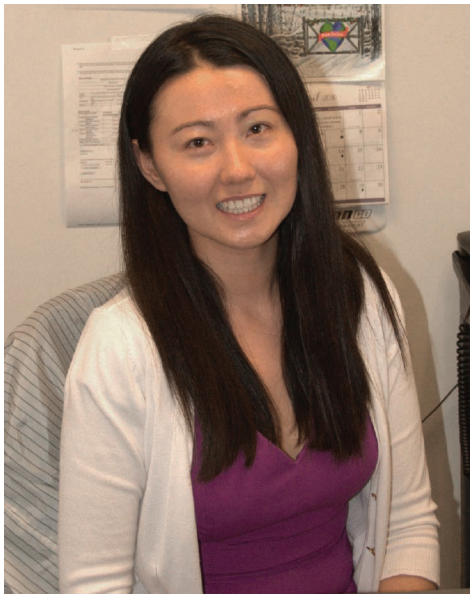
CAPTURING CARBON FOR POSTERITY AND PROFIT

More than 170 world leaders gathered at United Nations headquarters on Earth Day in April to sign the Paris treaty on climate change, which calls for sharp reductions in carbon emissions linked to global warming. Despite their united appeal for action, however, there is little consensus so far over how best to meet the aggressive targets spelled out in the agreement.

The Obama administration's proposed Clean Power Plan, for example, focuses on capping emissions from electrical generation plants, among other measures. The U.K. has proposed replacing power plants nearing the end of their operational lives with low-carbon alternatives and heating its homes and businesses more efficiently. China's leaders have targeted coal and heavy industry. While their approaches will differ, each nation faces a similar balancing act: figuring out how to curb greenhouse gases while minimizing the impact on the economy and energy supply.



Assistant Professor Selina Cai

"THERE IS NO SINGLE TECHNOLOGY OR POLICY THAT CAN COMBAT CLIMATE CHANGE ALONE, AND SO WE WILL NEED A PORTFOLIO OF METHODS TO BE USED JOINTLY TO GET TO WHERE WE NEED TO BE."

Selina Cai, an assistant professor of industrial engineering who specializes in operations research, is working on one possible approach: a pollution control strategy called carbon capture and storage (CCS) that separates CO_2 from the waste streams of coal and gas-fired plants, compresses it into liquid and injects it deep into the ground under layers of rock. Backed by a three-year grant from the National Science Foundation, Cai is not, however, devising capture methods. Rather, she is developing models that demonstrate how the CCS market would work.

"Many scientists are actively working on improving the technology to be more efficient and less costly to deploy," she says. "Gaining a better understanding of how market incentives would affect deployment would smooth its adoption should these technologies come to fruition."

Cai's model would help power plant operators choose from a menu of contract options — for example, the optimal amount of carbon to emit and how much to capture under various regulatory schemes, from a flat tax, to an incremental tax, to a cap-and-trade program.

She takes into account the capital costs of capturing carbon and the expense associated with constructing pipeline networks that an emerging sector of service providers would need to build to transport the liquid gas first to the storage site and later to end-users should a robust market emerge for CO_2 reuse, as a feedstock to produce chemicals, for example.

"The idea is to make carbon capture more attractive. Whether emitters are willing to participate will likely depend on the menu of options they are offered by service providers and how economically feasible they are," she explains. "The emitters would select the best contract based on their emissions profiles and the distance between them and the sequestration site. If a plant is very remote, and far from a storage site, then the plant may choose to participate in a different CCS network or to buy pollution permits under a cap-and-trade policy from another plant that can more easily make steeper reductions."

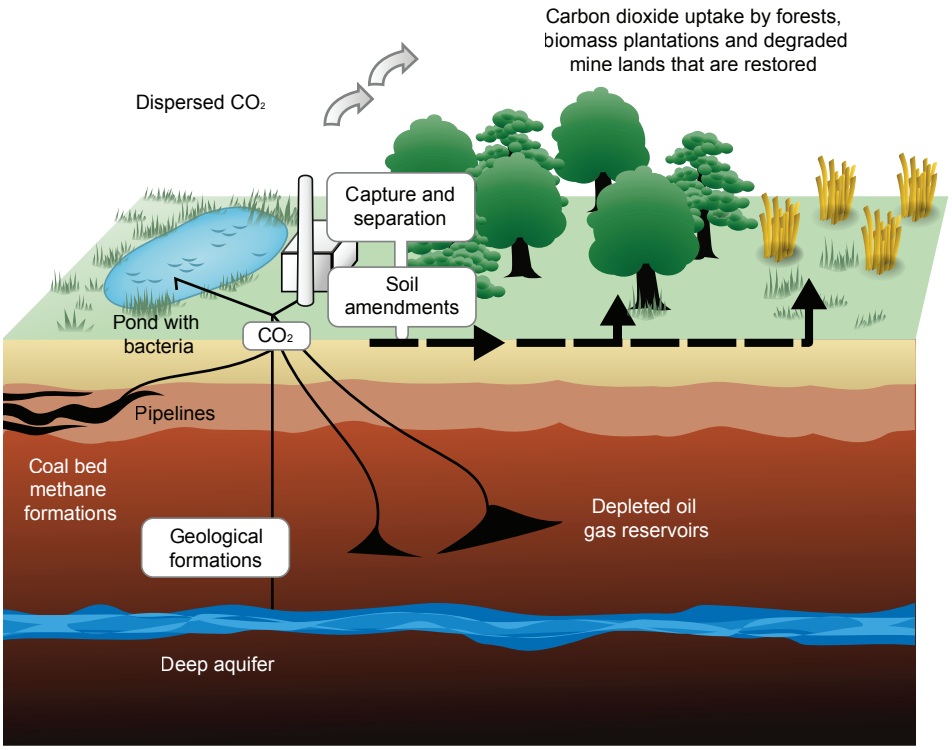
Unlike low-carbon energy alternatives such as solar panels, for example, the focus of CCS is not on the consumer, but rather on the collaboration among the key players — emitters, regulators and service providers, a business sector that does not yet exist. Her model would help CCS storage operators looking to enter the market decide, for example, which emissions sources to serve, what pipeline capacity to build and what contract prices to offer to induce power plants to participate. It also looks to optimize market logistics, figuring out how and where providers would build a network and how large its pipelines would be, she said.

"If businesses do this individually, it's very costly, but if a CCS storage operator provides the service to many businesses, then it becomes more affordable," she explained, adding, "The goal is to bring down the overall cost so that more emitters are incentivized to participate and are willing to capture more carbon."

INJECTING FOSSIL FUELS BACK INTO THE GROUND

Cai's primary focus is on coal plants, which emit 1,800 megatons of CO_2 or more, depending on their efficiency, for each megawatt of electricity produced, as compared with 1,100 megatons from plants running on natural gas. While the more polluting coal industry has taken a beating recently in the midst of a natural gas boom, coal still accounts for about a third of the country's energy supply, she notes.

Under current technologies, CO_2 is captured, or separated from other emissions, by injecting chemicals into the gas stream, and it is then compressed before



A schematic showing both terrestrial and geological sequestration of carbon dioxide emissions from a coal-fired plant. Rendering by LeJean Hardin and Jamie Payne. Source: Wikimedia Commons.

it is transported to what is called "geological storage," where it is deposited into deep underground rock formations.

There are currently 15 large projects in operation and seven more coming on line, associated primarily with manufacturing facilities and power plants, according to the Global CCS Institute, an organization that promotes carbon capture. Since 1996, oil companies in Scandinavia have been injecting CO_2 into the seabed beneath the Sleipner gas field in the North Sea, which has an estimated storage capacity of up to 600 billion tons.

"These are largely individual demonstration projects, attempts to see how feasible and costly it is to capture carbon. There is very little collaboration as yet," Cai notes.

The market for CO_2 reuse is also currently small, she says, and is mostly limited to "enhanced" oil and gas recovery, where it is injected into the ground to displace these fossil fuels. While its use in recovery operations has a revenue component, it is not ideal as a pollution control, she says, as only 40 percent stays in the ground and 60 percent escapes.

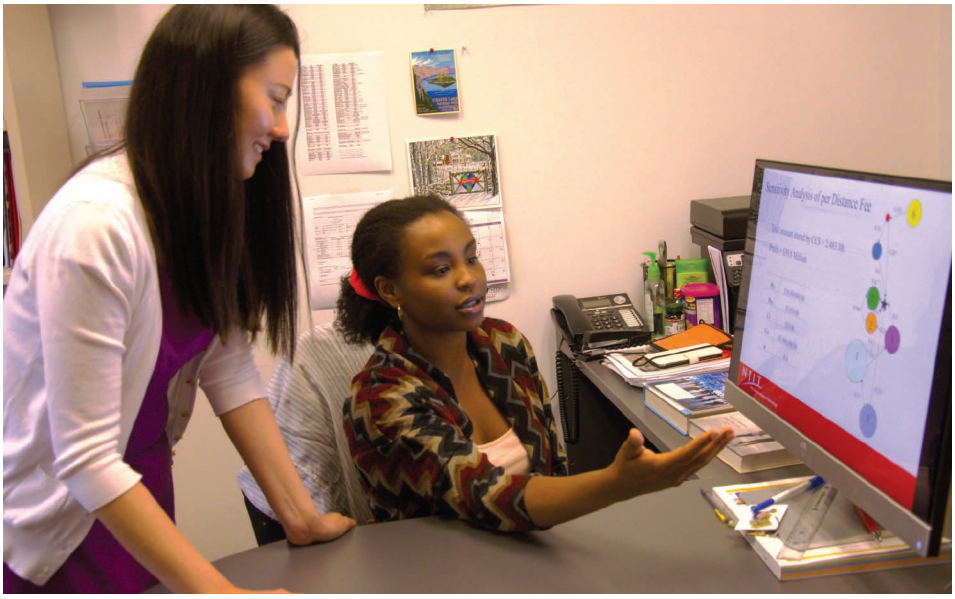
"For now, the thinking behind CCS is that if it's stored in the ground, it's there for good," she says. "But there are potential future markets, such as a feedstock for algae in the development of biofuels."

ENGINEERING REMEDIES THAT ANTICIPATE POLITICAL ONES

To date, only a small number of countries have adopted carbon regulations, but they are for the most part either weak or loosely enforced.

"Chinese coal plants now have carbon scrubbers, but they don't use them, because without a meaningful carbon tax, there is little financial incentive to do so," Cai said. "Europe's emissions trading program is weakly effective because the cap is too high."

The U.S.'s Clean Power Plan, which would set the first-ever national standards to address carbon pollution from power plants, includes a flexible, state-based program for curbing emissions from existing plants and a federal program that sets performance standards for new, modified and reconstructed power plants. Just months after the plan was announced last August, however, it was stayed by the Supreme Court pending judicial review.



Cady Kagume '16 discusses her student research with Selina Cai

"There is no single technology or policy that can combat climate change alone, and so we will need a portfolio of methods to be used jointly to get to where we need to be. CCS is one of those strategies," she says. "A lot of work is happening on technical aspects of the problem, but there is little research to date on the economic side and so there is a knowledge gap. Figuring out implementation strategies that will bring down the cost is how I hope to contribute to solving this problem."

THE RISE OF OPERATIONS RESEARCH

Cai, who received a Ph.D. in industrial engineering and operations research from the University of California, Berkeley, in 2012, is collaborating on the CCS project with Dashi Singham, a classmate at Berkeley who is now a research assistant professor at the Naval Postgraduate School.

"The field of operations research was launched during World War II, with the use of applied mathematics to solve logistics and supply problems, and the Navy has a lot of expertise in this field and a deep interest in the country's energy future," she says. "After the war, researchers in the field focused on manufacturing and increasing efficiency in the supply chain. As manufacturing declines, however, the field is shifting toward the service sector. We use principles from economics and operations research to solve business-related problems in operations management, such as responding to customer demand."

Cady Kagume '16, an industrial engineering major from Carlstadt who is also an operations research enthusiast, has spent the past several months working on Cai's model.

"We start with the general idea that we could build a pipeline to transport the gas and store it that would be more economical than paying a penalty for emitting carbon. Then we look at the constraints, the costs, the logistics, such as the optimal location for a storage facility, and variables such as fluctuations in demand that might present themselves in the real world," she said, adding, "This is an important project, but I've also really enjoyed it as a complex problem-solving exercise. We take seemingly disparate factors — cost, geological constraints and human factors like the technical expertise needed to implement CCS — and put them all into a mathematical formula."

Kagume, who presented her research at the Dana Knox Student Research Showcase in April, will be heading out into the real world herself this summer — to Hannibal, Mo., to be precise — where she will be solving production management problems at a General Mills snack foods production facility.

"I'll be working on optimization projects, managing production and demand, working on a warehouse management system for rotating stock at the facility's warehouse, and leading projects to implement technologies to improve the facility's efficiency in food production," she said. "This research project has allowed me to practice techniques needed in improving the production processes that I'll be working with later on." ■

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