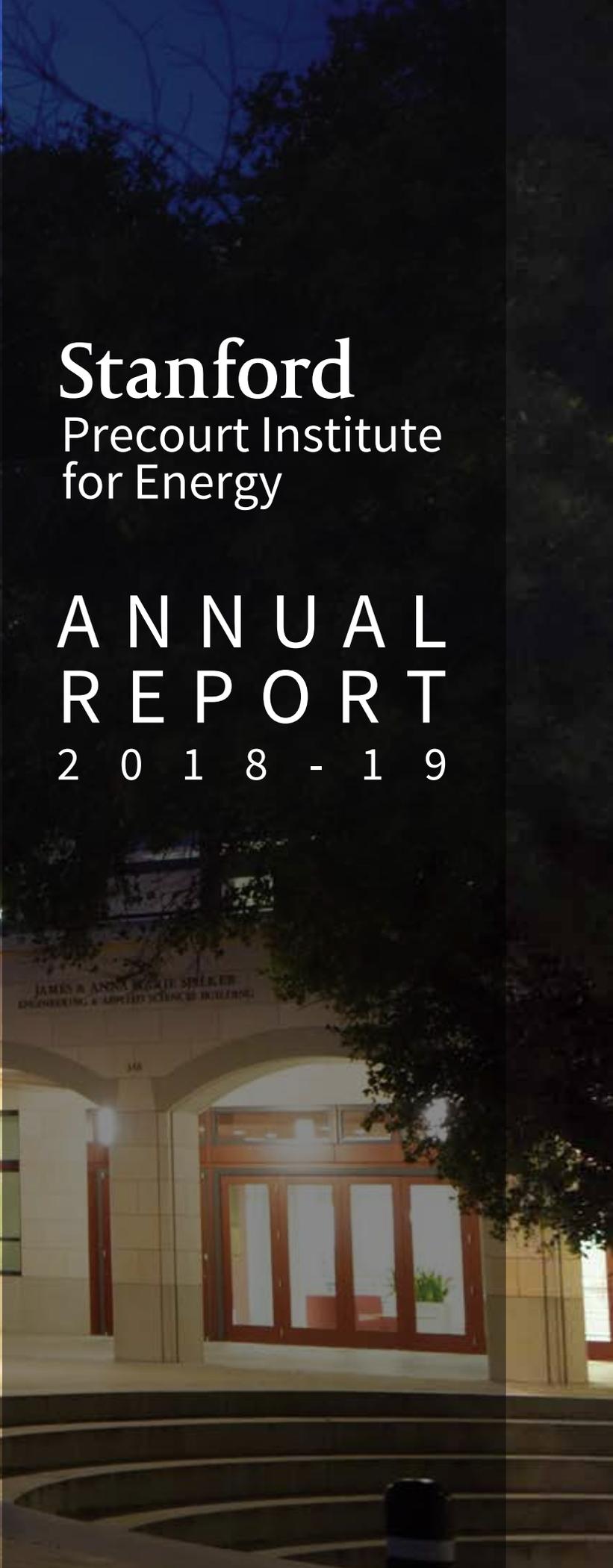




Stanford  
Precourt Institute  
for Energy

ANNUAL  
REPORT  
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JAMES W. ANSON BEGHE SPEAKER  
ENGINEERING & APPLIED SCIENCE BUILDING

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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](#)

[Global Climate & Energy Project](#)

[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](#)

REALIZING THE VISION of sustainable, affordable and secure energy for everyone will take decades of hard work from countless people around the world. To keep ourselves invigorated and committed, it is important to take stock occasionally of contributions within that large, shared mission.

In looking back over the 2018-19 fiscal year, we are filled with appreciation for the remarkable achievements of the faculty, students, post-doctoral fellows, staff, industrial collaborators and supporters, all of whom comprise the Precourt Institute for Energy and its Stanford-wide programs. We entered the year with these stated top objectives:

1. Launch the Sustainable Finance Initiative
2. Launch the Stanford StorageX Initiative
3. Strengthen existing initiatives and programs
4. Launch the Stanford Energy Global Council
5. Create a Stanford presence on carbon management
6. Establish a fully-funded, comprehensive student energy program

The following pages provide details on how the Precourt Institute was able to make significant progress on these goals. We launched the Sustainable Finance Initiative in October 2018 with the support of Bank of America. The StorageX Initiative started in the summer of 2019 with seven industrial affiliate members and two great faculty members agreeing to lead it.

Existing programs gained additional resources for research. Shell joined the Strategic Energy Alliance in August 2019 with a significant commitment to support research. The Bits & Watts Initiative and Stanford Energy Corporate Affiliates added new members, too.

The Global Energy Council held its first meeting – on the future of transportation – in August. This led to the release of the meeting’s key messages. A full report is due spring 2020.

We began to create a Stanford presence on carbon management with the integration of the Precourt Institute and the Stanford Center on Carbon Sequestration. Similarly, we started to develop the Explore Energy program, a revamped and cohesive energy education program for launch in the 2019-20 fiscal year, which we are very excited about. You can read more on both of these objectives and others for the current fiscal year on [page 19](#).

Beyond these big priorities, this report highlights some achievements from the year in research, education and external engagement. The education of future leaders is Stanford’s highest calling. The Precourt Institute is very much a part of this. Our courses include *Stanford Energy Seminar*, *Stanford Energy Ventures*, *Sophomore College* and *Smart Grid Seminar*. During the year, the Precourt Institute and its programs funded 83 internships and fellowships, mostly for undergraduates, as well as eight postdoctoral fellows.

We were also able to foster much productive engagement between Stanford and the global energy community. The highest profile of these engagements was our first Global Energy Forum, but smaller meetings, participating in conferences organized by others, interacting with industry, publicizing research results, publishing opinion pieces and advising policy makers are all part of the interactive whole.

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

With warm regards,



SALLY BENSON  
Co-director, Precourt Institute for Energy  
Professor, Energy Resources Engineering



ARUN MAJUMDAR  
Co-director, Precourt Institute for Energy  
Jay Precourt Professor, Mechanical Engineering





## 2018 – 2019 RESEARCH HIGHLIGHTS

The past fiscal year – September 1, 2018 through August 31, 2019 – produced a wide range of important research advances among Precourt Institute programs, from capturing energy in brackish waters to the impact of a U.S. carbon tax on households by income. Below are a few examples. (Studies highlighted in the [Stanford Energy Research: Year in Review 2018-19](#) are not included here.)

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### **Advance in hydrogen from water**

Solar water splitting using photoelectrochemical cells has long been considered a potential way to store renewable energy. Solar-driven production of hydrogen from water has been blocked by the fact that high quality and abundant photovoltaic materials, such as silicon, are not stable under the electrochemical conditions needed to split water. Moreover, many photoelectrochemical cell designs incur unacceptable losses in light absorption compared to solar cells.

In April 2019, a team led by Paul McIntyre, professor in Materials Science & Engineering, developed an integrated solar water splitting device using efficient silicon heterojunction photovoltaic cells that avoids such losses. Series-connected cells generated sufficient photovoltage for unassisted water splitting. The cells achieved stable water splitting with a record high solar-to-hydrogen efficiency for an integrated silicon photosynthesis device.

[This work](#) was funded in part through the Precourt Institute's Stanford Energy Corporate Affiliates program, (formerly known as Energy 3.0).

### **Cities can follow Stanford's energy makeover**

The multi-year Stanford Energy System Innovations project cut the campus's total greenhouse gas emissions 68 percent and is lowering the system's operating costs by \$425 million over 35 years. In May, a [new study](#) laid out how to increase those benefits at Stanford, as well as how other campuses and communities could adopt some of the innovations.

First, the authors found that the campus could maximize its purchases of electricity at times of day when the grid is flush with renewable power. By 2025 this protocol could reduce the university's carbon emissions from heating



**“Stanford isn’t just a university.  
It’s a living laboratory as well.”**

–Joseph Stagner, executive director  
of sustainability and energy management

and cooling an additional 40 percent. If broadly adopted, “carbon-aware scheduling” could help maintain the reliability of electricity grids increasingly dependent on intermittent renewables, while lowering customer costs and increasing climate benefits.

Sally Benson was the senior author. Doctoral candidate Jacques de Chalendar was the lead author. Peter Glynn,

professor of management science and engineering, was a co-author. Stanford University provided its energy data.

The work was funded by the Global Climate & Energy Project and a Bits & Watts graduate student fellowship.

### **Impacts of a U.S. carbon tax on households**

Would a carbon tax hurt America’s poor disproportionately to other income groups? Many earlier studies found that it would. A [new study](#) led by Lawrence Goulder, economics professor and director of the Stanford Environmental & Energy Policy Analysis Center, found that, on average, low-income households would not be disproportionately affected.

The relative impact on the poor depends on the relative strength of two contrasting effects. As indicated in earlier studies, the higher prices for goods and services due to a carbon tax would impact lower-income consumers more than the wealthy as a percentage of income. However, the new study reveals carbon-tax-induced changes in wage, capital and transfer incomes that would likely hit the wealthy disproportionately. The overall result: The study found that the impacts on incomes would be greater than the price impacts. Under a range of policy approaches, the effect of a carbon tax overall would be either progressive or close to proportional.

### **Sustainable Finance Initiative launches**

The global transition to low-carbon economies is transforming the investment landscape, especially in the energy, agriculture and transportation sectors. For the energy sector alone, global investment needs to triple from its current level to \$2.3 trillion annually through 2040 to limit global warming to less than 2 degrees Celsius, according to the International Energy Agency.

To help unlock the massive amount of capital needed, the Precourt Institute launched the Sustainable Finance Initiative in October 2018. The initiative works with public, private and development institutions to engage Stanford researchers in developing the finance and policy tools needed for the transition toward a decarbonized and climate-resilient global economy.

“Significant barriers block capital deployment at anywhere near the level needed, especially investments from economically developed countries in economically developing economies,” said Thomas Heller, the Sustainable Finance Initiative’s faculty director and professor emeritus at Stanford Law School.

Bank of America, a founding member of the Precourt Institute’s Strategic Energy Alliance, is funding the Sustainable Finance Initiative.

### Energy from mixing seawater and freshwater

Every cubic meter of freshwater that mixes with seawater produces about .65 kilowatt-hours of energy from the difference in salinity of the two types of water. That is enough to power an American house for half an hour.

Stanford researchers developed an affordable, durable technology that could harness and store the energy created wherever ocean water and freshwater mingle. The team's new battery is not the first technology to succeed in capturing what is known as "blue energy," but it is the first to use battery electrochemistry instead of pressure or membranes.

"Our battery is a major step toward practically capturing that energy without membranes, moving parts or energy input," said the research project's lead, former Stanford postdoctoral scholar Kristian Dubrawski, who worked in professor Craig Criddle's lab.

[This research](#) was funded in part by a 2017 Innovation Transfer Grant from the TomKat Center for Sustainable Energy.



### Artificial catalysts inspired by living enzymes

All living organisms depend on enzymes – molecules that speed up biochemical reactions that are essential for life. Scientists have spent decades trying to create artificial enzymes capable of cranking out important chemicals and fuels at an industrial scale with performance rivaling their natural counterparts.

A research team led by Matteo Cargnello, an assistant professor of chemical engineering, succeeded in doing so, according to [their study](#) published in August. Their discovery could lead to industrial catalysts capable of producing methanol using less energy and at a lower cost than current commercial processes. Methanol has a variety of applications, and demand for its use as a fuel with lower emissions than conventional gasoline is rising.

The team made their catalyst from nanocrystals of palladium embedded in layers of porous polymers tailored with special catalytic properties. Most protein enzymes found in nature also have trace metals, like zinc and iron, embedded in their core.

This project was funded by a Natural Gas Initiative seed grant in 2015.

### New discipline proposed: Macro-energy systems

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?

Research that seeks to answer such big-picture questions constitutes a new academic discipline – "macro-energy systems" – proposed by a group of researchers led by Sally Benson, management science professor John Weyant, and doctoral candidate Patricia Levi. The [new discipline](#) would address topics that account for a large portion of energy use, like the global car fleet; or cover vast geographical regions, like supply chains; or that cover decades, like energy investments. Formalizing this kind of research and education as macro-energy systems could produce a standard textbook, establish core methods and terminology, foster collaboration, and avoid redundant work.

After the August publication of the proposal, almost 200 researchers and other professionals contacted the authors to become involved in establishing the discipline. The Precourt Institute will host the first workshop in late winter or early spring 2020.

### New mobile technologies find methane leaks

On trucks, drones and airplanes, 10 promising technologies for finding natural gas leaks quickly and cheaply competed in the Mobile Monitoring Challenge, the [first independent assessment](#) of moving gas leak detectors at well sites. The organizers of the challenge – Stanford’s Natural Gas Initiative and the Environmental Defense Fund – did not declare a winner, because the participants focused on some different aspects of leak detection.

“The technologies are generally effective at detecting leaks, and can act as a first line of defense,” said Adam Brandt, an associate professor of energy resources engineering and the senior author of the study.

Despite accurate leak detection, most of the systems need to improve their ability to quantify the size of the leaks. For example, one startup’s drone-based system



impressively detected 100 percent of leaks and identified the leaking piece of equipment – rather than just the well pad – 84 percent of the time. When quantifying the size of leaks, though, this system’s estimates were close just 36 percent of the time. Quantification accuracy for the other study participants ranged from 18 to 53 percent.

### \$1.3 million for new energy research projects

The Precourt Institute, TomKat Center and Bits & Watts initiative awarded \$1.3 million to 11 new energy research projects on campus in the summer of 2019 for projects set to start in the fall. The research will explore multiple technologies and policies. Five of the project teams are interdisciplinary.

The competitively awarded seed grants enable researchers to pursue concepts very early in development, but with the potential to produce major benefits. The Precourt Institute and the TomKat Center have made such awards annually since 2010. Bits & Watts has done so since 2017. While the principal investigators must be Stanford faculty members, several teams this year include non-Stanford collaborators.

Topics of the new set of research projects include improving geothermal energy exploration, next-generation off-shore wind turbines, standardizing accounting of greenhouse gas emissions and environmental justice in transportation choices. One project, CarbonHouse, seeks to make buildings completely from carbon produced by heating – not combusting – natural gas.



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## NEW FACES



### Dionne and Kanan become TomKat co-directors

[Jennifer Dionne](#) and [Matthew Kanan](#) were announced in August as the new co-directors of the TomKat Center for Sustainable Energy. TomKat Center founding director Stacey Bent stepped down from her TomKat role to fulfill her new responsibilities as Stanford's vice provost for graduate education and postdoctoral affairs.

Dionne, an associate professor of materials science, develops methods to directly image and control dynamic nanoscale processes, such as optical energy conversion and storage. Kanan, associate professor of chemistry, develops new catalysts and chemical reactions for applications in renewable energy and utilization of captured carbon-dioxide.

"Matt and Jen are stars in energy research. It's been great to watch their research trajectories on campus over the past ten years," said Stanford's vice provost and dean of research, Kathryn Moler. "Now they will enthusiastically lead TomKat to create solutions for one of our most urgent challenges."



### Cui and Chueh named co-directors of the new Stanford StorageX Initiative

[Yi Cui](#) and [Will Chueh](#) agreed to take the helm of the new StorageX Initiative, which tackles the complex, interdisciplinary challenges in creating modern energy storage systems. The initiative funds research to prove new energy storage technologies and concepts. Working closely with industrial partners, the StorageX Initiative develops in-depth technical and commercial understanding of the emerging challenges in the sector.

Cui, a professor of materials science and of photon science, studies nanoscale phenomena and their applications broadly defined. Chueh, an associate professor of materials science, leads a group of more than thirty researchers tackling the challenge of decarbonizing various energy transformation pathways. Both are senior fellows of the Precourt Institute.



### Heller and Seiger picked to lead the Sustainable Finance Initiative

Emeritus law professor [Thomas Heller](#) became the faculty director of the Sustainable Finance Initiative at its launch in October 2018, and [Alicia Seiger](#) became its managing director. Heller has focused his research on the rule of law, international climate control, global energy use, and the interaction of government and nongovernmental organizations in establishing legal structures in the developing world. He is founder and chairman of the board of the Climate Policy Initiative, which works with governments, businesses and financial institutions around the world to drive growth while addressing climate risk.

Seiger has been designing and executing climate and energy strategies for businesses, foundations and investors since 2004. She headed business development at startup TerraPass, a pioneer of the U.S. carbon offset market. In 2018, New York Governor Andrew Cuomo appointed Seiger to the Decarbonization Advisory Panel for the \$209 billion New York State Common Retirement Fund. (See page 17.) She earned an MBA at Stanford.



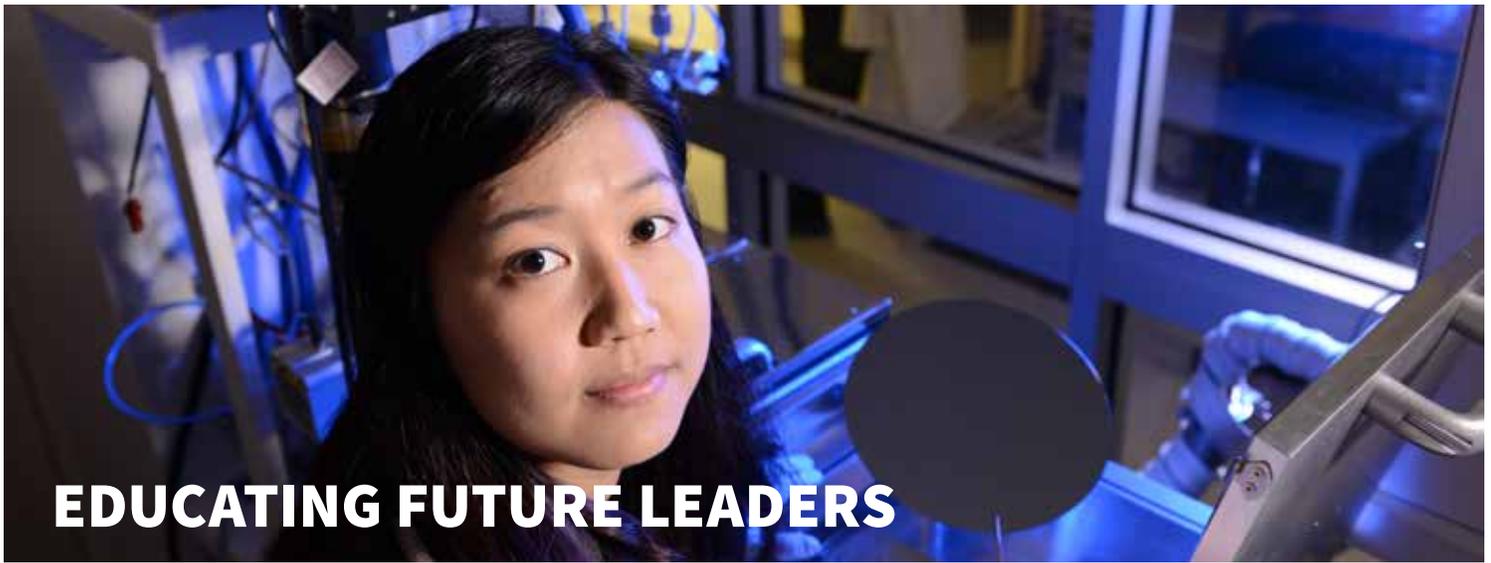
### Sarah Saltzer becomes managing director of SCCS

In May, [Sarah Saltzer](#) became the new managing director of the Stanford Center for Carbon Storage. Saltzer worked for 25 years at Chevron, where she held a series of scientific, managerial and executive roles in more than ten countries. She earned a PhD in geology from Stanford in 1992. Under the direction of professors Sally Benson, Mark Zobak and Anthony Kocscek, SCCS studies flow physics, monitoring, geochemistry, and simulation of the transport and fate of stored CO<sub>2</sub>.



### Liang Min named managing director, Bits & Watts Initiative

The Precourt Institute appointed [Liang Min](#) as the managing director of the Bits & Watts Initiative in June. Since 2011, Min had worked at the Lawrence Livermore National Laboratory, most recently as the associate program leader for the national lab's Cyber & Infrastructure Resilience program. He was also Livermore's founding group leader on energy delivery and utilization. Min earned a PhD in electrical engineering from Texas A&M University in 2007.



## EDUCATING FUTURE LEADERS

The Precourt Institute and its programs organize and fund courses, internships, postdoctoral programs, and orientation week for new graduate students interested in energy. They also are major sponsors of the student energy club. In the 2019-20 school year, the institute is launching a comprehensive education program, (see [page 19](#)).

### Stanford’s only energy entrepreneurship course

*Stanford Energy Ventures* is a unique Stanford course: It focuses completely on energy and climate entrepreneurship. Student teams envision, develop and create new clean energy ventures in the Precourt Institute class, (formerly *Energy Transformation Collaborative*). Each term, four teams of four to six students develop their projects as well as the skills that will enable them to become innovation leaders.

*Stanford Energy Ventures’* impact over the past three years:

- 30 projects have resulted in 16 startups
- \$33.2 million raised (\$27.9 private investment; \$5.3 in philanthropic awards)
- 85 employees
- Four countries: United States, Uganda, Kenya and India

One company started – Fervo Energy – is bringing the technology of the shale revolution to geothermal power for the first time. Another – Swift Solar – is developing

high efficiency tandem perovskite solar cells. Suryodaya is developing an affordable, solar drying system for agriculture products in India.

The donor-supported class is offered autumn, winter and spring terms, and teams can take the course for multiple terms. It is taught by Dave Danielson, managing director of Bill Gates’ Breakthrough Energy Ventures; Stuart Macmillan, chief scientist at the National Renewable Energy Laboratory; and Joel Moxley, founder of Foro Energy and Rho AI.



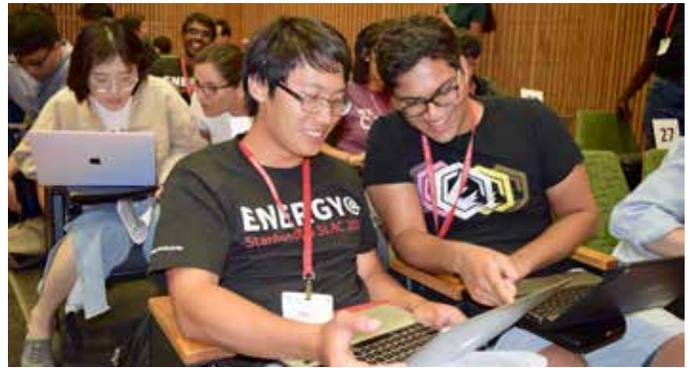
Joel Moxley (far left) with Stuart MacMillan (second from right) and Dave Danielson (far right) working with Stanford Energy Ventures students.

### Translating Stanford discoveries into products

The TomKat Center for Sustainable Energy’s Innovation Transfer [Program](#) assists Stanford students and recent alumni in advancing 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 funded projects with industry and finance mentors to provide hands-on entrepreneurship training as market opportunities are accessed and commercialization begins. The program helps participants develop a business-centric focus through Stanford resources, including the Stanford Entrepreneurship Network.

Since the grant program began in 2013, \$4.1 million in TomKat funding has been transformed into \$235 million in external, follow-on funding to date.



PhD candidates Taiyi Wang and Vivek Nath Lam, working on Energy@Stanford group activity.

### Energy bootcamp for new graduate students

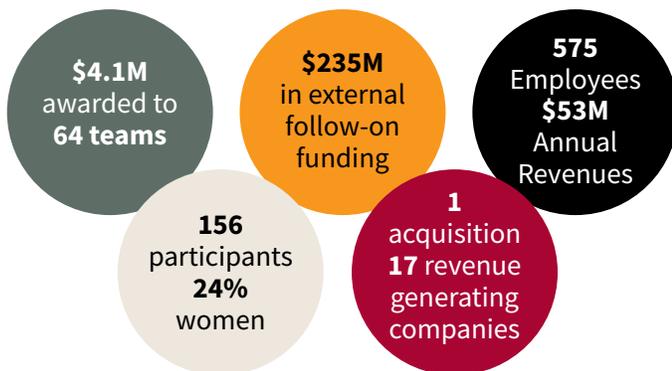
In September 2018 about 5 percent of all incoming graduate students began their Stanford careers in a week-long boot camp to learn about the breadth and depth of energy research at Stanford. [Energy@Stanford](#) & SLAC is one of 12 courses in the Vice Provost for Graduate Education’s Stanford Graduate Summer Institute and by far its largest.

New graduate students begin to grow networks of interdisciplinary peers, meet Stanford energy faculty and alumni, and experience a team challenge. Faculty speakers provide a broad overview of the state of play in their domain, describe their research and often meet new graduate students who become members in their labs. Some 125 students from 20 Stanford departments participated in the 2018 program, which is the norm since the program began in 2011. More than 35 Stanford energy faculty and industry experts spoke.

The week is sponsored by the Vice Provost for Graduate Education, the Precourt Institute, and the Stanford Institute for Materials & Energy Sciences.

### Stanford Energy Seminar in its 13th year

Every Monday during the fall, winter and spring terms, the Precourt Institute’s [Stanford Energy Seminar](#) amounts to a weekly convocation of the university’s energy community, including students, faculty, staff and all interested members of the public. Typically more than 100 people attend, but the seminar’s reach is much wider than that. The 22 posted videos on the Stanford



Energy YouTube channel from the 2018-19 academic year had been watched a total of almost 17,000 times as of this publication.

The past year's roster included John Deutch, MIT professor and former CIA director; David Keith, Harvard professor; Hal Harvey, chief executive of Energy Innovation; Clea Colster, consultant at Energy & Environmental Economics (E3); Charles Greene, Cornell professor; Sila Kiliccote, chief executive and founder of eIQ Mobility; and Douglas Kimmelman, founder of Energy Capital Partners. The seminar is offered as a for-credit course for Stanford students.

During the summer term, the *Energy Seminar* transforms to graduate students and postdoctoral scholars presenting their research results to a more intimate setting of peers. To help presenters develop public-speaking skills, a Stanford oral communication tutor coaches the students. At summer's end, a panel of Precourt senior staff choose several students to give a group *Energy Seminar* the following fall or winter term.

Chevron has sponsored the seminar during fall, winter and spring terms for 10 years. The Precourt Institute covers the cost of the summer seminar. The *Energy Seminar* was founded in 2007 by Stanford Woods Institute for the Environment.

### Summer internships in public service

Stanford undergraduate and graduate students interested in possibly pursuing a career in energy policy making – or who just want to learn how the sector is governed – can discover much about energy policy making in a summer. The [Stanford Energy Internships in California & the West](#) is a Precourt Institute program that offers paid summer work at a suite of energy agencies, like the California Public Utilities Commission and Western Interstate Energy Board.

The number of internships has grown from 10 in 2016, its first year, to 14 in 2019. But the demand for more is great. The number of students applying grew over the four years from 84 to 133. This summer, the program expanded to Utah with a position at the Western Electricity Coordinating Council, and also added an internship at the City of Palo Alto Public Utilities in memory of Karl Knapp.

Interns take a one-unit class on energy policy and governance in the U.S. West in the spring. Dian Grueneich, the program's founder and a Precourt energy scholar, this year produced a six-part, public video series explaining the responsibilities of the agencies involved and how they work together.

The internship program is funded by the Precourt Institute, Bill Lane Center and the Haas Center for Public Service's Stanford in Government program.



### True cost calculator for electric vehicles

By Gabriela Augustina Uribe, '21

As an intern at the California Air Resources Board this summer, I researched the total cost of ownership of zero-emission vehicles. First, I studied different models for figuring out lifetime costs of owning an electric car. Then, with the help of CARB staff members and other energy experts, I created a calculator designed for car buyers to determine how certain zero-emission vehicle models compare to conventional vehicles on total cost.

A major misconception in the public is that electric vehicles are much more expensive than conventional cars. In reality, they can save you money in the long run. With the calculator, consumers can tailor the estimate based on their specific details and see how much money they could save by driving an electric car. The board will improve the calculator and plans to post a version of it to their clean vehicle website so people can make well-informed, environmentally conscious car purchases.

## Solving national security issues with the Lean LaunchPad

The course *Hacking for Defense* is about mission-driven entrepreneurship. Instead of students learning and applying Steve Blank’s “Lean LaunchPad” to form startups, they apply the methods to solve societal challenges. Topics can be about defense or about national security more broadly—like energy or the environment—or anything for which student teams can find a government sponsor.

Projects in spring 2019 included: more effectively promoting innovative practices in the Veterans Health Administration; building rapport between U.S. and South Korean personnel in the Korean Demilitarized Zone; and curtailing the advantages of stealing cryptocurrency.

The course, administered through the Precourt Institute, also supports teaching faculty members and students at Stanford and other universities about the Hacking for Defense methodology to connect their research to solving challenges facing society. The Stanford course has spread to more than 30 other universities.

## Stanford Energy Club

More than 300 students, faculty and energy professionals attended [Stanford Energy Club](#)’s premier annual event – Stanford Energy Week – in January 2019. In one panel, senior executives from Facebook, Anadarko Petroleum,

Sunrun and the California Public Utilities Commission all advocated for a clean energy future. The week included student tours to Tesla and Chevron facilities, as well as workshops on design thinking and communication within energy.

In April, the Stanford Energy Club launched its first-ever hackathon: the Stanford Cleantech Challenge. In this 36-hour event, 20 student teams developed solutions to business and technology challenges posed by Google, Total, Silicon Valley Clean Energy and the Coalition for Renewable Natural Gas. Also, students published about two articles per month during the academic year in the club’s *Stanford Energy Journal*, and the group hosted its networking night and quarterly “Energy 360” seminars.

The Precourt Institute and TomKat Center are major financial supporters of the Stanford Energy Club.



*Stanford Energy Club’s Hackathon 2019 winners, (from left): Eric Trusiewicz, MBA ’19, Robbie Harding, ’MS ’19, Valerie Shen, MS/MBA ’19, Michael Levin, MS/JD ’19.*

“Everyone on our team cares about these issues deeply, so seeing how we could put our education and experience into practice was rewarding.”

–Michael V. Levin, JD/MS ’19  
Stanford Energy Club’s Cleantech Challenge 2019 participant



2019 Energy Impact Fellows in front of the California capitol building.

### TomKat fellowships, internships and postdocs

Since 2014, the TomKat Center has supported 150 primarily undergraduate students through its two summer programs, the Energy Impact Fellowships and the energyStartup Summer Internships.

The [Energy Impact Fellowships](#) program is operated by the TomKat Center in collaboration with the Haas Center for Public Service. This program gives Stanford undergraduates an opportunity to work on a sustainable energy project with significant social impact. Students spend eight weeks working as a team to define a multifaceted renewable energy generation blueprint. Students interact with mentors and experts in the technical, policy, societal and economic components of their projects. Through this research, they develop and provide informed recommendations to a variety of stakeholders. In 2019, for example, they studied the co-location of renewable energy generation resources with agriculture and presented their findings and recommendations to California State Senators in Sacramento.

The TomKat Center's [energyStartup internship program](#) provides Stanford students an opportunity to work on the cutting edge in startups that are advancing big ideas, such as converting a greenhouse gas into a marketable commodity, streamlining solar installations, reducing the cost of liquid sterilization, and making the transportation industry greener. The immersive 8- to 12-week internships are mostly located in the Bay Area, spanning from Redwood City offices to space in Lawrence Berkeley National Laboratory.

Placements include positions predominantly for undergraduate students, but with some positions available to master's students. Interest in the program has grown each year, with 37 energyStartup summer interns in 2019.

In addition, TomKat Center [Postdoctoral Fellowships](#) support outstanding recent PhD graduates working on projects that explore new research directions in sustainable energy and its intersection with food, water, the environment, or human health. The fellowships are intended to attract exceptional early-career researchers to Stanford University. Three to four postdocs are selected each year, fully funded to explore creative research for up to two years.

### Summer Undergraduate Program on Energy Research

[SUPER](#) pairs undergraduate students with faculty mentors for 10 weeks of paid energy-related research on campus. The interns also learn about the breadth of energy research across Stanford. The program inspires students to consider energy as a field of study and to prepare them to engage as leaders in the sector.

In 2019, SUPER was able to expand from 10 interns to 16. Under the direction of Sally Benson and Precourt postdoc Michael Machala, Daniella Grimberg found that rural electrification in India could profitably boost the country's rapidly expanding industrial production even further. Grimberg, a rising sophomore, was selected to present her work at the Clean Energy, Education & Empowerment (C3E) 2019 symposium.

SUPER is funded by the Office of the Vice Provost for Undergraduate Education, a Precourt Institute donor and the Office of the Dean of the School of Engineering.



PhD candidate Justin Luke presenting to Ram Rajagopal on his team's work on optimal charging of autonomous EV fleets in a high penetration PV solar distribution grid.

### Smart Grid Seminar

Many diverse issues need to be tackled if the electric grid is to be modernized using a holistic approach. Bits & Watts' monthly *Smart Grid Seminar* provides experts from startups, research institutes and large corporations to familiarize seminar participants with the challenges and advances in grid data analytics, economics, market design, battery storage, electrified transportation, power electronics, renewable energy integration, and system operations and resiliency.

More than 100 people attended a seminar on batteries with a Tesla senior engineer. Generally, participants wanted to learn about data utilization, solutions to real-world problems, and the evolution of new technologies. The top research subjects were batteries and electric vehicles – including their evolving market structure and operations.

**“Working at the Energy Commission has been an incredible experience that has shown me how exciting, engaging and impactful work in energy policy can be, and how big of a role local and state government must play in the fight against climate change.”**

–Kiki Annalise Velez, ERE '21  
SUPER intern, 2019

### Sophomore College: Energy in Hawaii

Due to a lack of conventional energy resources, Hawaii is at the forefront of technical changes in the electric grid and the uses of electricity. State law targets 100 percent fossil-free transportation by 2040 and carbon-free electricity by 2045. This summer, the Precourt Institute and the Bill Lane Center for the American West's sophomore college course was *Energy in Hawaii: Forefront of Clean Energy Technology and Policy*. Twelve rising second-year students were selected from 120 applicants. The immersive experience was led by Sally Benson and Terry Surles, a senior advisor at the California Institute for Energy & Environment who works extensively in Hawaii.

After a week of classroom learning on campus, the cohort spent two weeks in Hawaii, including trips to a wind farm, a utility-scale solar farm, an oil-fired power plant, a waste-to-energy facility and solar-powered hot water systems. Unparalleled exposure to Hawaii's energy industry included a visit with Governor David Ige.

Housing, food, textbooks, and all travel and activities were included in the class. Students paid a fee of \$750, though many received additional support to lower or eliminate the fee based on need. Sophomore College 2019 was subsidized by the Office of the Vice Provost for Undergraduate Education, the Bill Lane Center and the Precourt Institute.



Sophomore College students in Hawaii.

PHOTO: STEPHANIE BURBANK



PHOTO: DAWN HARMER

## ENGAGEMENT

The Precourt Institute and its programs engage the energy community around the world to help realize the vision of sustainable, affordable, secure energy for everyone. It convenes meetings, participates in events convened by others, communicates Stanford achievements in energy research and education, and translates Stanford solutions for real-world impact.

### **Global Energy Forum's remarkable debut**

With the help of energy programs across campus, the university administration and more than two dozen sponsors, the Precourt Institute organized the first Stanford [Global Energy Forum](#) in November 2018.

“This conference will become the standard by which all future Stanford conferences will be measured,” said former U.S. Secretary of Defense William Perry at the conclusion of two days.

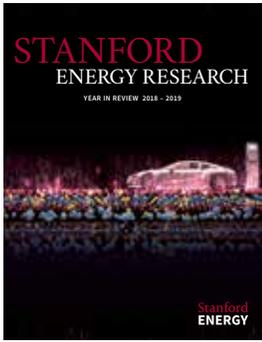
Perry co-hosted the sold-out event with fellow former U.S. cabinet members George Shultz, Condoleezza Rice and Steven Chu. Stanford President Marc Tessier-Lavigne opened the forum and spoke at the first day's dinner.

The forum featured 50 speakers from industry, government and research, including Bill Gates, U.S. Senator Lisa Murkowski, California Governor Jerry Brown, U.S. Deputy Director of National Intelligence Susan

Gordon, and the chief executives of Bank of America, Bloom Energy, Calpine, CMS Energy, Devon Energy, Engie and other companies. These speakers and many other thought leaders did not just speak at the Global Energy Forum. Most were present for much if not all of the two days, learning from other presenters and interacting with more than 500 attendees during breaks and meals.

The forum covered the breadth of energy topics from finance, climate science and security to data, fossil fuels and new technologies. During breaks, many participants enjoyed visiting with 33 innovation showcase companies and 75 students from across the United States. More than 15 news articles reported on various aspects of the event.

Perry said his personal test of whether a conference is worthwhile is whether he changes his thinking on any issue. “This conference,” he said, “actually changed my thinking on a few issues.”



### Stanford Energy communication channels flourish

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. The institute does this through our conferences, public

appearances, press releases, several Stanford Energy communication channels, a newsletter and our website, all of which promote results of Stanford accomplishments whether or not the Precourt Institute was involved.

During fiscal year 2018-19, growth in engagements on Facebook (@StanfordEnergy) and in subscriptions to the Stanford ENERGY YouTube channel was excellent. Media articles principally about Stanford energy research and followers on Twitter (@StanfordEnergy) made solid gains. Traffic at energy.stanford.edu was steady with 17,500 unique visits to the home page during the year.

The Precourt Institute for the first time produced *Stanford Energy Research Year in Review* with highlights from the academic year, and a directory of faculty and staff energy researchers across campus. The online version includes links to studies highlighted and Google scholar pages for researchers.

### Huge investment needed to fix energy’s pollution problem

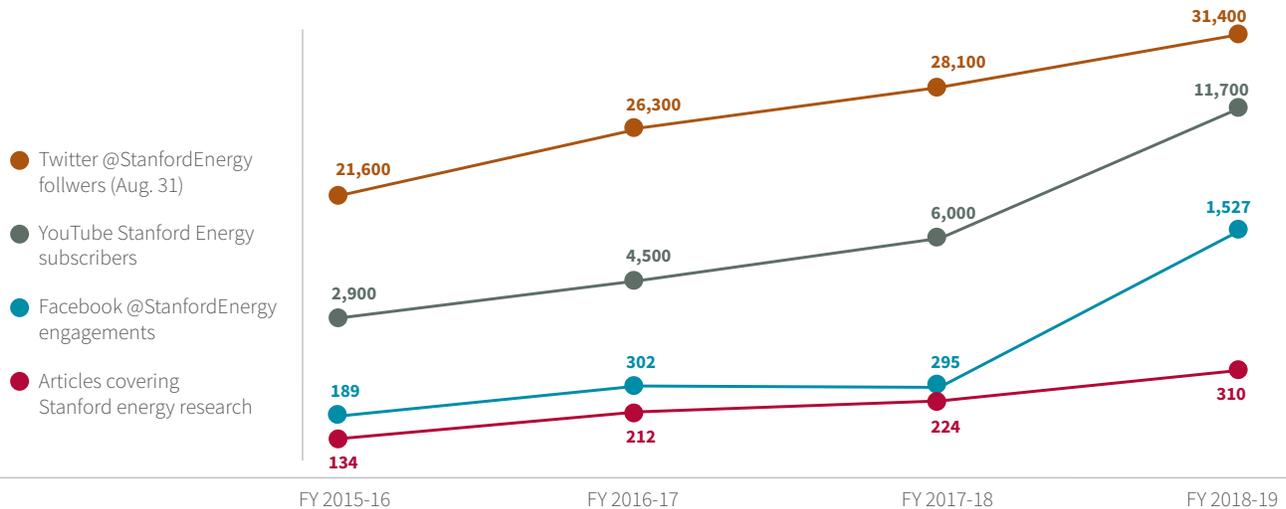
Three major trends are disrupting the \$10-trillion a year global energy sector, Arun Majumdar wrote in a December 2018 [opinion piece](#) in the *Financial Times*. These are: an expanding natural gas supply from fracking shale formations, electrifying transportation, and generating carbon-free electricity from wind and solar.

While all three trends can reduce greenhouse gas emissions, Majumdar wrote, 80 percent of global energy still derives from fossil fuels. Consequently, more investment is needed for research and development to create and scale affordable low-carbon solutions.

These could include cheaper electricity storage; small, cost-effective modular nuclear reactors; cooling systems that do not cause global warming; cost-competitive zero net energy buildings; advances in agriculture and industrial production; and capturing carbon dioxide to either sequester it or use it in plastics or fuel production. Furthermore, a fee on carbon emissions could prompt companies to invest in low-carbon technologies.

Majumdar called on world business leaders and the heads of the G20 largest economies to seize this opportunity for responsible growth: “Time is running out.”

SOCIAL MEDIA AND MEDIA COVERAGE FY 2016 THROUGH FY 2019





Sally Benson speaking at Accelerating Climate Solutions conference.

### Another way companies can fight climate change

The world is not yet ready to rely solely on renewable energy, Sally Benson wrote in a [CNN Business perspective](#) in April, but companies have other opportunities to combat climate change now.

While renewable energy innovations are important for reducing future emissions, energy leaders and experts have not yet figured out how to reduce emissions significantly within our existing carbon-based energy system. Until they do, making it cheaper for businesses to invest in carbon capture and storage is the best way to immediately reduce fossil fuel emissions.

To have a real impact, we need to implement carbon capture at a much larger scale and on a much shorter timeline than we are now. In a best-case, cost-optimal scenario, carbon capture and storage could eventually reduce global emissions by 14 percent, which could help to keep warming at 2°C, according to a 2017 International Energy Agency report.

### California's 2050 climate goals look very challenging

California will need to change all sectors of its economy extensively to reach its ambitious climate goals, but the right portfolio of technologies can help the state meet them – at least in the near term – according to a report by [Energy Futures Initiative](#), a non-profit led by former Secretary of Energy Ernest Moniz.

Meeting the state's 2050 goals will be “extremely challenging,” according to the report, which was released at an event hosted by the Natural Gas Initiative and the Precourt Institute in April. Moniz and panelists from Stanford and elsewhere discussed how investments and innovation might get the state on track to meet its mid-century goals through changes in industry, transportation, electricity and agriculture.

“This is not a policy document,” said Moniz, emeritus professor of physics at MIT and Stanford alumnus, PhD '72. “It takes the existing California policies and asks what the technology pathways that might address those are, and what are the prospects of actually reaching the objectives.”

State law requires a 40 percent economy-wide reduction in greenhouse gas emissions from the state's 1990 level by 2030. The 2050 goals target an 80 percent cut in emissions and a carbon-free electricity system.

**“Carbon capture isn't a moonshot solution, nor is it a silver bullet for decarbonization. It's a roll-up-your-sleeves solution. It can create new jobs, new clean energy products and protect public health.”**

– Sally Benson  
CNN Business

## Majumdar testifies to Congress twice on energy R&D

The Senate Committee on Energy & Natural Resources examined opportunities for energy innovation to address global climate change in April. A diverse set of experts, including Arun Majumdar, [told the committee](#) that to address climate change the federal government should play a bigger role in both energy policy innovation, and energy research and development.

Majumdar told committee members that research targets should include: large-scale energy storage at one-tenth of the cost of today’s lithium-ion batteries; small modular nuclear reactors at half the construction cost of today’s reactors; using renewable electricity to produce hydrogen from water instead of natural gas; affordably capturing carbon dioxide for making useful products; as well as innovations for low-carbon construction and agriculture.

In February, [Majumdar and others advocated](#) tripling the budget of the Department of Energy’s Advanced Research Projects Agency Energy to \$1 billion. Also, they told the House Committee on Science, Technology & Space’s Subcommittee on Energy, Congress could increase both the budgets and the effectiveness of the DOE’s five applied energy offices and its Basic Energy Sciences program. Majumdar was the founding director of ARPA-E.



Arun Majumdar testifying at the U.S. Senate Committee on Energy & Natural Resources.



Thomas Jaramillo at CERA Week 2019.

PHOTO: MAIYNE LYNN

## Stanford at one of energy’s biggest conferences

A major advance of late in the Precourt Institute’s efforts to elevate the visibility of Stanford’s energy research and education is its role as a partner organization of CERAWeek, one of the world’s premier annual energy conferences.

“What’s new at Stanford?” was the topic of a panel discussion in 2019. Prof. Thomas Jaramillo described his team’s work to produce fuels and chemicals sustainably. Prof. Michael Lepech described his efforts on behalf of NASA to develop micro-organisms that humans could take to the moon or Mars someday for use in making building materials from lunar and Martian soil. Prof. Arun Majumdar provided an overview of Stanford’s energy work. Each of the three speakers, as well as Prof. Simona Onori, also discussed their work in solo sessions at the March conference in Houston.

A day earlier, Prof. Sally Benson participated in a panel on carbon capture, use and storage in a large hall where every seat was taken. Interest in CCUS has risen, in part due to an increased U.S. corporate tax credit.

“CCUS is growing 5.5 percent a year, as it has since the 1990s,” Benson said. “The progress has been slow due to a lack of financial incentives. To meet our climate goals, we need to grow CCUS at 20 to 25 percent a year.”

In addition to the talks and private meetings, the Stanford professors were interviewed by *The New York Times*, *The Wall Street Journal*, Bloomberg News and other outlets.



C3E Lifetime Achievement Winner Elizabeth A. 'Betsy' Moler (center), receiving the award from Katie Jereza, DOE (left) and Kathryn Moler, Stanford University.

### Celebrating women champions of clean energy

In December 2018, the Precourt Institute hosted the annual Clean Energy Education & Empowerment (C3E) [symposium and awards](#). Kathryn Moler, physicist and Stanford's dean of research, presented the lifetime achievement award to her aunt, Elizabeth "Betsy" Moler, former chair of the Federal Energy Regulatory Commission.

Also, more than 360 women in business, policy making and research celebrated eight outstanding mid-career women who are advancing and implementing solutions that can transform energy infrastructure and reduce emissions. Industry leaders shared stories and experiences working in the clean energy industry, providing advice useful to young women just beginning their professional careers, as well as to other mid-career professionals. Past awardees shared what winning a C3E Award allowed them to accomplish, and how they have been able to inspire women and men in their own energy careers. Since 2011, four Stanford alumnae have received awards in the advocacy, entrepreneurship and international categories.

### \$20 million in free legal services for startups

In September 2018, the Global Climate Action Summit announced the launch of the Lawyers for a Sustainable Economy initiative. Thirteen major private U.S. law firms have committed to delivering \$20 million worth of free services by the end of 2020 to advance sustainability in energy, transportation and land use. The participating firms will offer pro bono legal services to US-based entrepreneurs and non-profits taking on key sustainability challenges.

Stanford Law School and the Precourt Institute for Energy are connecting potential pro bono clients with the participating firms, and will track the initiative's impact. Ali Zaidi, a Precourt energy scholar, spearheaded the initiative's creation. Zaidi also teaches the course *Engineering Energy Policy Change* with Prof. Paul McIntyre.

### Sustainable Finance Initiative's Seiger assists New York State on \$210B fund

In June, New York State Comptroller Thomas P. DiNapoli released a [Climate Action Plan](#) to protect and invest portfolio assets of the \$210 billion New York State Common Retirement Fund, with the goal of addressing climate risk. The Common Retirement Fund will develop investment standards for companies and major industries that face climate risks. Subject to fiduciary analysis, companies that fail to meet these standards may be divested.

The Climate Action Plan follows the recommendations made in April by the state's Decarbonization Advisory Panel, of which Stanford's Alicia Seiger was one of six members. Seiger is managing director of the Precourt Institute's Sustainable Finance Initiative.

**“The comptroller’s plan is a road map for aligning large investment portfolios with climate risk and opportunity, and it reflects the kind of translational research the Sustainable Finance Initiative develops and promotes.”**

– Alicia Seiger  
on New York State’s Climate Action Plan

### Team for California high-speed rail wins SVES debate

California should continue to build its high-speed rail system despite soaring costs and lengthening delays, according to the audience at the [annual debate](#) of Stanford’s Silicon Valley Energy Summit in June.

At the debate’s end, 18 percent of the audience – in person and following live on YouTube – switched to being in favor of the proposition that the state should press ahead. In the other direction, 17 percent changed their position to “con.” The “pro” team won by a nose.

Other SVES 2019 highlights: Kate Gordon, director of Calif. Gov. Gavin Newsom’s Office of Planning & Research, revealed changes in climate and energy policy under the new administration; executives from HP, Facebook and VMWare broke down the latest innovations for achieving corporate clean energy goals; former U.S. Rep. Phil Sharp discussed federal politics and climate policy; four founders of cleantech startups delivered TED-style pitches.

The administrative home of SVES moved in 2019 to the Stanford Institute for Economic Policy Research (SIEPR). James Sweeney, professor of management science and engineering, and a SIEPR senior fellow, remains the chief organizer of SVES. The Precourt Institute was a major funder of the 2019 conference and aided marketing efforts.



*From left: Mary Curtiss of HP, Urvi Parekh of Facebook and Natasha Tuck of VMWare discuss corporate clean energy strategies at SVES 2019.*

### 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.

The group is becoming Stanford’s nucleus for hydrogen research and teaching. Based largely on the workshop, the Hydrogen Focus Group will publish a review paper in early 2020 on hydrogen’s potential and the gaps in human knowledge inhibiting that potential. More than ten faculty members are affiliated with the focus group, and a new seminar course sponsored by their departments will begin in winter term 2020.

### The Stanford Energy Global Council

The Precourt Institute created the new Stanford Energy [Global Council](#) to create a deep dialogue on the trends in technology, business, investments and policy, and their complex interplay that is shaping and likely to shape the energy landscape in different parts of the world. The council comprises heads of international energy institutions, energy thought leaders from across the world, and a senior executive from each company in Precourt’s Strategic Energy Alliance.

The council will meet annually to provide insights on energy technology, policy, markets, business strategy and finance to help shape the strategic direction for Stanford’s energy research and outreach, while helping to cultivate a robust global energy ecosystem of thought leadership. The council held its inaugural meeting on August 22 on the future of transportation. It plans to publish a global outlook on transportation in the spring of 2020.



## FISCAL YEAR 2019-20: THE LOOK AHEAD

Precourt Institute leadership, senior fellows and our development officer played leading roles in planning the university's major sustainability efforts – both in research and in the campus as a living lab – as part of Stanford's long-range plan. We will continue to participate in these efforts, and ensure the institute's major objectives for 2019-20 are aligned with the university's.

We will launch **Explore Energy**, a comprehensive student energy program, this year thanks largely to the vision and leadership of adjunct professor and Precourt advisory council member Jane Woodward, '83, MBA '87. We are delighted to have hired a managing director, Diana Gragg, MS '04, PhD '12, and a program manager, Avery McEvoy, MS '19, this fall. The program will serve as a one-stop shop for Stanford students to explore all things energy at the university. This includes Stanford's many energy courses, internships/fellowships, experiential learning opportunities, and academic and career mentoring.

In May, about 500 leaders from industry, academia, government and civic organizations will converge at our second **Global Energy Forum**. Hosted by George Shultz, William Perry, Condoleezza Rice and Steven Chu, the 2020 Forum will focus on the urgent, challenging issues facing global decarbonization and a rapid transformation of the global energy system. This year, we are excited to introduce the Global Energy Heroes prize. The prize focuses on young leaders (18-30 years old) who are introducing affordable, sustainable, scalable energy solutions that are significantly benefitting their local communities. Three top winners will win \$20K and a trip to the Global Energy Forum, where the winning videos will be shown and prizes will be presented.

The Precourt Institute will launch **Stanford Energy Publications** as a platform for outlook, perspective and working papers on the full range of energy topics. These papers will undergo scrutiny on par with peer-reviewed publications as a requirement of release. The first paper, likely to be published in winter 2020, will be a perspective on the potential for hydrogen to contribute to decarbonization of our energy systems. The second, slated for spring 2020, will be on the future of transportation globally produced by the Stanford Energy Global Council.

The Precourt Institute is defining the scope of a new **Stanford Carbon Initiative** in 2019-20. The goal of the initiative is to bring together faculty and industry partners with an interest in carbon management to address climate change and sustainability of our energy system. The initiative will engage faculty from across campus involved in science and technology, policy, finance, and social acceptance in analyzing carbon mitigation pathways. The initiative will forge collaborations and partnerships in key areas including systems modeling of the global carbon balance, life cycle analysis of carbon mitigation pathways and tools to assess carbon mitigation options.

Finally, we will continue to strengthen existing initiatives and programs. A top priority here will be further defining the operation of the StorageX Initiative in its support of energy storage research at Stanford. Similarly, we are developing the competitively-based research program funded by pooled contributions from members of the Strategic Energy Alliance.

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# PRECOURT INSTITUTE FOR ENERGY RESEARCH CENTERS AND PROGRAMS

## [Bits & Watts Initiative](#)

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.

## [Global Climate & Energy Project](#)

Stanford's Global Climate & Energy Project was a unique \$200-million sponsored research program in which its leadership chose energy research projects for funding in a competitive process. GCEP funded research at other universities and research institutes, not only at Stanford. GCEP completed its operations at the end of the 2018-19 fiscal year.

## [Stanford Center for Carbon Storage](#)

The Stanford Center for Carbon Storage investigates questions related to enhanced recovery of oil and gas combined with CO<sub>2</sub> 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<sub>2</sub> injection, and computational optimization of large projects.

## [Stanford Energy Corporate Affiliates](#)

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](#)

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](#)

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

## [Stanford StorageX Initiative](#)

The new 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](#)

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](#)

The Sustainable Finance Initiative works to scale-up and accelerate the flow of capital toward the decarbonization of global systems by developing and promoting innovative policies and financial mechanisms, educating leaders, and engaging with the global policy and finance community.

## [TomKat Center for Sustainable Energy](#)

The TomKat Center harnesses the skills and creativity of Stanford's leading science, technology and policy experts to transform the world's energy systems for a sustainable future. In addition to funding research, the TomKat Center supports postdoctoral fellows, summer internships and fellowships. Its Innovation Transfer Program helps students and recent alumni in advancing technologies developed in their laboratories toward commercialization.

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