harvard University Center for the Environment, is launching a new Secondary Field in Energy and Environment (E&E) starting in the fall of 2014. Drawing on the continuing commitment of the University to support research and education on the climate-energy challenge, the new E&E secondary field provides a unique opportunity for Harvard students to understand these issues as they prepare to take on positions of leadership in the future.

The new offering is designed to respond to the broad demand from across the College to increase students’ exposure to, and literacy in, the interdisciplinary nature of issues related to energy and the environment. “Our goal is to give undergraduates from every possible concentration the opportunity to be engaged in these issues because they affect everyone here,” said Daniel Schrag, Hooper professor of geology and HUCE director. “People who study the arts, economics, history, psychology, philosophy...there’s really no field that is not relevant to this issue.” Students have the opportunity to explore the field from broad disciplinary perspectives, including how these perspectives intersect and inform one another. For example, a student concentrating in English may wish to increase their knowledge of the environment and energy from the perspectives of environmental literature or history. A student studying global health may want to better understand the impacts of climate change on water resources, nutrition, and human health. Or, a student in the physical sciences may want to expand their training by improving their understanding of climate dynamics and energy production to support their interest in materials science and energy storage.

“We’re excited to add this new offering to the ESPP program,” said Paul Moorcroft, head tutor and chair of ESPP and professor of organismic and evolutionary biology. “We want to provide an intellectual forum for students from a wide range of concentrations to engage with the key questions, challenges, and opportunities intertwined in energy and environmental issues.”

The secondary field requires four half courses, including a choice of foundational courses that feature the intersection of energy and environment, as well as upper-level courses grouped into either social sciences/humanities, or natural sciences/engineering categories. The broad reach of the field will enhance ties with other programs across the University, and students will gain valuable perspectives through participation in a colloquium led by faculty members. The E&E secondary field will also tap into the pool of ESPP faculty, as well as the community of nearly 250 HUCE faculty associates, to serve as student advisors.

“Our faculty and students have vital roles to play in confronting the challenge of climate change, and we’re committed to advancing their work,” University President Drew G. Faust said in a statement. “This new secondary field creates an important new academic pathway for our undergraduates to engage with one of the most pressing issues of our time.”

HUCE Consortium Reaches Enrollment Milestone

The HUCE Graduate Consortium on Energy and Environment reached a significant milestone this year when the total number of students that have enrolled in the program surged past the 100 mark. A large (the largest since the inaugural class) and diverse cohort of participants this past year brought the total number to 118 students, demonstrating the continued popularity of the Consortium to doctoral students across campus since its inception in 2009.

The Consortium aims to foster a community of doctoral students who are well-versed in the broad, interconnected issues of energy and environment while maintaining their focus in their primary discipline. The program engages students from over twenty different departments in eight different Schools—from urban planning and engineering, to earth sciences and public health—providing participants with a unique opportunity to gain exposure to faculty and peers in other disciplinary areas who share their interests. In addition to working together in Consortium courses, students in the program also have the opportunity to interact with one another—and with over 80 different Harvard faculty members to date—through a weekly reading seminar series.

The success of the program, reflected by its 86 percent completion rate, is due in large part to generous financial support from a group of HUCE donors, which has allowed the Center to provide more than one million dollars in fellowship support since 2009 to Consortium students. The program also provides a research/travel stipend for students to broaden their Consortium experience even further through attendance at relevant workshops and conferences.

The Center will welcome its newest group of doctoral students in Fall 2014. HUCE gratefully acknowledges Robert Ziff ’38, Phillip Duff ’79, and Karlo Duvnjak ’80 for their generous support.
Entering an Age of Climate Change Beyond 400 ppm

A half century ago on a Hawaiian mountaintop, atmospheric chemist Charles David Keeling used what was then a pioneering technology to make precise measurements of atmospheric CO₂. The resulting “Keeling Curve” has documented nearly 50 years of CO₂ accumulation and fluctuation tied to seasonal cycles, and has had a profound and lasting impact on the study of global climate change. Today, the research of his son, geochemist Ralph Keeling, continues to expand our knowledge of the factors influencing climate change.

Keeling’s research is of particular relevance as we enter uncharted atmospheric territory, reaching an average carbon dioxide level above 400 parts per million. To mark the occasion, Keeling presented the special HUCE talk, “O Brave New World! Entering an Age of Climate Change Beyond 400 ppm.”

The day began with a video message from former Vice President Al Gore, who warned that without “immediate and decisive action, the favorable conditions on Earth that have given rise to the flourishing of human civilization could be at grave risk as we continue to build more crisis into the climate system for future years to come.”

Daniel Schrag, Hooper professor of geology and HUCE director, then introduced Keeling and the importance of his research, noting, “No human being—ever—has witnessed this atmosphere.”

Keeling explained that although 400 ppm is not a climate threshold that will yield immediate and dire consequences, it does signify that our best chance to confront climate change has passed. “We're way out of the natural range,” Keeling said. “If there's a symbol of us being at a dangerous level, it's that we're already at 400 parts per million.”

Keeling pointed to fossil fuel burning as a major contributor to increasing carbon dioxide levels, and estimated that Earth's fossil fuel reserves have the capacity to send atmospheric CO₂ levels soaring to 2000 ppm.

On the positive side, oceans and forests act as carbon “sinks,” and have aided in counteracting the effects of fossil fuel burning, and halting the rise of CO₂ would not require a complete abandonment of fossil fuels. However, says Keeling, even cutting emissions to zero would likely be too late to counter the effects of accumulated atmospheric CO₂.

He concluded, “There's a loss of innocence that we've already bought into this problem deeply enough that the conversation has to change to being what do we do next.”

2014 Undergraduate Summer Research Award Recipients

HUCE provides stipends for students to conduct environmental research each summer through the Undergraduate Summer Research Fund. This year, the Center awarded 11 research assistantships with Harvard faculty and eight independent research projects to undergraduate concentrators in Organismic and Evolutionary Biology, History of Science, Environmental Science and Public Policy, Social Studies, Earth and Planetary Sciences, Environmental Engineering, Engineering Sciences, Economics, American History and Literature, and Chemistry. Summer research opportunities are made possible through the generous support of Bertram Cohn ’47, Barbara “B.” Wu (Ph.D. ’81), and Eric Larson (’77). The recipients are:

- **Oludamilola Aladesanmi** ’15, “Environmentally-Informed Policy Approaches to the Elimination of Malaria in the American South from 1930 to 1951”
- **Florence Chen** ’15, “Using Clumped Isotope Thermometry to Understand Historical Climate Change”
- **Brian Chang** ’17, will work with Professor Diane Davis (Graduate School of Design) on “Transforming Urban Transport: The Role of Political Leadership (South Korea Case)”
- **Michelle Chang** ’15, “BedZED: A Case Study in Sustainable ‘Eco-City’ Community Development in the UK”
- **Laura Clerx** ’16, will work with Professor Missy Holbrook (Dept. of Organismic and Evolutionary Biology) on “The Hydraulic Limits to Carbohydrate Transport in Trees”
- **Victoria Elliott** ’16, will work with Professor John Spengler (Harvard School of Public Health) on “China Health and Places Initiative (CHPI)”
- **Lydia Gaby** ’15, will work with Professor Ann Forsyth (Graduate School of Education) on “Carbohydrate Transport in Trees”

Environment @ Harvard
A sampling of the academic year’s events

Ongoing Series
The Future of Energy
The Future of Energy lecture series drew 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 October, the series welcomed Eamon Ryan, party leader of the Irish Green Party and former minister for energy and communications in the Irish government. He explored Ireland’s transition to clean energy over the past decade, and outlined its plans for clean growth in the years ahead.

John Deutch, Institute professor at MIT, co-chair secretary of energy advisor, and former undersecretary of energy and director of the Central Intelligence Agency, visited Harvard in November for a discussion on major challenges to America’s energy future, including managing energy prospects without a national energy plan.

The spring semester opened with Granger Morgan, University and Lord Chair professor of engineering at Carnegie Mellon University, who called for an improvement in energy forecasting to allow for some measure of uncertainty.


Jeff Bingaman, distinguished fellow, Stanford Law School, former U.S. Senator of New Mexico and chairman of the Senate Energy and Natural Resources Committee, closed the series with a look at the challenges of creating a clean energy economy.

This lecture series is sponsored through generous support from Bank of America.

China 2035: Energy, Climate, Development
This new series, convened in Spring 2014 by the Center for the Environment and the Harvard China Project, explores the challenges China is expected to face over the next two decades at the intersection of economic development, demands for energy, and environmental degradation.

Michael Spence, former dean of Harvard’s Faculty of Arts and Sciences and Nobel Prize-winning economist, kicked off the series by discussing China’s future economic growth prospects, political leadership, and its handling of environmental challenges. Robert Zoellick, former president of the World Bank and current chairman, International Advisors, Goldman Sachs continued the conversation.

Robert Zoellick, former president of the World Bank, speaks with Michael McElroy (bottom right), chair of the Harvard China Project, during a China 2035 lecture.

School of Design) on “Sustainable Cities: Strengthening Urban and Housing Policy in Mexico”
• Sally Gee ’16, will work with Professor Elizabeth Wolko (Dept. of Organismic and Evolutionary Biology) on “Trees, Traits and the Future of North American Forests with Climate Change”
• Emily Kraemer ’15, “Sustainable Groundwater Use in the Bahamas: Evaluating Direct Surface Aquifer Recharge”
• Rachel Moon ’16, will work with Jonathan Losos (Dept. of Organismic and Evolutionary Biology) on “The Effects of Anthropogenic Habitat Change on Territorial Behavior in the Brown Anole Lizard (Anolis sagrei)”
• Joanne Nghiem ’15, will work with Professor Chad Vecitis (School of Engineering and Applied Sciences) on “Conductive CNT-PVDF Membrane for Capacitive Biological Fouling Reduction”
• Ekta Patel ’15, “Urban Population Vulnerabilities, Climate Variability, and Environmental Governance: Surat, India”
• Matthew Ricotta ’15, will work with Professors Kiel Moe and Jane Hutton (Graduate School of Design) on the energy history project “Plot: Excavating Central Park and the Empire State Building”
• Ellen Robo ’16, will work with Professor Dustin Tingley (Dept. of Government) on the project “Politicians Talking Science”
• Anna Santoleri ’14, “Conserving America’s Youth: An Examination of Nature, Education, and Class in the Civilian Conservation Corps”
• Tyler VanValkenburg ’16, will work with Professor Alán Aspuru-Guzik (Dept. of Chemistry) on the project “Molecular Orbital Analysis of the Best Organic Research Solar Cells”
• Deng-Tung Wang ’17, will work with Professor Daniel Jacob (SEAS, Dept. of Earth and Planetary Sciences) on the project “Modeling Surface Ozone Measurements from Meteorological Factors”
• Sophia Watkins ’15, “Deconstructing the Role of Finance in the Deforestation of the Amazon: An Analysis of the Brazilian Beef Sector”
• Canyon Woodward ’15, “We Must, Therefore We Can: Student Divestment Movements at Harvard”
lawsuit that prevented Myriad Genetics from patenting two human breast cancer genes.

The spring installment featured Craig Calhoun, director of the London School of Economics and Political Science, for a talk on the role of social sciences in reaching the public; the mission of public universities and corresponding funding; and the shifting meaning of the words “public” and “private.”

This series features panel discussions moderated by Sheila Jasanoff, Pforzheimer professor of science and technology studies at the Harvard Kennedy School.

Geoengineering: Science & Governance

This series, now in its sophomore year and co-sponsored with MIT’s Joint Program on the Science and Policy of Global Change, explores the science, technology, governance, and ethics of solar geoengineering. In bringing together international experts, participants explore the challenges and opportunities of geoengineering, and analyze how this technology could and should be managed.

In October, the series began with a special event, “Debating Climate Engineering,” featuring David Keith, McKay professor of applied physics and professor of public policy at Harvard University and Clive Hamilton, professor of public ethics at the Centre for Applied Philosophy and Public Ethics, Charles Sturt University, Australia. In the spring, the series welcomed: Scott Barrett, Linstedt-Earth Institute professor of natural resource economics, Columbia University; Phil Rasch, chief scientist for climate science, Pacific Northwest National Laboratory; and Lynn Russell, professor of atmospheric chemistry at the Scripps Institution of Oceanography.

HUCE Film Screening
Chasing Ice

HUCE opened the academic year with a film screening of “Chasing Ice,” a documentary exploring National Geographic photographer James Balog’s mission to gather undeniable evidence of climate change. The screening, co-sponsored by the Harvard Museums of Science and Culture and the Office for Sustainability, was followed by a panel discussion with Harvard faculty members James Anderson (Department of Chemistry and Chemical Biology), Peter Huybers (Department of Earth and Planetary Sciences), and Daniel Schrag (Department of Earth and Planetary Sciences, School of Engineering and Applied Sciences).

HUCE Special Lecture
Peak Water: What Happens When the Wells Go Dry?

Lester R. Brown, president and founder of the Earth Policy Institute, visited Harvard to discuss “Peak Water: What Happens When the Wells Go Dry?” Brown’s presentation explored the future of agricultural systems, which are threatened by improper irrigation and a declining supply of fresh water.