Stanford
Precourt Institute for Energy

ANNUAL REPORT
2019-2020

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ABOUT STANFORD UNIVERSITY'S PRECOURT INSTITUTE FOR ENERGY

Through collaborations across campus, Stanford University's Precourt Institute for Energy fosters and supports the Stanford energy community. The institute and its programs fund 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.

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.

PRECOURT INSTITUTE CENTERS AND PROGRAMS

Bits & Watts Initiative

Energy Modeling Forum

Explore Energy

Stanford Center for Carbon Storage

Stanford Energy Corporate Affiliates

Stanford Environmental & Energy Policy Analysis Center

Stanford Natural Gas Initiative

Stanford StorageX Initiative

Strategic Energy Alliance

Sustainable Finance Initiative

TomKat Center for Sustainable Energy

THE WORLD HAS CHANGED a great deal since the Precourt Institute for Energy's last annual report. We hope that everyone is finding ways to stay productive, engaged and healthy. Thank you for your commitment to the institute, to Stanford University and to the vision of sustainable, affordable, secure energy for all.

At the beginning of Stanford's 2019-2020 fiscal year, we stated these top priorities:

- Launch our comprehensive student program, Explore Energy.
- Host the second Global Energy Forum in May 2020.
- Award the first Global Energy Heroes prizes.
- Lay the groundwork for a new Stanford Carbon Removal Initiative with Stanford Woods Institute for the Environment.

Despite the constraints of the COVID pandemic, the following pages provide details on how the Precourt Institute was able to make much progress on these goals. We launched Explore Energy, as you can see in the education section of this report, and we look forward to serving students in person again soon. The second Global Energy Forum had to be postponed, but we pressed ahead by awarding the Global Energy Heroes prizes and launching the popular Global Energy Dialogues online. The Carbon Removal Initiative is prepared to launch in 2021.

This report also tells the story of how the institute and its initiatives, research centers and programs continued to deliver on the dual challenge of the energy transition through research, education and engaging with the world. The Stanford energy community persevered, adapted and found new – and in some cases superior – ways to advance our mission, as have so many of you.

In August, we announced that we were both stepping down from leading the Precourt Institute after more than eight years for Sally and more than five years for Arun. We are not going far. Both of us expect to remain involved in the work of the institute, committed to executing on the energy transition. The Precourt Institute will always be a part of us.

We are so delighted that Yi Cui, our good friend and a brilliant scientist, has taken the helm. We very much look forward to watching this new chapter for the Precourt Institute unfold at a moment in Stanford's and the world's history where its leadership is needed more than ever before. We have no doubt that Yi, the institute and the Stanford Energy community will meet that need vigorously.

Thank you for all your contributions to the institute, its programs and the broader mission during the past year. As this report illustrates, working together with sustained effort we can have a bright and secure energy future.

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

Arun Majumdar
Co-director, Precourt Institute for Energy
Jay Precourt Professor, Mechanical Engineering

2019– 2020 RESEARCH HIGHLIGHTS

The past fiscal year – September 1, 2019 through August 31, 2020 – produced a wide range of important research advances among the Precourt Institute's initiatives, research centers and programs. The next generation of lithium-based batteries came closer to reality on several fronts, as did generating electricity from radiative cooling of buildings at night. Fresh analyses were given to sustainable finance and a research agenda for thermal science. Below are a few such examples. (Research highlighted in the campus-wide *Stanford Energy Research: Year in Review 2019-2020* are not included here.)

New electrolyte may boost range of electric vehicles

A new lithium-based electrolyte invented by Stanford scientists could pave the way for the next generation of battery-powered electric vehicles. In a study published in the June 2020 issue of *Nature Energy*, researchers led by Zhenan Bao, professor of chemical engineering, and Yi Cui, professor of materials science and engineering, demonstrated how their novel electrolyte design boosts the performance of lithium metal batteries, which are lighter than lithium-ion batteries. Lithium metal batteries could deliver twice as much energy per kilogram as its dominant rechargeable kin.

For decades, however, the development of lithium metal batteries has been stymied by the growth of dendrites on the surface of the anode, which can cause the battery to fail or even catch fire. The researchers added fluorine to a common, commercially available liquid electrolyte. The results were dramatic. The experimental battery retained 90 percent of its initial charge after 420 cycles of charging and discharging. In laboratories, typical lithium metal batteries stop working after about 30 cycles.

Two of the co-authors are supported by TomKat Center postdoctoral fellowships.

Financial innovation for energy innovation

Owners and managers of energy infrastructure assets often must rely on short-term and costly financial products and services to fund the long-term projects needed for the global energy transformation. Stanford researchers Ashby Monk and Soh Young In described in a study in the Brown *Journal of World Affairs* in 2020 how to catalyze long-term investment capital to support energy innovation. They outlined how to transform the governance of investment organizations, improve the management and operations of investors via new collaboration, and increase cooperation among asset owners and managers.

New financial products and services must adopt a long-term view. Asset owners, for example, need to create and execute clear mandates to asset managers, and align their investment portfolios with sustainable growth and long-termism, the study found. Also, asset management models must be upgraded to better align investment opportunities and risks with the appropriate investor profiles.

Soh Young In is the financial innovation lead at the Precourt Institute's Sustainable Finance Initiative.

$1.8 million for 17 new energy research seed grants

Stanford University's Precourt Institute for Energy, StorageX Initiative and Bits & Watts Initiative selected 17 new energy research projects on campus to fund in August 2020.

Competitive selection was based on new, potentially transformative ideas for building a sustainable, affordable, secure energy future for the world. The $1.8 million will enable Stanford faculty to explore their concepts for high-risk, high-reward ideas through initial experiments and study.

Topics of the new set of research projects include hybrid materials for CO_2 capture and conversion, potential electrification of heavy-duty vehicles, and developing a system to better manage battery packs. Several studies will address the climate and health effects of battery production, and how to better reuse and recycle the cells. Another project will examine how the COVID-19 pandemic and wildfires affected electricity use, and how to prepare the grid more for such rapid changes in demand.

The Precourt Institute has made such awards annually since 2010. Bits & Watts has done so since 2017. This is the first year of seed grants for the new StorageX Initiative, which is supporting eight teams. Read the news article here.

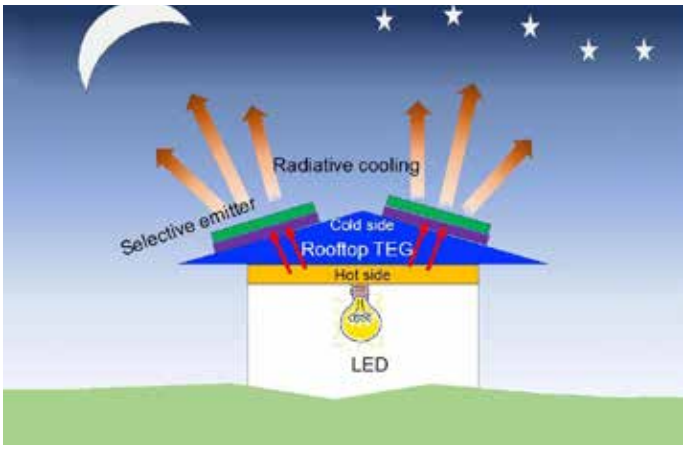
Low-cost system produces power at night

A team led by Shanhui Fan, professor of electrical engineering, designed a nighttime generator utilizing radiative cooling and thermoelectric power. The modular system, which uses commercially available technology, could someday produce nighttime lighting economically in dense urban and off-grid rural areas, as well as in countries with developing economies. That would reduce the dependence on energy storage technologies that are relatively expensive.

The researchers expressed confidence in the system's economic feasibility in the study published in *Optics Express* in August 2020. With a power density of more than 2 Watts per square meter, the new device showed a gain of 153 percent in power density compared to existing experimental materials that radiate building heat to the cold of space.

"A modular energy source could also power off-grid sensors used in a variety of applications and be used to convert waste heat from automobiles into usable power," said Lingling Fan, the student first author of the paper.

This research began with funding from the Global Climate & Energy project in 2018.



Finding super-emitting gas leaks from the sky

Methane emissions from the U.S. oil and gas system likely exceed 2 percent of production. Airplane-based remote sensing tools could detect as much as half or more of these emissions by focusing on super emitters, Adam Brandt, associate professor of energy resources engineering, and postdoctoral fellow Evan Sherwin, wrote in a Natural Gas Brief published by Stanford's Natural Gas Initiative in June 2020.

At present, finding leaks is costly and labor-intensive. More than a million oil and gas wells in the United States are connected to hundreds of thousands of miles of gathering and transmission pipelines. Leak detection generally requires ground crews operating specialized handheld equipment.

However, an estimated 5 percent of sources account for about half of total emissions. Remote sensing from aircraft or satellites could rapidly screen for only these big leaks. Methane has a distinct radiation signature, for the same reason it is a powerful greenhouse gas, making it well-suited for these applications. Plus, because these super emitter leaks are large, they are likely quite profitable to fix.

New catalyst can turn CO_2 into fuels

Imagine grabbing carbon dioxide from car exhaust pipes and other sources and turning the main greenhouse gas into fuels like natural gas or propane: a sustainability dream come true.

Several recent studies have shown some success in this conversion, but they involved a two-step process. The first step reduces CO_2 to carbon monoxide, then the second combines the CO with hydrogen to make hydrocarbon fuels.

A research team at Stanford and SLAC, led by Matteo Cargnello, created a new catalyst that simultaneously strips an oxygen molecule off of CO_2 and combines it with hydrogen. The catalyst yielded four times more ethane, propane and butane than existing methods that use similar processes, the research team reported in *Angewandte Chemie* in October 2019.

"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," said Cargnello, an assistant professor of chemical engineering.

The research was funded in part by a 2017 Precourt Institute seed grant.

Five thermal energy grand challenges for decarbonization

About 90 percent of the world's energy use involves generation or manipulation of heat, from making steel to cooling buildings. Maintaining modern economies and improving life in developing ones while mitigating climate change will require advances in five major areas of how the world converts, stores and transmits thermal energy, according to a study in *Nature Energy* in August 2020 from Stanford, MIT and Berkeley Lab.

"Modern renewable technologies are the most inexpensive source of electricity we have today, but solar and wind power are intermittent and account for a small percentage of the world's energy," said Arun Majumdar, one of three co-authors and a Stanford professor of mechanical engineering. "We need to increase this percentage, but we also must decarbonize heat, and use heat to store electricity from solar and wind."

The technical analysis outlines promising areas for thermal technology breakthroughs with the potential individually to reduce greenhouse gas emissions by at least one gigaton. One gigaton is about 3 percent of annual energy-related GHG emissions globally.

New solid electrolyte could improve lithium-ion batteries

Stanford scientists identified a new class of solid materials that could replace flammable liquid electrolytes in lithium-ion batteries. The low-cost materials – made of lithium, boron and sulfur – could improve the safety and performance of electric cars, laptops and other battery-powered devices, according to the scientists.

"Solid electrolytes hold promise as safer, longer-lasting and more energy-dense alternatives to liquid electrolytes," said senior author Evan Reed, an associate professor of materials science and engineering.

The researchers took a closer look at four lithium-boron-sulfur compounds identified in previous work, which used an algorithm to rapidly screen more than 12,000 lithium-containing compounds for good candidates. Using a technique called density functional theory, the new work found that the lithium-boron-sulfur solid electrolytes could be about twice as stable as the leading candidates, they reported in the July 2020 issue of *ACS Applied Materials & Interfaces*. The greater stability is expected to increase considerably the amount of energy per unit weight a battery can store.

The research was funded in part by the TomKat Center.

Majumdar elected to National Academy of Sciences

In April 2020, Arun Majumdar was one of nine Stanford faculty members elected to the National Academy of Sciences, which the U.S. Congress created in 1863 to advise the nation on issues related to science and technology. Selection to the non-governmental organization is considered one of the highest honors in science.

Majumdar's research has involved the science and engineering of nanoscale materials and devices, especially in the areas of energy conversion, transport and storage, as well as biomolecular analysis. His current research focuses on electrochemical and thermochemical redox reactions that are fundamental to a sustainable energy future; multidimensional nanoscale imaging and microscopy; and a new effort to re-engineer the electricity grid using data science.

EDUCATING FUTURE LEADERS

The Precourt Institute and its programs contribute to the education of Stanford students by providing courses, internships, entrepreneurial training, information and guidance, and an annual orientation week for 125 new graduate students interested in energy. During spring and summer terms 2020, despite moving online, all the programs continued to deliver on our mission.

A virtual advisor for students interested in energy

In 2020, the Precourt Institute launched Explore Energy, a one-stop resource for energy education at Stanford, thanks largely to the vision of adjunct professor and Precourt advisory council member Jane Woodward, '83, MBA '87. Explore Energy will host a launch event when such in-person activities resume on campus.

The program's managing director is Diana Gragg, MS '04, PhD '12. The *Extreme Energy Efficiency* spring break course was one of Stanford's first classes to transition to online due to COVID-19 (see page 8). After Gragg played a leading role in that transition, she provided guidance and support to other Explore Energy programs as they moved online. Gragg co-teaches *Understanding Energy* in the autumn, spring and summer terms, in addition to Extreme Energy Efficiency. Bianca Patel, a former Fulbright Scholar and graduate of Emory University and the University of Texas, became Explore Energy's program manager in October 2020.

Explore Energy helps students navigate and connect with energy classes, majors, research opportunities, internships, clubs, mentoring, networking, events and jobs. It also contributes to student literacy broadly on energy and environment issues.

The program supports Precourt Institute-related courses, like the *Stanford Energy Seminar*, *Understanding Energy*, *Extreme Energy Efficiency*, *SmartGrid Seminar*, *Stanford Climate Ventures*, *Hydrogen Economy and Sustainable Finance Seminar*. Explore Energy staff manages Energy@ Stanford & SLAC, the annual bootcamp for new graduate students interested in energy just before autumn term begins, as well as the institute's two internship programs: the Shultz Energy Fellowships program and the Summer Undergraduate Program on Energy Research.

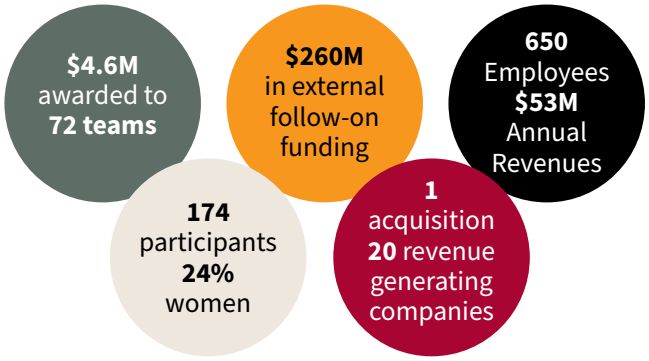
Due to COVID-19, Explore Energy's activities have been online, on Zoom or on the phone since March, but Gragg and Patel look forward to more immediate contact. Until then, a revamped "Student" section of energy.stanford.edu has streamlined information about Stanford energy courses and degrees, and made Stanford internship programs in energy more accessible.

Translating Stanford discoveries into products

The TomKat Center for Sustainable Energy's Innovation Transfer Program is critical to the ecosystem that develops cleantech entrepreneurs at Stanford. The Innovation Transfer Program trains Stanford students and recent alumni to advance technologies developed in their laboratories toward commercialization.

The program is educational, requiring all applicants to have a committed faculty advisor. Grants are awarded to develop prototypes, refine business plans, and conduct customer trials and market research. Executive Director Brian Bartholomeusz connects the leaders of projects with industry and finance mentors to provide hands-on entrepreneurship training as market opportunities are accessed and commercialization begins.

Since the grant program began in fall 2013, $4.6 million in TomKat funding has been transformed into $235 million in external, follow-on funding to date.



A recent Innovation Transfer spotlight explains how one team of Stanford PhDs are using air injection to streamline long-haul trucking. A spotlight in May 2020 features ClearFlame, which is developing a modified diesel engine that runs on renewable ethanol and delivers greater performance with lower soot and CO_2 emissions. The 13 new teams entering the Innovation Program in 2019-20 are described in this news article.

Stanford's climate-tech startup course

Stanford Climate Ventures, (*Stanford Energy Ventures* until fall 2020), focuses completely on energy and climate entrepreneurship. Students learn how to identify and assess the commercial potential of technologies to reduce or manage the damage of climate change, and then how to design, launch and build startups.

Each fall, winter and spring term, four interdisciplinary teams of four to six students develop their projects as well as the skills that will enable them to become innovation leaders. Many students take the course multiple times. The course was taught in 2019-2020 by David Danielson, Joel Moxley and Stuart Macmillan, until Stuart's passing in April. (See "In Memoriam" on page 8)

In the four years ending in August 2020, *Stanford Climate Ventures*' 45 projects have resulted in:

- 25 startups;
- $47.6 million in funding ($34.9 million of private investment and $12.7 million in philanthropic awards);
- 124 employees across 10 U.S. states and nine countries

"You just get a sense that something special is in the air in the climate-tech space at Stanford right now," said Danielson, "and it feels like it's just getting started."

In May, Stanford News published a feature that explored how *Stanford Climate Ventures* prepared students for challenges from concept development to startup launch. A September profile covered a recent course team's first test of a new device that produces carbon-free fertilizer on site at a tomato farm in Fresno.

PHOTO: NICO PINKOWSKI

Stanford Climate Ventures alumni harvest the first tomatoes grown with their carbon-free fertilizer.

Two weeks to redesign an intense spring break course

In 2018 and 2019, about forty Stanford University students chose to spend their spring break week in still-cold Colorado studying how to design buildings, vehicles, equipment and factories that use very little energy. *Extreme Energy Efficiency*'s teachers banned computers and other devices from the classroom. They wanted students to be present, focused, mindful.

Skiing was not on the agenda. Instead, students learned from an energy efficiency legend, Amory Lovins, who grows bananas in his zero net energy home in Colorado in the winter.

In March 2020, two weeks before students were set to fly to Colorado, the teachers were told to cancel the class or move it online due to COVID-19. They decided to press on, doing their best to virtualize the experience of wandering among ripening bananas in a greenhouse beneath snowy skies. The no-computers policy was turned on its head.

Enrolled students were given the option to drop the course, but 30 of 40 took a leap of faith at the very beginning of classes moving online. After the disappointment over not getting the full Colorado experience and some early adjustments, the students agreed that they had learned a lot that week.

"It was engaging, intense, informative, exhausting at times, wonderful and completely worthwhile," said Grace Johnson, PhD candidate in chemistry.

A news article describes the quick pivot and includes a video of the experience.

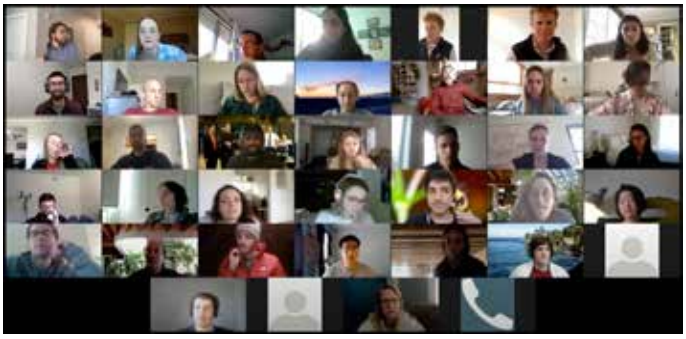


PHOTO: ERIN CLAYTON

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 and Energy@ Stanford & SLAC. He was a member of the teaching team of the popular course *Stanford Climate 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 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. Read more.

Public-service energy internships honor Secretary Shultz

The public-sector, energy-focused internship program for Stanford students was renamed in honor of one of the most widely admired American public servants over the past half-century: former Secretary of State George P. Shultz.

The Shultz Energy Fellowship program, (previously Stanford Energy Internships in California & the West), is a partnership of the Precourt Institute, Bill Lane Center for the American West, Haas Center for Public Service and Stanford in Government. The program offers undergraduate and graduate students paid summer positions at energy agencies in California, Colorado, Utah and Hawaii. Students work with mentors and gain real-world, public-sector experience at the local, state and regional levels. A long-time leader on energy policy and research, Secretary Shultz said he was honored and touched when he heard about the program's new name.

"We're beginning to pull bright young people into this orbit and have them work at the energy problem. That's the future," said Shultz, who chairs both the energy policy task force at the Hoover Institution and the advisory council at the Precourt Institute.

With a decades-long career in public life that includes serving in four different U.S. Cabinet positions — one of only two people to do so — Secretary Shultz is a model of the public service attributes the program seeks to develop in students.

Read more in this Precourt Institute news article.

Secretary Shultz, who turned 100 years old in December 2020, shares his insights every year at Energy@Stanford&SLAC. After speaking, he always takes time to chat with students.

Seven students in cleantech make *Forbes* "30 Under 30"

In December 2019, *Forbes*' "30 Under 30" lists featured five Stanford alumni and two current students developing energy-related technologies. The magazine applauds auspicious achievements in 20 categories, from manufacturing to games. From Stanford, "30 Under 30 in Energy" for 2020 featured the two co-founders of Shyft Power Solutions, Ugwem Eneyo, MS '16, and Cole Stites-Clayton, '14, MS '15; as well as a co-founder of Swift Solar, Kevin Bush, PhD '19. In addition, Forbes selected the four co-founders of WindBorne Systems for its "30 Under 30 in Science" category: Paige Brown, '20; Andrey Shushko, '16; Kai Marshland, '19, MS '21; and John Dean, '19.

Shyft has developed sustainable, reliable and affordable energy systems for homes in developing economies. Swift Solar is developing next generation perovskite-based solar cells. WindBorne is reinventing weather balloons that could help humanity adapt to the growing threat of climate change.

Like past Stanford students recognized by *Forbes*, the 2020 students benefited from the *Stanford Climate Ventures* course and the TomKat Center's Innovation Transfer Program. The founders of Shyft Power Solutions and Swift Solar came through both the course and program. The WindBorne team received an Innovation Transfer grant in 2019. Over the years, many of Stanford's "30 Under 30" students in cleantech have also been supported by research grants and fellowships from the Precourt Institute and its programs.

Stanford students, alumni and faculty in energy have been featured in *Forbes*' "30 Under 30" in each of its nine years. The Precourt Institute and TomKat Center work with the magazine's editors on nominations from Stanford every year. Read more about the 2020 winners.

"We are at a critical point in determining the world's future. We believe the Stanford community and our doctoral students, especially, can spur positive change."

–Jen Dionne
Co-director, TomKat Center for Sustainable Energy;
Associate Professor of Materials Science & Engineering

TomKat Center adds graduate fellows to educational mission

The TomKat Center launched its graduate fellowship program in 2020. The new program supports advanced Stanford doctoral students for two years, including tuition, a stipend and some research funding. Under the guidance of Stanford faculty, fellows pursue research projects to move beyond the proof-of-concept stage toward high impact solutions to sustainability challenges in energy and elsewhere.

The program aims to move innovations out of the lab and into the wilds of the real world, dovetailing with the center's Innovation Transfer Program. Despite the innovation program's record of success, TomKat codirectors Jen Dionne, associate professor of materials science and engineering, and Matt Kanan, associate professor of chemistry, saw a gap. "We wanted to create a chance for people to focus their research toward meaningful applications—without having to take the jump and say, 'I'm going to start a company,'" said Kanan.

Three PhD candidates comprise the first cohort, which was selected over the summer and began receiving support in the fall. Tuofei (Francis) Chen is designing an electricity inverter to help integrate renewable energy into the grid. Anna-Katharina von Krauland is creating a highly detailed digital atlas of potential wind farm locations. Nathan Ratledge is accelerating clean energy and electric mobility in sub-Saharan Africa.

From left, Tuofei Chen, Anna-Katharina von Krauland and Nathan Ratledge.

The new fellowship program augments TomKat's existing postdoctoral fellowships program, which attracts outstanding recent PhD graduates primarily from other universities to Stanford. TomKat is funding the new program with money that previously supported seed grants for early-stage research.

Read more about the first TomKat graduate fellows.

Summer Undergraduate Program on Energy Research pivots to virtual internships

In 2020, the Summer Undergraduate Program on Energy Research again provided research opportunities for 15 students. One major challenge was determining whether SUPER projects could be done remotely. Three of the original 15 professors decided that the research they were to have overseen could not be. However, program leaders found other faculty members to work with the three students. Some students did more statistical and model-based work rather than the hands-on lab or field work they had planned on.

The program's classes, held on Zoom, featured a virtual tour of Stanford's Central Energy Facility, and guest lectures by past SUPER students Carlos Ciudad-Real and Takao Yatagai. Ciudad-Real has is collaborating with GSB's Prof. Stefan Reichelstein on the economics of battery electric bus fleets. Takao is working on popular integrated assessment models with John Weyant, professor of management science and engineering

Looking ahead, SUPER is seeing increased interest from students and the Precourt Institute intends to meet the needs through the Explore Energy platform. The Vice Provost for Undergraduate Education grant has historically provided funding for eight or nine students. Even with the increase in internships since SUPER was started, applications have remained at least double the available slots.

Stanford Energy Seminar celebrates 300

In January 2020, Stanford Energy Seminar commemorated its 300th lecture with a talk by Lynn Jurich, chief executive of Sunrun, which is the largest dedicated provider of residential solar, storage and energy services in the United States. Jurich earned her bachelor's degree and MBA at Stanford. After the 300th lecture, Energy Seminar's founding faculty lead Roland Horne, professor of energy resources engineering; his successor Sally Benson, professor of energy resources engineering; and current lead John Weyant, professor of management science and engineering, celebrated the occasion with many past speakers, regular attendees and students.

Over the years, the Precourt Institute has compiled a wealth of videos documenting more than a decade of innovation in energy. More than 200 videos are available to everyone around the world through the "Energy Seminar" playlist on the Stanford Energy YouTube channel. Videos from the 2019-2020 academic year have been watched more than 23,000 times, an average of over 1,000 views per video. The year featured talks from John Deutch, Will Chueh and Yi Cui on StorageX, and Vivas Kumar, an MBA candidate at the GSB and a principal at Benchmark Mineral Intelligence.

> "We're beginning to pull bright young people into this orbit and have them work at the energy problem. That's the future."
>
> –George P. Shultz
> Thomas W. and Susan B. Ford Distinguished Fellow Hoover Institution, Stanford University

ENGAGEMENT

PHOTO: DAWN HARMER

During the second half of fiscal year 2019-20, engaging with others involved in the energy transition became a challenge. As did so many others, the faculty, students and staff of the Precourt Institute figured it out and even took advantage of the ability to expand engagement online. After in-person engagement resumes, the institute will have the experience to select the most appropriate option among fundamentally different means of interacting.

Stanford launches StorageX Initiative

After two years in the making, Stanford's StorageX Initiative was launched at its first symposium in October 2019. In line with the university's long-range vision, a big part of StorageX's mission is to translate academic discovery into commercial impact.

Led by co-directors Yi Cui and Will Chueh, professor and associate professor, respectively, of materials science and engineering, the broad energy storage research program focuses on nine topics. Six cover application sectors: electric vehicles, aviation, consumer electronics, manufacturing, stationary storage ranging from residential to grid scale, and the role of storage in energy systems. The other three address cross-cutting technological domains within energy storage: data science, new materials and techno-economics. Affiliated faculty come from disciplines ranging from energy resources engineering to computer science to business.

Some 170 researchers, industry executives and policy makers participated in the launch symposium. The level of enthusiasm and interest in the topic and the initiative was unmistakable. A new company joined StorageX immediately as a result of the conference.

Stanford speakers at the launch symposium included Vice Provost and Dean of Research Kathryn Moler and former Secretary of State George Shultz. Non-Stanford speakers included Tim Holme, QuantumScape's chief technology officer; Hartmann Leube, BASF's senior vice president of new technologies; Kang Sun, CEO of Amprius; Amanda Simpson, vice president of research and technology at Airbus Americas; and Abraham Anapolsky, manager of accelerated materials design and discovery at Toyota Research Institute.

In the summer of 2020, StorageX started its International Symposium Series webinar. Stanford's standing as a complete research center for energy storage was utilized to create a global dialogue on storage and battery technology that had not previously existed. The first StorageX International Symposium Series was with Nobel laureate Stan Whittingham and University of Washington professor Jun Liu, who also serves as director of the U.S. Dept. of Energy's Battery500 program. The discussion focused on the history and potential future of lithium-ion batteries.

Some 3,600 battery professionals and others from around the world joined the first StorageX International Symposium. An average of 2,200 participants joined the weekly events. The five webinars produced in FY 2020 have been viewed almost 12,000 times on the StorageX Symposium playlist on the Stanford Energy YouTube channel.

StorageX also launched the first quarterly StorageX Research Forum in July 2020. Faculty and industry members exchanged ideas and explored areas of interest for further collaboration. As a result, the Consortium on a Battery Circular Economy was born, involving faculty from Stanford's School of Engineering, School of Earth, Energy & Environmental Sciences and Graduate School of Business.

Jun Liu, M. Stanley Whittingham and Yi Cui speaking at the inaugural StorageX International Symposium.

Global Energy Dialogues maintain momentum

Precourt Institute launched the Global Energy Dialogues to continue engaging and expanding the Global Energy Forum community after in-person events had to be postponed. Thought leaders around the world convened to examine the challenges and opportunities for decarbonizing energy and extending modern energy services to all people. They did so often within the context of the health and economic crises of the ongoing COVID-19 pandemic, as well as other social, environmental and economic issues. The series has been web cast every two weeks since June 2020 and is planned to continue through 2021.

Speakers for the six sessions that aired by the end of the fiscal year included two former U.S. energy secretaries – Ernest Moniz and Steven Chu, professor (emeritus) of physics, and of molecular and cellular physiology – and the chairman of Royal Dutch Shell plc, Chad Holliday. Almost 6,500 people registered to attend the first six sessions, and more than 7,000 people subsequently watched these six webinars on the Global Energy Forum, Dialogues & Heroes playlist on the Stanford Energy YouTube channel.

Precourt communications staff writes a news article on each session. Several sessions have been covered by *Forbes*, (85,000 views), E&E News' *EnergyWire*, *The Australian* and *Australian Business Review*.

PHOTO: BILL & MELINDA GATES FOUNDATION

Video entry from Solar Freeze.

Global Energy Heroes inspire optimism

Even though the Global Energy Forum had to be postponed, Precourt Institute leadership decided to press ahead with awarding the related Global Energy Heroes prizes in May. They figured then that the world could really use some good news about the work and dedication of young people making the world more sustainable. With the support of sponsors of the Global Energy Forum, three community-based sustainability organizations received the prizes and global recognition they deserve.

The competitive prizes drew submissions from 27 countries across six continents. Organizations led by people under 30 years of age were eligible. Although many organizations in advanced economies entered, the three winners were from developing economies. Mee Panyar is helping remote communities in Myanmar upgrade their miniature electric grids, replacing costly diesel generators with solar power. Solar Freeze provides solar-powered refrigerated storage and transportation for small-scale farmers in Kenya. Takataka Plastics is recycling low-value plastic waste in Uganda into high-demand construction materials. Each organization received $20,000 to advance their enterprise and a trip to Stanford for the next Global Energy Forum, planned for the second half of 2021.

Stanford Energy Club co-presidents Kailash Raman and Sebastian Schneider spearheaded the competition. "Though focusing on the specific needs of their communities, many of the teams developed solutions that hold the potential to be widely implemented across the globe," said Schneider.

If your spirit could use a little lift now, read about the inspiring young winners and watch their videos here.

Bits & Watts teams up with EPRI to advance digital grid

Stanford's Bits & Watts initiative and the Electric Power Research Institute (EPRI) co-hosted a summer webinar series on the digital grid and integrating distributed energy resources. The webinar series brought together utilities, information technology companies, government organizations and universities in interactive panel sessions to discuss the latest advances, emerging policies, and breakthrough research.

This interactive panel series provided an opportunity to advance conversations about the latest research on using distributed energy resources to realize the vision of a digital grid. It was moderated by Liang Min, managing director of the Bits & Watts Initiative, and Omar Siddiqui, senior program manager of electrification at EPRI. All episodes of the webinar series can be viewed on the Electric Grid playlist on the Stanford Energy YouTube channel.

Shultz, Baker and Halstead argue for U.S. climate leadership

The U.S. case for action on climate change is usually made on environmental grounds. But, as George Shultz, James Baker and Ted Halstead wrote in *Foreign Affairs*, economic, geopolitical, and national security reasons are equally strong grounds.

"Even those who remain skeptical of the environmental urgency of the problem should recognize the overwhelming strategic advantages of U.S. climate action at home and abroad," they wrote in May 2020.

In January 2020, Shultz and Halstead had penned and op-ed in *The Washington Post* arguing that conservative U.S. politicians should support putting a price on carbon as the best way to reduce greenhouse gas emissions, along with federal support for R&D.

Re-emergence of a hydrogen economy

Based on very high interest in hydrogen's capacity to possibly transform the global energy landscape, the Stanford Energy Corporate Affiliates program, the Natural Gas Initiative and SUNCAT Center for Interface Science & Catalysis formed Stanford's Hydrogen Focus Group. The group convened a two-day hydrogen workshop in March with executives from industry and government. The 85 participants came from Europe, Asia, the Middle East, and North and South America.

This group is becoming Stanford's nucleus for hydrogen research and teaching, with more than 10 faculty members affiliated. For winter term 2020, professors Sally Benson, professor of energy resources engineering, and Xiaolin Zheng, professor of mechanical engineering, co-taught a new seminar "Hydrogen Economy" with Naomi Boness and Jimmy Chen. This seminar explored hydrogen as a critical piece of the global energy transformation and was renewed for winter term 2021.

$35 million in free legal services for startups

Karen Skelton, David J. Hayes and Ali Zaidi worked with California Gov. Jerry Brown, Attorney General Xavier Becerra, Stanford Law School and Stanford's Precourt Institute for Energy to launch Lawyers for a Sustainable Economy in 2018. Nine law firms committed to provide $15 million in pro bono legal services to startups and nonprofits working on environmental sustainability. By 2020, the initiative grew to include 14 firms pledging $23 million.

The firms did not stop there. Once they hit their financial commitments, several firms – including Nixon Peabody, Latham & Watkins, Arnold & Porter, Wilson Sonsini, and Morrison & Foerster – exceeded their pledge by millions of dollars. In the end, $35 million worth of legal services were contributed in the two-year period ending September 2020.

Member firms are eager to extend the initiative beyond the original 2020 end date. Stanford Law School and the Precourt Institute are launching a new phase of the initiative in 2021, with hopes of growing the client and firm base even more.

The potential for a bipartisan energy infrastructure bill

"America is facing an inflection point as we seek to jumpstart our economy and create millions of new jobs even amid fresh security concerns over reliance on global supply chains," Arun Majumdar, professor of mechanical engineering and Sasha Mackler wrote in an op-ed for *The Hill* in July 2020.

The energy transition can provide new opportunities for infrastructure investments and members of both parties in Congress can and should work together to make that happen, they said, in an argument still valid months after the opinion piece was published. A big area for investment is information technology that can make the most of large investments in energy efficiency made in previous years.

New investments in the electrification of transportation, production of carbon-free hydrogen, carbon-dioxide removal and the domestic production of batteries could be huge creators of new jobs, as the investments in energy efficiency have been. Investing in domestic production and supply chains would make the United States more secure, and the idea enjoys growing bipartisan support, wrote Majumdar and Mackler, who is the director of the Energy Project at the Bipartisan Policy Center.

Strategies for decarbonizing Mexico's economy

The Mexico Clean Economy 2050 project is part of the California Global Energy, Water & Infrastructure Innovation Initiative, a collaboration between the Precourt Institute and the Bill Lane Center for the American West. The initiative pursues low-carbon development and investment opportunities for the transition to zero emissions in North America.

In May, MCE2050 published the report "Natural Climate Solutions: An Opportunity to Enhance Mexico's National Climate Investment Policy." It is a set of policy recommendations to the government of Mexico from domestic and international experts who participated in an MCE2050 workshop in late 2018 followed by subsequent discussions and research. With the right incentives and regulations, the authors write: "Mexico can be a global demonstration case for implementation of natural climate solutions, becoming a leader in the application of an innovative and additive solution to the challenge of climate change, and the management of national natural capital, focusing in particular on temperate and tropical forests in the center, south and southeast of the country."

A goal of MCE2050 is to support the emerging innovation hubs at the U.S.-Mexico border, focusing initially on Baja California and Nuevo Leon. In July, the Bay Area Council Economic Institute published an analysis, "The Baja California & Nuevo Leon Industry, Innovation and Talent Clusters: Growing the California-Mexico Binational Economy." The study was commissioned by MCE2050

C3E annual symposium celebrates women in clean energy

The Clean Energy Education & Empowerment (C3E) initiative, with its annual symposium and awards, inspires women to pursue careers and leadership roles in clean energy by recognizing achievements and providing professional networks for mentoring. The initiative is a collaboration of the U.S. Department of Energy, the Precourt Institute, MIT Energy Initiative and the Texas A&M Energy Institute.

Inspiring the future generation of clean energy leaders in crossing boundaries—both academically and professionally—echoed throughout the eighth annual C3E symposium in November 2019. CEOs, directors, global managers, founders and researchers gathered to honor both established and emerging energy leaders. They also explored how to inspire the next generation for the energy transformation and routes to meaningful careers in clean energy.

Maria Vargas (left) of U.S. Dept. of Energy and Nicole Ardoin of Stanford University discuss the importance of inspiring the next generation of leaders in clean energy transformation at C3E Symposium 2019.

Planning longitudinally is important, because energy solutions require all of us to work together, said symposium speaker Nicole Ardoin, Stanford associate professor of education and director of the Emmett Interdisciplinary Program on Environmental & Resources. She also talked about being inspired by the many ways the energy sector involves everyone.

Denise Gray, the 2019 Lifetime Achievement award winner, reflected on how her seventh-grade science teacher pushed her into STEM and set Gray on her path to an illustrious clean energy career. "In our busy lives…we're going to encounter people who, all they're looking for is just a little bit of encouragement…I'm asking all of you to continue to [encourage others] because all it took was one teacher who had the audacity to push [me] forward," said Gray, who is president of LG Chem Michigan Inc. Tech Center.

Highlights from the contributions of the awardees include Suzanne Singer, winner of the entrepreneurship award and founder of Native Renewables, which is bringing energy access to the Navajo Nation through affordable off-grid solar electricity solutions.

Also, 46 undergraduate and graduate students from universities across the U.S. presented their work in a poster session. Winners included Ali Andrews and Sita Syal of Stanford for their research project on the benefits of involving communities in the design of renewable energy projects.

Majumdar joins American Energy Innovation Council

Arun Majumdar was one of three people chosen to join the American Energy Innovation Council, along with Liz Shuler, secretary-treasurer of the AFL-CIO and Geisha Williams, former president and CEO of PG&E Corp., the organization announced in August.

Formed in 2010 by Bill Gates and John Doerr, the council comprises prominent American executives and thought leaders working to encourage technology innovation as a path to generate economic growth, security, and environmental sustainability. This group brings together innovators, labor and industry to advocate for the development and adoption of the next generation of technologies needed to meet climate goals.

"Advanced new energy technologies reduce emissions, cut costs, improve efficiency, and make our businesses more competitive," said Majumdar, founding director of the U.S. Department of Energy Advanced Research Projects Agency-Energy, (ARPA-E).

The council has increasingly focused on policies that support large-scale commercialization of proven effective technologies.

Role of natural gas and oil in decarbonization

In October 2019, the Natural Gas Initiative hosted its annual NGI Week, which focused on methane conversion and utilization, and the future of gas-fired electricity. Stanford faculty, as well as industry executives and scientists, shared the latest research and ideas about best practices and the road ahead. Specific topics included: the production of fuels and chemicals; thermo-, electro- and photo-chemical and biological approaches for its conversion; and utilization of natural gas as a feedstock for materials.

In February, Naomi Boness, NGI's managing director, discussed the role of natural gas for decarbonizing the world at the Baker Hughes annual meeting. "What's stopping us from getting there right now? It's really simple: we need a price on carbon," said Boness.

In July, Mark Zoback, NGI's director, professor of geophysics and chair of the Society of Petroleum Engineers (SPE) said that for carbon capture and storage to play a meaningful role in limiting global warming to 2 degrees Celsius, the world must inject about 4 billion tons of carbon dioxide underground annually. The oil and gas industry, said Zoback speaking in an SPE discussion on the industry's decarbonization challenge, is uniquely positioned to handle that undertaking and could start doing so fairly quickly.

PHOTO: BAKER HUGHES

Naomi Boness (left) of Stanford University and Richard Newell of Resources for the Future discuss the path to decarbonization at the Baker Hughes Annual Meeting 2020.

Meeting greater need for digital communication

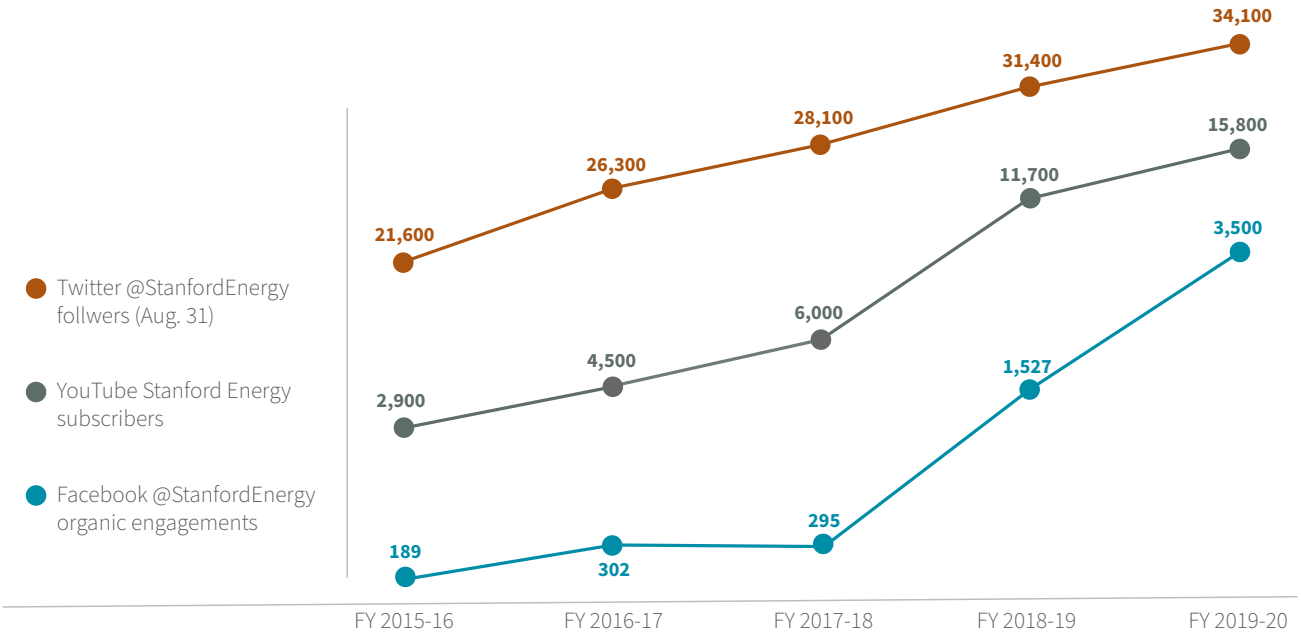
One of the Precourt Institute's primary goals since its founding has been to raise the visibility of all Stanford achievements in energy research and education, and help promote events. In 2020, as in-person communications came to a halt in March, the need to communicate digitally became paramount to maintaining relationships. This also provided the opportunity to expand engagement.

The Precourt Institute, through its Stanford Energy channels and in coordination with other Stanford communicators, worked to meet the greater communication needs of Stanford energy researchers and educators. The communications team helped promote two major new webinar series, Global Energy Dialogues and StorageX International Symposium, while producing news articles, enterprise features and publications about Stanford energy research and education. As always, it did so whether or not the institute was involved in the research, educational outcomes or events publicized.

Engagement across social media and in mainstream media rose, as shown in the chart below. Also, some 2,600 reporters viewed the Precourt Institute's press release on Zhenan Bao's and Yi Cui's new battery electrolyte via the press release platform of the American Association for the Advancement of Science (AAAS). The Global Energy Heroes prize release captured the interest of almost 1,800 AAAS reporters. Both Global Energy Dialogues and the StorageX Symposium Series garnered mainstream media coverage.

Follow Stanford Energy on Twitter, Facebook, LinkedIn and YouTube, and subscribe to Stanford Energy News.

SOCIAL MEDIA COVERAGE FY 2015 THROUGH FY 2020



FISCAL YEAR 2020-21: THE LOOK AHEAD

The current year holds much promise for progress on energy's dual challenge: mitigating emissions and their impact on the environment while meeting the growing demand for energy around the world. And, as the pandemic subsides and the global economy begins to recover, many of the lessons learned in 2020 will sharpen the world's resolve to meet with determination the greatest challenge of the 21st Century.

The Precourt Institute is positioned to contribute much to that progress this year and beyond. The Stanford Energy community, including the Precourt Institute's leadership, advisors and senior fellows, continue to play leading roles in planning the university's **new school focused on climate and sustainability**. We are excited that university leadership is concentrating research and education on urgent issues facing the planet. The institute's top priority is to ensure that our major objectives this year are aligned with the university's emerging plans.

The Precourt Institute and Stanford Woods Institute for the Environment will launch the **Stanford Carbon Removal Initiative** in 2021. The initiative will engage faculty across the campus and beyond to carry out the many types of research needed to capture, utilize and store carbon emissions – from CO_2 and methane – at the gigaton per year scale in a sustainable way. The university awarded the initiative seed funding to move forward. The faculty leadership and staff, working with potential sponsors, have been defining the scope of the initiative's research through a series of workshops and a Stanford course.

Also this year, Precourt leadership is exploring the potential for a new research **initiative on the use of artificial intelligence** to help meet the energy and climate challenge. The efficient use of big data will be instrumental in smartly executing the global energy transition. Stanford University, working with existing partners and large information technology companies, seems uniquely qualified to deliver benefits to humanity from such a large undertaking.

The **Global Energy Forum** will return in the second half of 2021 in a virtual format. We will monitor public health guidelines in the spring and summer in the hope of being able to add some in-person components. In any case, thought leaders from industry, academia, government and civic organizations will engage with each other and potentially thousands of people involved in the energy transition. Global Energy Forum 2021 will be productive and inspiring.

Simultaneously, the Precourt Institute's existing programs must and will continue to deliver results in energy research, education and engagement to address climate change and extend the benefits of sustainable, affordable and secure energy to all people.

This year is a potential inflection point in making the world a better place. Ultimately, historians will decide that, but let's see if we can tip the scales toward better.

PRECOURT INSTITUTE FOR ENERGY RESEARCH CENTERS AND PROGRAMS

Bits & Watts Initiative | bitsandwatts.stanford.edu
Bits & Watts develops innovations for the 21st century electric grid that are needed to incorporate large amounts of clean power and a growing number of distributed energy resources, while simultaneously enabling grid reliability, resilience, security and affordability.

Energy Modeling Forum | emf.stanford.edu
The Energy Modeling Forum improves the use of energy and environmental policy models for making important corporate and government decisions. EMF harnesses the collective capabilities of multiple models to improve the understanding of important energy and associated environmental problems. This helps explain the strengths and limitations of competing approaches to a given problem, providing guidance for future research efforts.

Explore Energy | energy.stanford.edu/explore-energy
Explore Energy is the one-stop resource for energy education at Stanford. The new program's mission is to increase energy literacy, experiential learning, mentoring and networking at Stanford. Explore Energy supports Precourt Institute-related courses. Its staff manages the institute's two internship programs and the annual bootcamp for new graduate students interested in energy.

Stanford Center for Carbon Storage | sccs.stanford.edu
The Stanford Center for Carbon Storage investigates questions related to enhanced recovery of oil and gas combined with CO_2 storage, mixed gas injection processes, the development of monitoring technologies for all classes of geological storage, the characterization of both near-well and distal geochemical processes during CO_2 injection, and computational optimization of large projects.

Stanford Energy Corporate Affiliates | seca.stanford.edu
The Stanford Energy Corporate Affiliates program promotes interaction between companies and Stanford's faculty and graduate students across the full range of energy-related topics. It is for corporate affiliates whose interests lie outside existing initiative topics, for example solar energy, hydrogen and sensors for energy applications. The Stanford Energy Corporate Affiliates program coordinates all of the industrial affiliate activities of the Precourt Institute.

Stanford Environmental & Energy Policy Analysis Center | seepac.stanford.edu
The Stanford Environmental & Energy Policy Analysis Center (SEEPAC) was established to develop practical and economically viable solutions to the pressing energy and environmental problems facing 21st Century societies. SEEPAC undertakes and disseminates research that can help decision makers shape environmental and energy policy.

Stanford Natural Gas Initiative | ngi.stanford.edu
The Natural Gas Initiative is an industrial affiliate program through which members support Stanford researchers in engineering, science, policy, geopolitical and business disciplines to advance the knowledge needed to use natural gas to its greatest social, economic and environmental benefit. NGI is a joint effort of Stanford's School of Earth, Energy & Environmental Sciences and the Precourt Institute.

Stanford StorageX Initiative | energy.stanford.edu/storagex-initiative
The Stanford StorageX Initiative will accelerate the development, translation and adoption of game-changing energy storage solutions. From materials science and computer science to economics and energy resources engineering, the interdisciplinary initiative is addressing gaps between academic and industrial R&D.

Strategic Energy Alliance | energy.stanford.edu/strategic-energy-alliance
The Strategic Energy Alliance matches large companies with Stanford faculty members who share common research objectives across the spectrum of energy topics. It does this for both sponsored research and donor-supported research.

Sustainable Finance Initiative | energy.stanford.edu/sustainable-finance-initiative
The Sustainable Finance Initiative works to scale-up and accelerate the flow of capital to decarbonize global systems by developing and promoting policies and financial mechanisms, educating leaders, and engaging with the global policy and finance community.

TomKat Center for Sustainable Energy | tomkat.stanford.edu
The TomKat Center harnesses the skills and creativity of Stanford's science, technology and policy experts to help make the world's energy systems more sustainable. The center funds graduate and postdoctoral fellows, as well as summer internships and fellowships. Its Innovation Transfer Program supports students and recent alumni in advancing technologies developed in their laboratories toward commercialization.

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