

# Finding Climate Solutions

**Stanford**  
University



# The Challenge

MARCEL CLEMENS

**MEETING THE NEEDS OF A GROWING POPULATION IS AN** essential challenge of the 21st century. Climate change is critically intertwined with this challenge, in part because providing people with resources such as food and energy produces inadvertent consequences in the form of greenhouse gas emissions. The effect of these emissions on the climate system in turn makes resource production significantly more difficult.

In a world expected to reach 10 billion people this century, the stakes for limiting climate change and its impacts—and adapting to the changes that are now under way—are higher than ever.

How can we provide for humanity without harming the planet, so that future generations can also be provided for? How can we solve problems on a global scale? Stanford University is pursuing answers to these critical questions about climate change and the risks it poses for current and future generations.

## Stanford and the Climate Discussion

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**THROUGH THE END OF THE LAST CENTURY, MOST OF THE SCIENTIFIC DISCUSSIONS** and debate around climate change focused on characterization: What factors are driving climate change? To what extent are human activities responsible for those changes and which are the most important? How much will the climate change, given different scenarios of greenhouse gas production? What are the uncertainties in all of this?

Today, the scientific consensus about the causes and consequences of climate change is strong and clear. For many in the research community, the tasks at hand have now evolved to include understanding the full suite of impacts and risks associated with ongoing climate change, limiting the amount of climate change that will happen, and beginning to adapt to changes that are already entrained in the global system.

Free from partisan lines, major research universities conduct technical, biophysical, and social scientific research—as well as policy analyses—to inform society’s choices. What’s more, universities teach young scholars how to search for the next great discoveries—concepts unknown today that could alter the behaviors, technologies, or tactics available to respond to climate change in the future.

Stanford’s legacy of studying the human relationship with the global environment dates to the 1970s, when Professor Paul Ehrlich and his colleagues began to focus on the role of humans in driving environmental changes. Other pioneering research by Stanford faculty articulated the rapid rise of environmental changes and their interactions with human wellbeing. In the 1980s and 1990s, Hal Mooney and colleagues Chris Field, Pamela Matson, Peter Vitousek, and others led national and international efforts to increase scientific understanding of the causes and consequences of global environmental changes. “Climate warrior” Stephen Schneider was a world leader in estimating the climate consequences of greenhouse gas increases, and he consulted with federal agencies and White House staff in every presidential administration from Nixon’s until his untimely death in 2010. The first global environmental and climate change courses at Stanford were offered in the mid-1980s, and, beginning in 1990, Stanford’s scientific expertise was increasingly called upon as the world awoke to the implications of greenhouse gas emissions and climate change.

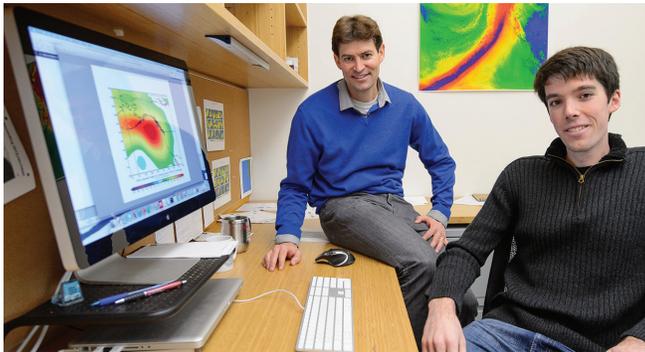
An important part of what sets Stanford apart from other universities is its tradition of interdisciplinary collaboration and its ability to move scientific knowledge into the solution space. The university’s seven schools hire faculty, recruit promising graduate students, and host top-ranked departments and degree programs. Stanford’s well-known interdisciplinary institutes play an important convening role, bringing together researchers from each of the schools to collaborate on today’s most pressing issues. Stanford’s current efforts to address climate change and associated risks are led by a partnership between the School of Earth, Energy & Environmental Sciences (Stanford Earth, for short), the Stanford Woods Institute for the Environment, and the Precourt Institute for Energy.

Today, Stanford’s rising stars in climate science say they came here to study with the best, to have access to the university’s preeminent interdisciplinary institutes, to teach and be inspired by some of the brightest undergraduates in the world, and to mentor graduate students and researchers who will become the next climate leaders.

## Understanding Climate Change Risks

**FOR TWO DECADES, STANFORD FACULTY HAVE BEEN GLOBAL LEADERS IN** research to understand the consequences of climate change for people and ecosystems, including, for example:

- Quantifying the influence of warming oceans and ocean acidification on coral reefs and phytoplankton
- Evaluating the consequences of change in carbon dioxide and warming on plants and ecosystem function
- Assessing the implications of rising temperatures for crop yields



- Evaluating relationships between climate change and social unrest, human health, and other critical societal concerns
- Testing relationships between near-term climate and weather dynamics and climate change
- Predicting the effects of saltwater intrusion on freshwater aquifers as the oceans rise

This work gives climate research the specificity needed to understand risks and inform action.

*In 2014 Professor Noah Diffenbaugh (left) and graduate student Daniel Swain, PhD '16, used a novel combination of computer simulations and statistical techniques to show that a persistent region of high atmospheric pressure hovering over the Pacific Ocean that diverted storms away from California was a condition much more likely to form in the presence of modern greenhouse gas concentrations. Diffenbaugh is the Kara J Foundation Professor in the School of Earth, Energy & Environmental Sciences and the Kimmelman Family Senior Fellow at the Stanford Woods Institute for the Environment.*

California offers a case in point. In January 2014, the snowpack in the Sierra Nevada range was a mere 18 percent of normal, setting it up for the driest year on record, until the next year proved to be even drier. Professor Noah Diffenbaugh has studied California's crippling droughts extensively. In 2015, he and his laboratory colleagues published research showing that the worst droughts in California have historically occurred when conditions were both dry and warm, and that climate change is increasing the probability that dry and warm years will coincide. In other words, droughts are likely to become more prevalent in the future. Officials in the governor's office took note, and invited Diffenbaugh to provide more detail about the science. Meanwhile, Professor Barton Thompson and Leon Szeptycki, executive director of the Stanford Woods Institute's Water in the West program, consulted with the governor and other state officials on ways to improve water management in California in the context of increased risk of scarcity.

In April 2015, Governor Jerry Brown issued mandatory water use reductions for the first time in California's history, requiring a 25 percent cut. This landmark executive order had been in motion since California declared a state of emergency the year before, but Stanford research helped articulate the scientific rationale for the difficult political move that would pay off in the longer term.

Another example of how Stanford faculty are working to characterize potential impacts of climate change comes from the laboratory of Professor Marshall Burke. He and his colleagues have leveraged new data analytical tools to explore the relationship between rising temperatures and human conflict, disease, and economic output. In doing so, they have shown that drought-related income shocks can contribute to the spread of HIV in Africa, with infection rates rising as much as 10 percent in a year with very low rainfall. They have also discovered that hotter than normal temperatures are strongly correlated with both an increase in human conflict and a decrease in economic output. Their estimates indicate that, by 2100, worldwide incomes could decline 23 percent relative to a world without climate change, worsening global inequality.

## Climate Change and the Oceans

Microscopic phytoplankton, which form the foundation of the food chain in the world's oceans, also play a very important role in the global carbon cycle. Kevin Arrigo, the Donald and Donald M. Steel Professor and Victoria and Roger Sant Director of the Earth Systems Program, has led international scientific expeditions to the Arctic to study how shifting light, temperature, and sea ice conditions affect the productivity of phytoplankton, how those changes reverberate up the food chain, and what effects they may have on the uptake of anthropogenic carbon dioxide.



KATHRYN HANSEN

## Informing Policy Decisions with Science

Professor Chris Field was one of two Americans on the delegation that accepted the Nobel Peace Prize on behalf of the Intergovernmental Panel on Climate Change (IPCC) in 2007.

Field is a founder and principal investigator of Stanford's long-running Jasper Ridge Global Change Experiment (JRGCE), which examines the impact on grassland ecosystems of four major components of global change: warming, elevated CO<sub>2</sub>, increased precipitation, and increased nitrogen deposition. Established in 1998, JRGCE is the first study to examine these four factors in a natural ecosystem.



PATRICK FREEMAN

More recently, as co-chair of the IPCC's Working Group II, Field led a group of more than 300 scientists who contributed to the 2014 Fifth Assessment Report—a milestone that shifted the global conversation to what can be done. "The world is going to be much more focused on solving the climate problem than asking whether or not the climate problem is real," he says.

Field is the Perry L. McCarty Director of the Stanford Woods Institute for the Environment, the Melvin and Joan Lane Professor of Interdisciplinary Environmental Studies, professor of biology and Earth system science, and senior fellow at the Precourt Institute for Energy.



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## Communicating Climate Change

**WITH A CHALLENGE SUCH AS GLOBAL CLIMATE CHANGE—INDEED WITH ANY GLOBAL** issue that hinges on the choices of individual people as well as corporations and governments—communication is key. How do you convey the urgency in a credible and compelling fashion? How do you make the abstract idea of future impacts relatable today? Stanford researchers are trying to understand how people are hearing messages about climate change and how we can improve these messages to more clearly communicate what is known—and what is not known.



NATHAN MITCHELL

Jon Krosnick, the Frederic O. Glover Professor in Humanities and Social Sciences, presents Stanford research at the National Press Club in Washington, D.C.

Since the mid-1990s Professor Jon Krosnick and the Stanford Political Psychology Research Group have been studying American public opinion about global warming. By conducting a series of national surveys, regional surveys, and experiments, the group has tracked shifts in opinions about climate change across the nation and over time.

Stanford is also focused on communicating about climate change to policymakers and, of course, to its own student population. For several decades, Stanford faculty have shared their knowledge about climate change by:

- Producing scientific assessments and reports for the Intergovernmental Panel on Climate Change (IPCC) and the U.S. National Academies
- Engaging with decision makers for formal and informal information exchange
- Participating on boards and advisory groups for nonprofit and government organizations
- Testifying before Congress and state legislatures
- Communicating through traditional and social media channels

In 2014, the Stanford Woods Institute for the Environment opened an office in Washington, D.C. Having established a physical presence in the capitol, Stanford is now even better positioned to share climate research with decision makers of all types.

Back on Stanford's campus, the School of Earth, Energy & Environmental Sciences has introduced broadly appealing courses such as *Climate and Society* to share the scientific underpinnings of climate science in a way that is accessible to all students. In addition, the school offers a co-terminal master's degree in Earth Systems that focuses on environmental communication for those looking to strengthen the connection between scientific knowledge and decision making.

For the past 10 years, Stanford has also hosted the Leopold Leadership Program, training more than 200 mid-career environmental academic researchers to effectively communicate their science in the public policy arena and to lead change for sustainability goals.

## Up Close and Personal

Climate change has finally penetrated the popular consciousness, but it remains primarily an intellectual construct for most people. Even many of its most demonstrable impacts are slow moving and nearly invisible. How to bridge the gap?

At Stanford, marine scientist Fiorenza Micheli teamed up with Jeremy Bailenson's Virtual Human Interaction Lab to see whether people change their perception of climate change after virtually diving in a coral reef and seeing the effects of ocean acidification. Those who spent 15 minutes virtually observing colorful reef dwellers such as sea urchins, sea bream, and sea snails being replaced by slimy green algae—before the reef disappeared altogether—demonstrated greater empathy for the environment, even a week after the experience.

Micheli is co-director of the Center for Ocean Solutions and the David and Lucile Packard Professor in Marine Sciences. Bailenson is the Thomas More Storke Professor in the Department of Communication. Both are senior fellows at the Stanford Woods Institute for the Environment.

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ROB DUNBAR

## Teaching and Learning About Climate Change

From Stanford to Sitka and Seine-Saint-Denis on the outskirts of Paris, Stanford undergraduates enjoy special opportunities to learn about climate change in the classroom, the laboratory, and the field.

Occasionally, they go very far afield indeed. Every two years, 12 Stanford sophomores venture to Southeast Alaska (right) for a special field program directed by Rob Dunbar, the W. M. Keck Professor of Earth Science and senior fellow at the Stanford Woods Institute for the Environment. The program combines classroom and experiential learning to explore global questions of land use change and sustainable resource management in a region already experiencing measurable impacts from global climate change.



ROB DUNBAR

Back on campus, courses like EARTH 2: *Climate and Society* are open to students of all class years and majors. And in December 2015, 29 undergraduate and co-terminal master's students traveled to Paris with Stanford faculty to observe the COP21 climate talks. A quarter-long course, *International Climate Negotiations: Unpacking the Road to Paris*, prepared them with the context and tools they would need to follow the events. In France, the students met with scientists, negotiators, journalists, and nonprofit leaders while pursuing individual research projects they later presented at a Stanford symposium.



RICHARD NEVLE

The experience was far more than a research exercise, especially for students like Josh Lappen, '17, whose cautious optimism about the accord reflects his generation's relationship with climate change: "These words, partially by design, are no guarantee of action. . . . The power of Paris is not that it mandates action, but that it empowers us to mandate that action."

## Limiting Climate Change

**BURNING FOSSIL FUELS TO PRODUCE ELECTRICITY AND HEAT AND TO FUEL** transportation is responsible for more than half of global warming pollution, a fact that has inspired growth in the number of faculty doing energy-related research at Stanford in recent decades. This robust community numbers approximately 225 today, thanks in part to the resources and facilitation provided by research entities like the Precourt Institute for Energy and the TomKat Center for Sustainable Energy.

Stanford's work covers a broad spectrum—from the invention of new batteries and solar cells to the development of synthetic fuels and wireless technology for charging electric cars on the highway. Underlying it all is an urgency to prepare for a global energy system that is predicted to double within the next few decades, as countries such as China, India, and Brazil adopt modern utilities on a greater scale and populations everywhere continue to swell. Finding ways to empower this growth—even capitalize on it—while mitigating negative effects on the climate is essential.

Broadly, Stanford researchers are taking several different, interacting approaches to climate change mitigation. Many teams are focused on **reducing emissions**. Some of these researchers seek to improve the efficiency of both fossil fuel-based technologies and energy consumption, others to sequester carbon released from fossil fuel combustion. Still more direct their research toward reducing emissions by curtailing deforestation and developing new management technologies and approaches in agriculture.

Other teams aim to limit climate change through the development of **non-carbon-based energy technologies**, including wind, solar, wave, geothermal, and chemical technologies, and through improvement in the electric grids and storage needed to support the hard-to-predict fluctuations inherent to green power.

Stanford faculty are also **evaluating policy choices** that will drive more energy-efficient behavior and incentivize the development and uptake of low- and no-carbon technologies in the energy and agricultural sectors.

Using analytical and quantitative approaches, they conduct research to inform evidence-based decision making at all levels of policy. How do you measure economic progress in a way that takes account of changes in the natural resource base and in environmental quality? What market-based approaches might achieve environmental goals at lower cost than traditional regulations? How can the health and other impacts of air pollution be quantified, and how can the public value of policies that prevent negative health impacts be assessed?

These faculty include Professors Larry Goulder and Charles Kolstad, both senior fellows of the Precourt Institute for Energy and faculty leaders of the Stanford Environmental and Energy Policy Analysis Center (SEEPAC). Goulder and Kolstad are internationally recognized leaders in the field of environmental and natural resource economics, which has grown enormously over the past several decades.



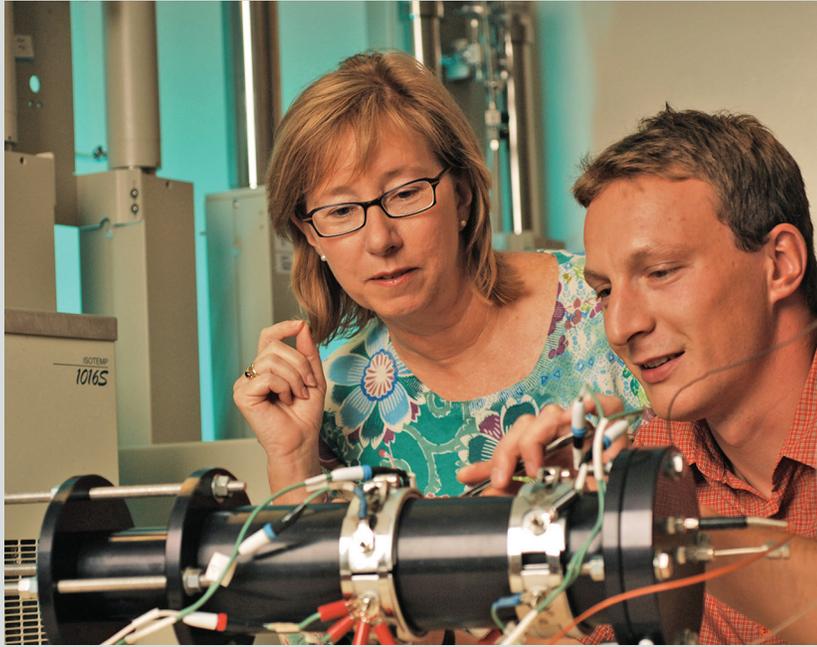
COURTESY OF SAMUEL ADEYEMO

*While he was a student in Stanford's Emmett Interdisciplinary Program in Environment and Resources, Samuel Adeyemo, MBA '13, MS '14, was part of a team that received an innovation transfer grant from the TomKat Center for Sustainable Energy. The comprehensive software the team created streamlined the design and installation of photovoltaic systems and inspired their Palo Alto-based startup.*

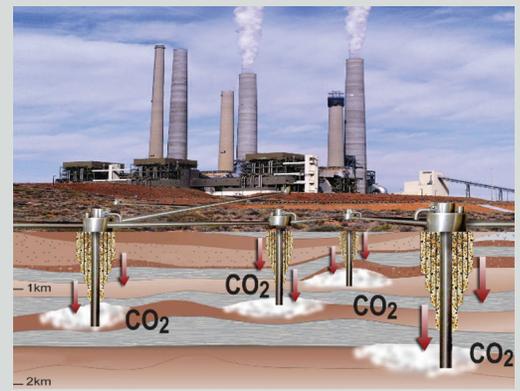
## Carbon Capture and Storage

With greenhouse gas emissions projected to continue rising in the coming decades, Stanford scientists are working hard to find ways to remove carbon dioxide (CO<sub>2</sub>) from combustion processes before it reaches the atmosphere.

Professor Sally Benson (below) is a leading authority on technologies for sequestering CO<sub>2</sub> in deep geological formations for long-term storage. She and her students operate a medical CT scanner to image the distribution of liquids and gases inside rock to learn more about how much CO<sub>2</sub> can be stored and to better understand the mechanisms that permanently trap CO<sub>2</sub> underground.



A professor of energy resources engineering, Benson is also co-director of Stanford's Precourt Institute for Energy.



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## Reducing Emissions from Agriculture

Approximately one-third of all nitrogen fertilizer used worldwide is applied in China. Most analysts agree it is being used in excess of crop demand, leading to high emissions of the potent greenhouse gas nitrous oxide and other pollutants.

Stanford professors Pamela Matson and Peter Vitousek are working with colleagues in China to develop “win-win” approaches to producing more food with less fertilizer.

Matson (right, in Gansu Province with graduate students from the Chinese Agricultural University in Beijing) is an Earth system scientist who holds the Richard and Rhoda Goldman Professorship in Environmental Studies. Vitousek, a biologist, is the Clifford G. Morrison Professor in Population and Resource Studies. Both are senior fellows at the Woods Institute for the Environment.



## Adapting to Climate Change

**CLIMATE CHANGE PRESENTS MANY RISKS FOR CURRENT AND FUTURE HUMAN** communities as well as the millions of species and ecosystems with whom we share the planet. Management of these risks requires a deep understanding of causes and consequences, coupled with the development and implementation of strategies to limit climate change and to increase resiliency through adaptation. Building on Stanford's ongoing contributions to understanding and limiting climate change, it is in this third sphere of study—adaptation—where many of the university's scientists are now focusing their efforts.



MEHA JAIN

*David Lobell, associate professor of Earth system science and William Wrigley Senior Fellow at the Stanford Woods Institute for the Environment and the Freeman Spogli Institute for International Studies, has determined where the largest vulnerabilities of crops to climate change will occur around the world, and he is working with foundations and international organizations to reduce these vulnerabilities.*

From coastal communities adjusting to sea level rise to farmers struggling with drought or extreme temperatures, people are having to respond to new pressures and vulnerabilities in the places they live and work. Stanford researchers are trying to determine who is most vulnerable to the changing climate, in what ways, and what can be done to increase resilience.

Current and future impacts on agricultural systems, for example, are increasingly well understood. Systematic knowledge of where these effects will hit hardest and how agriculture might adapt are essential to humanity's resilience in the face of a rapidly changing climate.

Stanford's Center on Food Security and the Environment, a joint center of the Stanford Woods Institute for the Environment and the Freeman Spogli Institute for International Studies, is doing extensive work in this area. Professor David Lobell has developed a number of indices that show where the largest climate-related vulnerabilities of crops are around the world, and he is working with foundations and international organizations to reduce these vulnerabilities, especially in sub-Saharan Africa. His work using advanced remote sensing to investigate global food security has led to a number of recognitions, including a MacArthur "genius grant" Fellowship in 2013.

Similarly, Stanford faculty are investigating questions about how coastal communities understand and respond to climate risks such as rising sea level and increased storm surge. They are developing approaches to predict spikes in food prices under climate variation, to restructure water rates for utility companies under water limitations, and to monitor and manage subsurface water resources as they change with drought.

Stanford researchers are also analyzing the potential for species to adapt and acclimate to climate change in coral reefs and kelp forests. Marine scientist Stephen Palumbi, for example, studies populations of purple sea urchins in California that can rapidly evolve in acidic ocean water and corals in the South Pacific that carry genes conferring resistance to coral bleaching. New genomic technologies developed for personalized medicine are pointing to a wealth of genetic diversity in many marine species that could help maintain robust populations amid the effects of global climate change. For scientists, measuring the rates and limits of these adaptive abilities could offer important clues about how quickly and successfully species may adapt to climate change.

## Measuring Crop Yields from Space

A Stanford-led team has developed a wholly new approach to estimating regional crop yields using satellites that can measure solar-induced fluorescence, a light emitted by growing plants. The research, which is expected to help

scientists study how crops respond to climate change, was led by Kaiyu Guan, a postdoctoral fellow in Earth system science working with Professor David Lobell.



NASA

When a plant is highly stressed, its fluorescence will drop significantly. Capturing these short-term responses to environmental changes will help scientists understand which kind of stresses most affect growth—and therefore yield, says Lobell. “This helps us figure out what we should be focusing on in terms of the next generation of cropping systems,” he says. “What should they be able to withstand that the current crops can’t?”

## Building Resilience to Coastal Hazards

Communities throughout California are responding to the threats of rising sea levels, growing coastal populations, and more damaging storms by building armoring concrete and metal structures that may threaten the continued existence of beaches, dunes, wetlands, and other coastal habitats.

With funding from the Stanford Woods Institute’s Realizing Environmental Innovation Program, an interdisciplinary team of Stanford researchers is working with planners across the state. They are identifying sites where natural coastal habitats



SASHA SAMARDZIJA / SHUTTERSTOCK



JOSH EDELSON

Deborah Sivas



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Gretchen Daily

can provide the most sustainable and cost-effective protection from coastal hazards and highlighting policy pathways for implementing these strategies.

In partnership with the Center for Ocean Solutions, the team is led by Deborah Sivas, the Luke W. Cole Professor of Environmental Law, director of the Environmental and Natural Resources Law and Policy Program, and director of the Environmental Law Clinic; and biologist Gretchen Daily, Bing Professor of Environmental Science, director of the Center for Conservation Biology, and co-director of the Natural Capital Project. Both are senior fellows at the Stanford Woods Institute for the Environment.

“Example is not the main thing in influencing others. It is the only thing.”

—Albert Schweitzer

## Leading by Example

Stanford’s campus spans 8,180 contiguous acres and accommodates thousands of students, faculty, staff, physicians, patients, and visitors on any given day. This makes the Farm a proving ground for new ways to limit and adapt to climate change. Indeed, leading by example is one of the ways that Stanford excels at refining climate solutions.

In 2015 Stanford replaced its natural gas-powered cogeneration plant with a new energy facility. In the first large-scale example of this technology ever built, the facility uses a heat recovery system in which water for cooling and heating buildings is used in a continuous loop to maximize efficiency. The new plant, along with Stanford’s solar power procurement, reduced campus greenhouse gas emissions by approximately 68 percent (and campus potable water use by 18 percent) compared with peak levels. The combined new system—Stanford Energy System Innovations (SESI)—makes Stanford one of the most energy-efficient research universities in the world.



*Stanford’s central energy facility is part of a new system that reduced campus greenhouse gas emissions by 68 percent.*

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