At Stanford, we believe it is essential to look to the future, identifying the great challenges facing our world—like the threat of climate change—and assembling our resources to make impactful contributions to them. Climate and sustainability researchers at Stanford have made great strides in probing the science of climate change, developing green technologies, and working with partners to implement solutions. Our plan for a new school focused on climate and sustainability will bring together Stanford’s existing strengths to advance vital research and make a difference for our planet and its people.

–Marc Tessier-Lavigne
President, Stanford University
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The world is on a hinge of history. The future is going to be different from the past in major ways. I think it's fair to say that when the Cold War came to an end, there had been built a security and economic commons in the world, which everybody benefited from. But that commons is now eroding—and it should be clear that new challenges are coming at us.

For example, the demography of the world is changing very rapidly. All developed countries have low fertility and rising longevity. So the structure of their populations is changing radically, with most now losing working age population (the only exceptions are immigration countries, like the United States). At the same time, the world population will continue to increase because of continued high fertility in Africa and South Asia; these developing countries are also ones with often poor governance and limited economic opportunities. Meanwhile, new additive or automated manufacturing technologies that will make it easier to produce goods closer to where they are consumed could upend a traditional trade-based path to industrialization. And being agriculture-oriented, they are particularly exposed to climate change. How will they respond? And how will we?

The virus is yet another example—it shows that we are part of an interconnected world. A pandemic is a clear example of a problem whose solution would benefit greatly from international cooperation and U.S. leadership. The global response to COVID-19 could have been more effective with better international cooperation—and better U.S. leadership. This is a recurring theme. Gradually building a new international consensus that benefits us as Americans, while also allowing others around the world to see how they will succeed along with it, will help us to navigate the transformational challenges now before us, including advancing technology, changing demographics, and large-scale migration—or energy and the environment. It doesn't take a grand plan. Just positive movement.

Although I am in my hundredth year, I am deeply concerned about the future. But I am also optimistic. We have many challenges, but the global situation is not as bleak as it may seem. Because when I look around, I see that wise and knowledgeable people are talking about these crucial issues, and hard at work on each one of them. Taken together, that adds up to something important. I see the research going on at a place like Stanford—on new and cleaner technologies or the policies and practices to make use of them—and it's clear that even now, there is real progress being made. So there is hope.

George P. Shultz
Thomas W. and Susan B. Ford Distinguished Fellow
Hoover Institution, Stanford University

“ I see the research going on at a place like Stanford—on new and cleaner technologies or the policies and practices to make use of them—and it's clear that even now, there is real progress being made.

So there is hope.”

Stanford Energy Research Year in Review: 2019-2020
A WORD FROM THE CO-DIRECTORS

Welcome to the second edition of Stanford Energy Research Year in Review.

The dual challenge of decarbonizing energy systems globally and making modern energy services accessible to all people may be the defining task of the 21st century. Over the past academic year, Stanford University researchers advanced our ability to make energy systems more sustainable, affordable and secure. These advances range from discoveries for carbon-neutral fuels and better batteries to innovative policies and financial structures. This research review is not exhaustive. Instead, it is meant to represent the comprehensive breadth and depth of energy research at Stanford University.

Energy is an all-campus affair at Stanford and the SLAC National Accelerator Laboratory. More than 300 faculty and staff researchers from all seven schools focus a significant part of their work on energy challenges. This vast work is funded by donors, government and companies around the world investing in the energy transition.

Beyond the faculty and staff researchers, hundreds of students and postdoctoral scholars perform much of Stanford’s work in energy. They, too, are celebrated in these pages. Every year, students learn diverse new skills, like advanced imaging and machine learning, which they then apply to new energy solutions. In turn, they can choose from hundreds of energy-related courses to expand their knowledge. Many experiential learning opportunities exist, too, like the Summer Undergraduate Program on Energy Research internship program and the Stanford Energy Ventures class.

For all our faculty, students, alumni, staff, collaborators and supporters, we hope this review provides a moment for collective pride in our accomplishments and excitement about the future.

Sally Benson
Precourt Family Professor and Co-director, Precourt Institute for Energy

Arun Majumdar
Co-director, Precourt Institute for Energy
Jay Precourt Professor, Mechanical Engineering
STANFORD ENERGY RESEARCH HIGHLIGHTS

THIS REVIEW SUMMARIZES some of the energy innovations at Stanford University published between July 2019 to June 2020. They cover renewable energy, modernizing the electric grid, energy efficiency, policy, finance, environmental impacts, macro system analysis, and making today’s use of fossil fuels more sustainable.

Following the lead of George Shultz in his book *Game Changers: Energy on the Move*, we have tagged these examples as “Available Today,” “Near at Hand” and “On the Horizon.” Such categorization, while imprecise, is meant to give readers context about the timeframe and perseverance needed to make global energy systems more sustainable, affordable and secure for all people.
Imagine grabbing carbon dioxide from car exhaust pipes and other sources, and turning it into fuels like natural gas or propane: a sustainability dream come true. A novel approach from engineer Matteo Cargnello and colleagues yields four times more ethane, propane and butane than existing methods that use similar processes. While not a climate cure-all, the advance could significantly reduce the near-term impact on global warming.

Previous efforts to convert CO₂ to fuel involved a two-step process: reduce CO₂ to carbon monoxide, then combine the CO with hydrogen to make hydrocarbon fuels. Cargnello’s team, in collaboration with the SLAC National Accelerator Laboratory, created a new ruthenium-iron oxide catalyst that transforms CO₂ into large quantities of ethane, propane and butane in a single step. Beyond fuels, researchers say the technique could also be used to sustainably produce ethylene, a precursor of plastics, and other industrial chemicals.

“One can imagine a carbon-neutral cycle that produces fuel from carbon dioxide and then burns it, creating new carbon dioxide that then gets turned back into fuel.”

-MATTEO CARGNELLO, ASSISTANT PROFESSOR OF CHEMICAL ENGINEERING
Machine learning method could supercharge battery development for EVs


Designing ultra-fast-charging batteries is a major challenge, mainly because the intensity of the initial charge can strain the battery causing it to fail early. Studies on fast-charging technologies typically require months or even years of laboratory testing.

Now, artificial intelligence has made the dream of recharging an electric vehicle in the time it takes to stop at a gas station more likely. Professors Stefano Ermon and William Chueh and colleagues at MIT and the Toyota Research Institute have developed a machine learning-based method that slashes testing times by 98 percent. Instead of manual trial-and-error, machine learning enabled the researchers to quickly find an algorithm for optimal ultra-fast charging.

Instead of charging at the highest current at the beginning of the charge, the algorithm’s solution uses the highest current in the middle of the charge. This surprising discovery can be used by other battery scientists to develop ultra-fast-charging EV systems at scale.

“With artificial intelligence, we’re able to quickly identify the most promising approaches and cut out a lot of unnecessary experiments.”

– STEFANO ERMON, ASSISTANT PROFESSOR OF COMPUTER SCIENCE
About 30 percent of U.S. greenhouse gas emissions come from fossil-fuel power plants. Professor Sally Benson’s students developed a way to track those emissions on an hour-by-hour basis across the entire electric grid. Their novel approach provides electricity consumers a precise tool for reducing carbon dioxide and associated air pollutants in real time. It will also enable regional grid operators to quickly evaluate the carbon intensity of electricity imports and exports across the continental United States.

The researchers found that U.S. hourly emissions vary significantly at different times of the year. Also, imported electricity consumed on one end of the grid can produce CO₂ hundreds of miles away at power plants that burn coal and natural gas. Tracking the true source of CO₂ emissions in real time will be critical for states and corporations to quantify their greenhouse gas emissions accurately and lower their carbon footprint, the researchers said.

“This new tool will provide policymakers and corporations a precise way to track carbon emissions in real time 24/7 using publicly available data sets.”

-SALLY BENSON, PROFESSOR OF ENERGY RESOURCES ENGINEERING
Assistant Professor Will Tarpeh and colleagues have designed a desalination device that could make converting seawater to freshwater profitable and environmentally benign. The new design offers an efficient way to transform water with very high concentrations of salt and chemicals, known as brine, into commercially valuable compounds, reducing the need for disposing hazardous chemicals in local ecosystems.

Conventional desalination is costly because it requires a lot of energy. It can also produce about one-and-a-half times more brine than potable water. The Stanford team designed an electrochemical device that splits the components of brine into sodium and chlorine ions. These ions then combine with other elements to form useful chemicals, like sodium hydroxide, or lye, which is used to manufacture soap, aluminum and many other products.

Researchers say the new process could help cut brine disposal costs, which can account for up to a third of total desalination expenses, while generating revenue.

“Desalination could be a powerful tool to mitigate water scarcity, but it is limited by energetic and monetary costs for pretreatment and brine management. By reimagining brine as a resource, we aim to incentivize its collection and treatment before discharge.”

—WILL TARPEH, ASSISTANT PROFESSOR OF CHEMICAL ENGINEERING
Plain old iron could make solar power more efficient


Photosensitizers are molecules that absorb sunlight and pass that energy along to generate electricity or drive chemical reactions. They are generally based on rare, expensive metals. The discovery that iron carbenes, with plain old iron at their cores, can do this, too, has triggered a wave of research on how these molecules work at the atomic level.

To find out, an international research team used a powerful X-ray laser at SLAC National Accelerator Laboratory to watch what happens when light hits an inexpensive iron carbene molecule. They discovered that carbene can respond in two competing ways, only one of which allows electrons to flow into devices or reactions where they’re needed. Molecules took the energy-producing path about 60 percent of the time. Future research will focus on getting close to 100 percent of the electrons to stay on carbenes much longer, so that energy from light can be used to drive photovoltaic cells and chemical reactions.

“The long-term goal is to engineer iron carbene molecules to carry out useful work with maximum efficiency.”

–KELLY GAFFNEY, ASSOCIATE PROFESSOR OF PHOTON SCIENCE, SLAC
Worldwide, more electricity is produced from coal than from any other energy source, but burning coal comes with significant costs to human health and the environment. Climate experts say that to prevent a significant rise in global temperatures by 2050, the world will have to stop generating electricity from coal or sequester coal plant emissions. But without realistic alternatives, many countries will likely rely on coal-generated electricity for years to come, says researcher Mark Thurber. Why? Coal is cheap, abundant, and relatively easy to transport and store. The coal industry also generates jobs and tax revenue for governments.

While the richest countries are trying to phase out coal, new coal plants are being built in Indonesia, the Philippines and other fast-growing economies. The challenge for the West is to help these countries develop clean, economically competitive alternatives to form the backbone of their energy supply, because constraining the expansion of modern energy grids in poorer countries is neither ethical nor realistic.

“We shouldn’t be asking poor countries that desperately need energy to rely solely on wind and solar, especially while we rich countries continue to burn so much coal.”

—MARK THURBER, ASSOCIATE DIRECTOR OF THE PROGRAM ON ENERGY AND SUSTAINABLE DEVELOPMENT
Coating brings lithium metal battery closer to reality


Hope has been restored for the rechargeable lithium metal battery—a potential battery powerhouse relegated for decades to the laboratory by its short life expectancy and occasional fiery demise while its sibling, the lithium-ion battery, rakes in more than $30 billion a year. Lithium metal batteries are lighter and deliver more energy per ounce than conventional lithium-ion batteries widely used in electric vehicles, smart phones and other devices.

Now a team led by professors Zhenan Bao and Yi Cui has invented a coating that overcomes some of the defects plaguing lithium metal batteries. In laboratory tests, the coating significantly extended the battery’s life and reduced combustion by greatly limiting the tiny needle-like structures—or dendrites—that can ignite the battery’s liquid electrolyte. Dendrites have prevented lithium metal batteries from being deployed in the next generation of EVs. In a subsequent study, the researchers designed a novel electrolyte that further improved the battery’s stability and cycle life.

“Here we present a completely different molecular-design concept from conventional wisdom, and it is changing the way we approach one of the most challenging problems for lithium metal batteries.”

—ZHENAN BAO, K.K. LEE PROFESSOR IN THE SCHOOL OF ENGINEERING
Methane leaks from water heaters are high, but fixable


Natural gas, which is 90 percent methane, escapes from water heating systems through leaks and inefficient combustion. Nationwide, these tiny inefficiencies add up, resulting in emissions of methane—a powerful greenhouse gas—that are at least three times higher than expected, according to a study led by Professor Rob Jackson.

Natural gas water heaters are letting less than 1 percent of their methane escape. That’s a very small part of total U.S. emissions, but it’s the equivalent of 1.7 million cars driving on gasoline for a year.

—ROB JACKSON, MICHELLE AND KEVIN DOUGLAS PROVOSTIAL PROFESSOR

Methane is about 84 times more potent than carbon dioxide at trapping atmospheric heat in the first two decades after release. In the United States, the 58 million water heaters that use natural gas leak around 91,000 tons of methane per year as uncombusted gas. The Stanford team monitored water heaters in 64 California homes and found that, on average, tankless water heaters emit about twice as much methane as storage water heaters. However, tankless heaters can be re-engineered to reduce leaks and uncombusted gas, the researchers said. For heaters with tanks, standard pilot lights can be replaced with efficient electronic igniters.
Improved air quality and human health are often discussed as co-benefits of mitigating climate change, yet they are rarely considered when designing or implementing climate policies.

In a recent study, Associate Professor Inês Azevedo and colleagues analyzed the implications of integrating health and climate when determining the best locations for replacing power plants with wind, solar or combined-cycle natural gas to meet a 30 percent carbon dioxide-reduction target in the United States.

The researchers developed a capacity-expansion model, coupled with an integrated-assessment model, to account for climate and health damages from air pollution. They found that reducing CO₂ emissions by 30 percent would yield $21 billion to $68 billion in annual health benefits, with an additional $9 billion to $36 billion possible when co-optimizing for climate and health benefits. This finding highlights the need to consider both health damages from air pollution and climate-change consequences when designing decarbonization policies, the authors said.

“Ultimately, CO₂ emissions reductions will provide meaningful benefits to society from the perspective of both climate mitigation and improved human health from better air quality.”

—INÊS AZEVEDO, ASSOCIATE PROFESSOR OF ENERGY RESOURCES ENGINEERING
Hydrogen's time as a cost-effective energy source finally may have arrived, say scholars Stefan Reichelstein and Gunther Glenk. Most hydrogen is produced from natural gas through a carbon-intensive process called steam reforming. A cleaner approach is to split water into hydrogen and oxygen using electricity from renewable sources, like solar and wind. However, electrolyzer technology is considered too expensive for large-scale use.

But what happens if electricity, either from a renewable source or from the grid, is fed to an electrolyzer at times when energy prices are low? To find out, the researchers created models to optimize the decision of selling wind-generated power to consumers, or instead use the clean electricity to produce hydrogen. The results showed that a vertically integrated “power-to-gas” system can break even, producing mostly green hydrogen at a price comparable to conventional hydrogen from steam reforming. Key factors contributing to the results are lower cost for renewable energy and electrolyzers, and increasing volatility in power prices.
A new map of the tectonic stresses acting on North America offers the most comprehensive view yet of the forces at play beneath the Earth’s surface. The map, developed by geophysicists Jens-Erik Lund Snee and Mark Zoback, provides a new, quantitative synthesis of faulting across the entire continent. It includes thousands of new measurements that indicate the direction and relative magnitude of the forces acting in the Earth’s crust.

Knowledge about the state of stress helps tell whether an existing fault is potentially active. In some areas, the researchers were surprised to see changes in stress orientations over very short distances, a feature not revealed in previous studies or reflected in current models of Earth dynamics. The new map will contribute to improved seismic-hazard analysis and safer energy exploration, especially with respect to the possibility of human-caused earthquakes from fluid injection, whether associated with oil and gas development or CO₂ sequestration.

“\n\nAt multiple scales, this map is teaching us new things about how the Earth’s crust works, things that now require geologic explanation.\\n\\n–MARK ZOBACK, BENJAMIN M. PAGE\\nPROFESSOR IN EARTH SCIENCES, EMERITUS\\n\n”
How we might wirelessly recharge electric cars, robots and drones on the move

Sid Assawaworrarit and Shanhui Fan (2020). Robust and efficient wireless power transfer using a switch-mode implementation of a nonlinear parity–time symmetric circuit. Nature Electronics, DOI: 0.1038/s41928-020-0399-7

Stanford engineers have taken a big step toward making it practical for electric cars to recharge wirelessly as they drive down the highway. Chargers embedded in the road could create a magnetic field that wirelessly transmits electricity to magnetic coils installed in the moving vehicle.

Professor Shanhui Fan and PhD candidate Sid Assawaworrarit had developed a system that automatically adjusts the resonating frequency of the magnetic field as the distance between the charger and the moving object changes. Their latest prototype can wirelessly transmit 10 watts of electricity a distance of two to three feet to a moving object, with a system efficiency exceeding 90 percent. Fan said the system can be scaled up to transmit hundreds of kilowatts, more than enough electricity to recharge a speeding automobile. Although highway charging may be years away, the opportunity for wirelessly charged robots and aerial drones is more immediate, he said.

“This is a significant step toward a practical and efficient system for wirelessly recharging automobiles and robots, even when they are moving at high speeds.”

—SHANHUI FAN, PROFESSOR OF ELECTRICAL ENGINEERING
A clean alternative to conventional air conditioning and refrigeration


Nearly half of all electrical power in the United States is used to air condition buildings and operate home cooling appliances. Carbon-dioxide emissions to produce that electricity aside, hydrofluorocarbons and other refrigerants used in conventional cooling devices can have a big impact on the climate. HFC gas is about 2,000 times more potent than CO₂ at trapping atmospheric heat. By 2050, HFC leakage could be responsible for up to 10 to 40 percent of global warming. A 2016 United Nations agreement called for an 80 percent reduction in HFC consumption by mid-century.

In conventional cooling, HFC gas can escape into the atmosphere from air conditioners and refrigerators. Now, for the first time, Professor Arun Majumdar and colleagues have demonstrated a promising alternative—electrochemical redox refrigeration. Instead of compressing gas, the researchers achieved cooling by electrically charging or discharging a liquid electrolyte, a technology similar to flow batteries. When scaled up, this water-based technology could eliminate the need for HFC refrigerants.

“Globally, the air conditioning and refrigeration sector will likely undergo marked growth in the next 30 years. It is, therefore, imperative that the greenhouse gases used in conventional cooling devices be phased out in favor of more environmentally friendly alternatives.”
–ARUN MAJUMDAR, JAY PRECOURT PROVOSTIAL CHAIR PROFESSOR
New route to carbon-neutral fuels from carbon dioxide


If the idea of flying on battery-powered commercial jets makes you nervous, you can relax a little. A new, practical starting point for converting carbon dioxide into sustainable liquid fuels could lead to fuels for heavier vehicles difficult to electrify, like airplanes, ships and freight trains.

Stripping oxygen from CO₂ to make carbon monoxide (CO) gas is the first step in turning CO₂ into useful liquid fuels. Now researchers William Chueh, Michal Bajdich and colleagues at Stanford in collaboration with the Technical University of Denmark have demonstrated that low-cost cerium oxide can convert CO₂ into CO better than conventional methods.

The researchers built two cells for CO₂ conversion testing: one with cerium oxide and the other with a conventional nickel-based catalyst. When electricity was applied, the ceria electrode remained stable, while carbon deposits significantly shortened the nickel catalyst’s lifetime. The research team envisions using renewable electricity and cerium oxide to make CO for use in carbon-neutral products like synthetic diesel and the equivalent of jet fuel. The market value of those products could help overcome the high cost of capturing CO₂.

“We showed we can use electricity to reduce carbon dioxide into carbon monoxide with 100 percent selectivity and without producing the undesired byproduct of solid carbon.”

--WILLIAM CHUEH, ASSOCIATE PROFESSOR OF MATERIALS SCIENCE AND ENGINEERING
The impact of proposed federal climate and energy rollbacks


The Trump administration plans to roll back several key climate change regulations from previous administrations, including requirements for energy-efficient light bulbs, reduced methane emissions and stricter fuel efficiency standards. If implemented, these rollbacks could have a major impact on greenhouse gas emissions in the United States and global climate change, says Professor Deborah Sivas.

The transportation sector alone accounts for about one third of U.S. emissions, so lowering vehicle fuel-economy standards would be significant, she said. Plans to weaken regulation of methane leakage from oil and natural gas fields would also contribute to the climate problem, since methane—the main component of natural gas—is about 80 times more effective than carbon dioxide at trapping atmospheric heat in the short term. The most baffling rollback would reverse a federal law phasing out incandescent light bulbs by 2020. High-efficiency LED bulbs reduce CO₂ emissions and would save consumers billions of dollars annually in electricity costs, she noted.

“I’m confident that the next administration, whenever that is, will reverse course again on all these environmental delays and rollbacks.”

–DEBORAH SIVAS, LUKE W. COLE PROFESSOR OF ENVIRONMENTAL LAW
Low-cost catalyst can generate clean hydrogen in a commercial device

Scientists have shown for the first time that a cheap catalyst can split water and generate clean hydrogen gas for hours in the harsh environment of a commercial device. Water-splitting devices powered by renewable energy have the potential for large-scale hydrogen production, but have been held back in part by the high cost of precious-metal catalysts, like platinum, that boost efficiency.

A study led by Associate Professor Thomas Jaramillo points the way toward a cheaper solution.

The researchers produced an inexpensive catalytic material made of cobalt phosphide and carbon to replace the platinum catalyst in a commercial water splitter. In the experiment, the cheap catalyst generated hydrogen for more than 1,700 hours – an indication that it may be hardy enough to split water at an industrial scale with elevated temperatures, pressures and extreme acidity. Replacing today’s expensive catalysts could lower the cost of producing hydrogen for fuel, fertilizer and clean-energy storage, the researchers said.

“Most of the hydrogen produced today is made with fossil fuels, adding to the level of carbon dioxide in the atmosphere. We need a cost-effective way to produce hydrogen with clean energy.”

–THOMAS JARAMILLO, ASSOCIATE PROFESSOR OF CHEMICAL ENGINEERING AT STANFORD AND OF PHOTON SCIENCE AT SLAC NATIONAL ACCELERATOR LABORATORY
New discipline proposed: Macro-energy systems—the science of the energy transition


What types of electricity storage could have the biggest impact globally for a low-carbon energy future? Can humanity simultaneously decarbonize energy and extend heat, lighting and transportation to more than a billion people now living without modern energy services? These are the types of big-picture questions being addressed in a new academic discipline—“macro-energy systems”—proposed by a research team led by professors Adam Brandt, Sally Benson and John Weyant.

The new discipline focuses on big-picture topics in energy use, like the global car fleet, supply chains and energy investments. The large spatial and temporal scale of these topics requires researchers from a broad range of disciplines to use similar techniques, such as modeling and abstraction. Formalizing macro-energy systems into a single discipline would improve research and education by establishing core methods and terminology, avoiding redundant work and fostering new careers in energy, said the Stanford-led team.

"Macro-energy systems research and education is happening already, but it’s being done in different departments and published under disparate academic journals."

—PATRICIA LEVI, PHD CANDIDATE IN MANAGEMENT SCIENCE & ENGINEERING
Blended finance could address climate financing gap, but course needs correcting


The world needs to invest trillions of dollars annually to address climate change, but current global finance flows are vastly inadequate. One promising solution is blended finance: the use of public and/or philanthropic capital to catalyze additional private capital that would otherwise not be available for climate investments in developing countries.

However, to have the intended impact at scale, blended finance needs some early course corrections, according to a study by Esther Choi and Alicia Seiger. Recommended changes include better governance structures, more transparency and a more systemic, holistic approach to achieving climate impact. Perhaps most important, blended finance interventions should fund transformative ventures, not one-off projects. To transform markets and maximize climate impact, these interventions must actively engage developing countries and align investments with local needs. The ultimate goal of blended finance is to create self-sufficient, well-functioning markets where public or philanthropic contributions are no longer necessary, the authors said.

“Projects with incremental, short-term impact won’t help industrializing economies avoid the trap of locking themselves into a fossil fuel-based system. Rather than focusing on the amount of mobilized capital, creators and managers of blended finance vehicles should look for the quality and scalability of projects that can have systemic impact.”

–ESTHER CHOI, RESEARCH FELLOW, SUSTAINABLE FINANCE INITIATIVE, PRECOURT INSTITUTE FOR ENERGY
New insights on high-temperature superconductors from SIMES


Hong-Chen Jiang and Thomas Devereaux (2019). Superconductivity in the doped Hubbard model and its interplay with next-nearest hopping t'. Science, DOI: 10.1126/science.aal5304


Superconductors, which conduct electricity with no energy loss, could significantly improve energy transmission on the electric grid. Conventional superconductors, however, must be kept extremely cold, barring practical application over long distances. Research from the Stanford Institute for Materials & Energy Sciences is providing new insights on this puzzling yet promising technology.

One experiment led by professors Zhi-Xun Shen and SIMES Director Thomas Devereaux focused on copper oxide, a widely studied superconductor. They found that at higher temperatures, electrons in copper oxide abruptly overcome their mutual repulsion, forming a collective soup that allows them to flow past obstacles without losing energy.

In another copper oxide study, staff scientist Hong-Chen Jiang and Devereaux demonstrated that a standard mathematical model of material behavior can also be used to simulate high-temperature superconductivity. The model could enable scientists to toggle superconductivity on and off by controlling the movement of electrons.

Professor Harold Hwang and SIMES researcher Danfeng Li led a team that created the first nickel oxide material with superconducting properties. In copper oxides, magnetism is thought to play a key role in superconductivity. The discovery of superconductivity in nickel oxide, a non-magnetic compound, could overturn leading theories of how superconductors work.

“The big thing we want to know is how to make superconductors operate at higher temperatures and how to make superconductivity more robust.”

–THOMAS DEVEREAUX, PROFESSOR OF MATERIALS SCIENCE & ENGINEERING AT STANFORD AND OF PHOTON SCIENCE AT SLAC NATIONAL ACCELERATOR LABORATORY
Computer vision helps SLAC scientists study lithium ion batteries


Computer vision technology is bringing new insights into how lithium-ion batteries degrade. Yijin Liu and colleagues combined sophisticated machine-learning algorithms with X-ray tomography data to produce a detailed picture of how one battery component, the nickel-manganese-cobalt cathode, degrades with use. NMC particles are held together by a carbon matrix, and the researchers had speculated that battery performance declines as the particles break away from the matrix.

To find out, they turned to computer vision, a subfield of machine-learning algorithms originally designed to scan images and identify objects, like dogs or cars. The scientists trained the algorithm to distinguish individual NMC particles and develop a three-dimensional picture of how the particles fracture and break away from the carbon matrix. They discovered that while detaching particles contribute significantly to a battery’s decline, making the particles smaller may not increase battery longevity as was widely assumed.

“Our findings highlight the importance of precisely quantifying the evolving nature of the battery electrode’s microstructure, which is a key to achieving higher battery capacity.”

– YIJIN LIU, LEAD SCIENTIST, SLAC NATIONAL ACCELERATOR LABORATORY

A new computer vision algorithm can better identify particles in an X-ray tomography image of a nickel-manganese-cobalt cathode. Older methods would mistake a single fractured particle for several different particles, while the new method can tell the difference.
Microbes’ DNA can reveal where underground fluids came from


Scientists are using microbial DNA to track the mysterious flow of water and oil below the Earth’s surface. This unique genetic-fingerprinting technique may help determine the size of an underground resource and where to drill new wells – important data for groundwater management and oil extraction.

“As geothermal scientists, we try to figure out where the fluids come and go. It’s like a subway system you don’t have a map of – you’re often searching in the dark trying to figure out what the underground plumbing looks like.”

—ROLAND HORNE, PROFESSOR OF ENERGY RESOURCES ENGINEERING

Studies suggest that wells located along the same rock fracture host similar communities of bacteria and other microbes. PhD student Yuran Zhang proposed using microbial DNA from different wells to map their connectivity. To test the idea, Zhang collected tens of thousands of DNA sequences from deep-water wells at a former South Dakota gold mine. Samples from two of the wells showed significant DNA overlap, indicating that they were connected through a shared fracture in the rock. This novel technique could also be used to track groundwater contamination, identify leaks at carbon-sequestration sites and map complex branching systems underground.
The strategic case for U.S. climate leadership

James Baker, George Shultz and Ted Halsted (2020). Foreign Affairs

There are compelling economic, geopolitical and national security rationales for the United States to lead the world on climate policy, say Distinguished Fellow George Shultz and co-authors James Baker and Ted Halsted.

The authors propose an ambitious plan to place the United States at the forefront of a clean-energy future. The plan calls for a revenue-neutral carbon fee in which the revenue is returned directly to the American people in the form of checks or dividends. The fee would rapidly reduce emissions and enable the government to simplify or even eliminate carbon regulations.

To protect American jobs and competitiveness, the plan also includes a carbon tariff that would apply the domestic carbon price to energy-intensive imports from countries without carbon fees. A new, U.S.-led global climate alliance would compel China, India and other major greenhouse gas emitters to do their fair share or risk being shut out of the world’s largest markets. Revenues from the tariff would also be returned to the American people.

“Climate change is the ultimate foreign policy challenge. The carbon dividends program we propose would enable environmentalists, businesses and political leaders to forge a lasting pact that leaves the majority of American families economically better off.”

—GEORGE SHULTZ, THOMAS W. AND SUSAN B. FORD DISTINGUISHED FELLOW AT THE HOOVER INSTITUTION
Wind farm costs cut by working with landowners and neighbors early

Recognizing the power of the human element in wind farm planning, Assistant Professor Erin MacDonald and co-workers have devised a mathematical model that considers how interactions between developers and landowners affect the success and cost of wind farms. The model highlights three actions developers could take during the process of landowner acquisition – community engagement meetings, preliminary environmental studies and sharing plans for wind turbine layout – and investigates how those actions would affect the eventual cost of the wind farm.

The model suggests that increasing landowner involvement in the planning process, while contributing to upfront costs, leads to more landowners accepting a development contract. Increased acceptance translates to cost savings overall, particularly in cases where acceptance prevents failure of the project. Techniques to improve landowner acceptance include designing virtual reality mockups of turbine plans, simplifying land-use contracts and offering landowners choices on how their land is used, the researchers said.

"Wind farm developers can include landowners in a collaborative way by showing them, not just where the turbines would be, but also explaining the advantages and disadvantages of different design layouts."

– ERIN MACDONALD, ASSISTANT PROFESSOR OF MECHANICAL ENGINEERING
The future of faster, more energy-efficient information processing may come down to light rather than electricity. Associate Professor Jennifer Dionne and postdoctoral scholar Mark Lawrence envision an all-optical computer where electricity is replaced by photons that drive high-speed information processing. This futuristic technology would require nanoscale photon diodes that allow light to flow in one direction but, unlike LEDs and other conventional light-based diodes, are small enough for consumer electronics.

As a first step toward nanophotonic technology, the researchers designed arrays of ultra-thin silicon disks that use acoustic vibrations to trap light and enhance its spiraling motion until it finds its way out. When illuminated in reverse, the vibrations spin in the opposite direction and cancel out any light trying to exit. In computers, these nanophotonic diodes could be as tiny as neurons, operating with the same interconnectivity and energy efficiency of the brain but with much faster computing speeds, the researchers said.

“Achieving compact, efficient photonic diodes is paramount to enabling next-generation computing, communication and even energy-conversion technologies.”

–Jennifer Dionne, Associate Professor of Materials Science and Engineering
Promising mobile technologies find methane leaks quickly

On trucks, drones and airplanes, 10 promising technologies for finding natural gas leaks swiftly and cheaply competed in the Mobile Monitoring Challenge, the first independent assessment of moving gas leak detectors at well sites. While billed as a “challenge,” the organizers – Stanford’s Natural Gas Initiative and the Environmental Defense Fund – did not declare a winner, because some of the technologies focus on leaks of different sizes.

The study examined finding leaks at natural gas fields, not below-ground leaks from city pipes. Leaks in the production, processing and transport of natural gas mostly emit methane, a potent contributor to global warming. Nine corporations and a university research team participated at two testing facilities in Colorado and California. All technologies were effective at finding airborne leaks. However, most of the systems tested needed to improve their ability to quantify the size of the leaks, the researchers said.

“Gas system operators will often want to confirm leaks with conventional optical gas-imaging systems, but mobile technologies can tell you where to look for leaks very quickly.”

–ADAM BRANDT, ASSOCIATE PROFESSOR OF ENERGY RESOURCES ENGINEERING
Plastics, fuels and chemical feedstocks from CO₂? SUNCAT is working on it.


One way to reduce carbon dioxide emissions is to capture CO₂ from industrial smokestacks, then use renewable energy to turn it into fuels, plastics, detergents and other valuable products, says Thomas Jaramillo, director of the SUNCAT Center for Interface Science and Catalysis.

One technique is to use a copper catalyst to convert CO₂ into useful chemicals like methanol, says staff scientist Christopher Hahn. SUNCAT researchers are trying to figure out why copper is the only catalyst that can make these chemicals from CO₂, says former PhD student Stephanie Nitopi. The problem is that copper produces more than a dozen unwanted compounds simultaneously. SUNCAT scientists discovered that redesigning the catalyst into a flaky “nanoflower” shape makes the reaction more selective, says postdoctoral researcher Lei Wang. With the right copper-based catalyst, these reactions could take place near room temperature, making them much more energy efficient than conventional methods, Hahn adds.

“When we use renewable energy to convert carbon dioxide to fuels, we’re storing the variable energy from those renewables in a form that can be used any time.”

–CHRISTOPHER HAHN, STAFF SCIENTIST AT THE SUNCAT CENTER FOR INTERFACE SCIENCE & CATALYSIS, STANFORD UNIVERSITY AND SLAC NATIONAL ACCELERATOR LABORATORY

Stanford Energy Research Year in Review: 2019-2020
Climate change is hitting the insurance industry hard. Here’s how Swiss Re is adapting

Jeffrey Ball (2019). Fortune

Major reinsurance companies have begun to address climate change by moving their investments and insurance policies away from coal and other carbon-intensive industries. Reinsurance provides coverage to insurance companies for major catastrophes, such as wildfires and hurricanes, which are expected to increase in frequency and size as the planet heats up.

In 2019, Swiss Re, the world’s biggest reinsurance company, said that it will divest from mining companies that produce at least 20 million tons of coal per year and from power generators with more than 10 gigawatts of coal-fired capacity. Swiss Re announced that by 2050, the company’s investment portfolio and insurance book will be carbon-neutral, meaning the companies and properties they insure will remove as much carbon from the air as they put into it. Swiss Re is also developing better forecasts of how global warming will affect future profits – a challenge facing corporations and investors worldwide.

“For the insurance industry, global warming has advanced from a future ecological challenge to a present financial shock.”

–JEFFREY BALL, SCHOLAR-IN-RESIDENCE AT THE STEYER-TAYLOR CENTER FOR ENERGY POLICY AND FINANCE
STANFORD ENERGY RESEARCH PROGRAMS

Bits & Watts Initiative: bitsandwatts.stanford.edu

Center for Automotive Research at Stanford: cars.stanford.edu

Center for Mechanistic Control of Water-Hydrocarbon-Rock Interactions in Unconventional & Tight Oil Formations: efrc-shale.stanford.edu

Energy Modeling Forum: emf.stanford.edu

Photonics at Thermodynamic Limits: pti.stanford.edu

Precourt Institute for Energy: energy.stanford.edu

Program on Energy & Sustainable Development:pesd.stanford.edu

School of Earth, Energy & Environmental Sciences industrial affiliate programs: earth.stanford.edu/industrial-affiliate-programs

Shultz-Stephenson Task Force on Energy Policy: hoover.org/taskforces/energy-policy

Stanford Center for Carbon Storage: sccs.stanford.edu

Stanford Energy Corporate Affiliates: seca.stanford.edu

Stanford Environmental & Energy Policy Analysis Center: seepac.stanford.edu

Stanford Institute for Materials & Energy Sciences: simes.stanford.edu

Stanford Natural Gas Initiative: ngi.stanford.edu

Stanford StorageX Initiative: storagex.stanford.edu

Steyer-Taylor Center for Energy Policy & Finance: steyertaylor.stanford.edu

Strategic Energy Alliance: energy.stanford.edu/strategic-energy-alliance

SUNCAT Center for Interface Science & Catalysis: suncat.stanford.edu

Sustainable Finance Initiative: sfi.stanford.edu

TomKat Center for Sustainable Energy: tomkat.stanford.edu
IN MEMORIAM: STUART MACMILLAN

STUART MACMILLAN, long-time Stanford teacher of sustainable energy technologies, died from natural causes suddenly and quietly at his home in Cherry Hills Village, Colo., on April 9, 2020. He was 68. Stuart, MS ’80, PhD ’84, was a lecturer at the School of Earth, Energy & Environmental Sciences and advisor to the Precourt Institute for Energy. He contributed to a broad range of initiatives at Stanford, including the Global Climate & Energy Project, Energy@Stanford & SLAC, and the popular course Stanford Energy Ventures.

After studying statistics and artificial intelligence as a graduate student at Stanford, Stuart worked at FMC Corp., where he helped launch a new AI research group focused on autonomous vehicles, machine vision and intelligent assistants. In 1987, he joined Sun Microsystems, where he was on the founding team of JavaSoft, a foundational Internet technology.

From 2008 through 2017, he was the chief scientist for energy informatics at the U.S. Dept. of Energy’s National Renewable Energy Lab, where he helped launch NREL’s program on energy systems integration. Most recently, in addition to his teaching at Stanford, he was a partner at Ridge-Lane Limited Partners.

“Stuart was a great mentor to dozens of students trying to create solutions to the sustainable energy challenge,” said Precourt Co-Director Sally Benson. “I always appreciated his advice and counsel. I will miss his steady and generous presence.”

Stuart is survived by his wife Kathleen, his daughter Elise, son Evan, daughter-in-law Julie and granddaughter Lucy, his brother Bruce, sisters Lynne Wiebe (Lloyd) and Laurie Pollitt (Kevin), 16 nieces and nephews and 15 grand-nieces and nephews.

ABOUT THE PRECOURT INSTITUTE FOR ENERGY

Through collaborations across campus, Stanford’s Precourt Institute fosters and supports the Stanford Energy community. Through its multiple programs, the institute funds research that has the potential to solve today’s toughest energy challenges and help transform the world’s energy systems.

Stanford students can discover energy through the institute’s experiential courses, internships, entrepreneurial activities and a one-week orientation for incoming graduate students interested in energy.

The Precourt Institute works with industry leaders, entrepreneurs and policymakers for the broad deployment of solutions. It also engages a wide range of stakeholders at events like the Global Energy Forum.

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