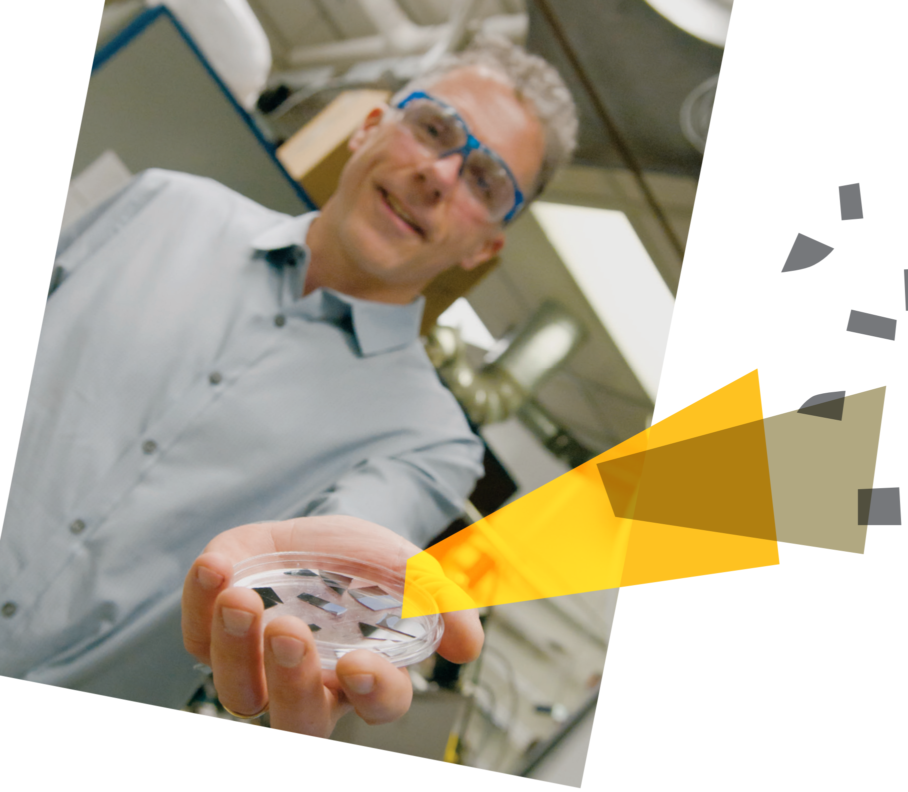


Pictured: Harry Atwater

a CO_2 molecule encounters that catalyst, Jaramillo says, “the catalyst is ready to rip that thing apart into its constituent atoms and then re-form them into the molecule we want at the expense of the one that we dont.”

Tools of the Trade

Scott Cushing, an assistant professor of chemistry at Caltech, is a self-described gearhead. “I grew up in West Virginia working on cars,” he says. “I like working on mechanical systems. When I went to college, someone showed me a laser, and I fell in love. I’ve been working on laser-based instrumentation science ever since.”

As evidence, Cushing spent his postdoctoral years working on a tabletop version of a synchrotron before joining the Caltech faculty in 2018. Typically seen in the form of a giant particle-accelerating ring, a synchrotron is a tool that takes advantage of fast-moving electrons’ tendency to emit X-rays when they change direction. Cushing’s downsized version fires a powerful laser to force electrons to change directions and emit X-rays. The X-rays then tell researchers how the electrons carry voltage through the ultrathin layers of a device. This is crucial for solar fuels research, Cushing says. “Our big goal is to try to measure these reactions all the way from when a material first absorbs sunlight until the product, a solar fuel, is made.” Since artificial photosynthesis starts on a femtosecond timescale, or one-quadrillionth of a second, this pushes laser technology, and thus our ability to measure the electrons, right to its current frontiers.

The need for high-precision instruments including Gregoire’s high-throughput characterization systems and ultrafast optoelectronic characterization at LBNL is one of the many reasons JCAP is a collaboration of researchers from scientific institutions across the state, says Frances Houle of LBNL, who serves as JCAP’s deputy director for science and research integration. In addition to laboratory instruments, she says, the success of this research relies upon the large synchrotron rings at LBNL and SLAC.

Houle’s focus on bringing together the many parts of JCAP requires that she also focus on another challenge: taking the fruits of the collaboration into the “real world.” After all, when solar fuels are someday able to be manufactured on an industrial scale, they will not be made using simple test setups in a research laboratory. JCAP scientists are learning how to work at larger scales testing how their materials react under real operating conditions, which will include changes in light flux, temperature, and humidity. Gregoire’s materials “will ultimately need to be able to sit out in the desert and work for one to three decades,” he says.

“You just can’t make technological advances without having a very deep science platform to work from,” Houle says.

Carbon to Carbon

Tearing water or carbon dioxide into their constituent parts is only half the battle. Scientists then need to combine those parts to make a fuel, which brings a new set of chemical challenges.

Consider, Atwater says, the problem of cooking up a solar version of Jet A, the principal variety of jet fuel that commercial airliners burn. Jet fuel abounds in hydrocarbons, or compounds in which hydrogen is bound to long carbon chains; those bonds release ample energy when burned, which means that these compounds can store a huge amount of energy in a small volume. That is why a major JCAP focus is on synthesizing the building blocks of jet fuel. Using carbon dioxide, sunlight, and their own advances in chemistry, they could create a sustainable way to manufacture the kinds of fuel airplanes must burn.

“The airplane manufacturers are interested in this because they know there is just no way that they can electrify their fleets in any reasonable timeframe that is going to bend the curve for climate change,” Atwater says. “So if they’re going to make an impact on climate, it’s going to be through solar fuels.”

Those industry hopes depend in part on the work being done on the second floor of Jorgensen, where a team of researchers led by chemistry professors Jonas Peters and Theo Agapie (PhD ’07) experiments with new tactics to tackle the problem of creating multiple-carbon bonds. Typically, Agapie says, breaking down carbon dioxide leaves behind single-carbon compounds such as carbon monoxide and formic acid. To build multicarbon compounds, such as those found in gasoline and other chemicals of interest, requires additional steps, and those steps require the right kind of electrode, a conductor that carries electrical charge into nonmetallic materials like carbon dioxide.

Scientists have found that the charge carried by copper electrodes, when applied to a solution of carbon dioxide, can create the desired carbon-carbon bonds. The problem is, it cannot do so “selectively,” which is a chemist’s way of saying that along with the carbon-carbon bonds, the reaction creates a host of extraneous molecules as well. To address that problem, over the past several years Agapie and Peters’ team has pioneered a way to grow an organic film upon a copper electrode via electrolysis (the application of direct electrical current to drive chemical reactions); that electrode can then drive the conversion of CO_2 into products with two or three linked carbon atoms with very few undesired by-products.

What the Future Holds

In addition to leading JCAP, Atwater heads up one of four main initiatives within Caltech’s Resnick Sustainability Institute (RSI), an effort called Sunlight to Everything. It is an apt phrase, he says. The basic chemical processes and new materials discovered during this decade of JCAP efforts have laid the foundation for the next phase of solar fuels research, which will include more affordable materials and efforts to test prototypes under real-world conditions, giving industry new starting points for tomorrow’s sustainability solutions. Future research also will focus on seizing CO_2 from sources such as power-plant flue gas or capturing it from the atmosphere or seawater and using it for solar fuels reactions.

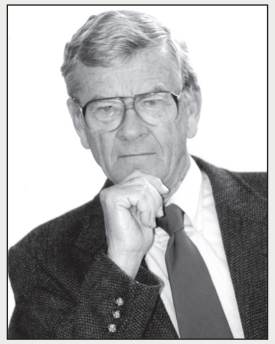
For solar fuels to be made at useful levels for society and industry, researchers must continue to find better photoactive materials, more efficient catalysts, and new ways to build fuels at the molecular level. That quest energizes Atwater. “I tell my students: when I started as a grad student, solar photovoltaics were in the same stage of development that solar fuels are today,” he says. “During my professional lifetime, I’ve seen solar photovoltaics grow from something that was done as a curiosity in research labs to a global industry that’s having an impact on the world’s energy transformation.”

Solar fuels hold the same promise. And as the JCAP team well knows, this kind of technological sea change begins with, and requires, basic research.

“We’re focused on the fundamental science, and we recognize that that fundamental science will have broad-reaching implications,” Jaramillo says. “The periodic table is our playground.”

In Memoriam

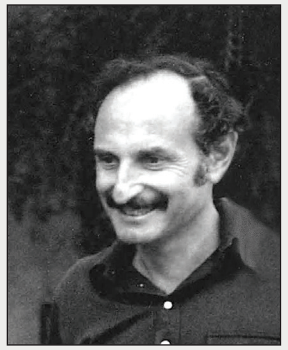
Read more about their lives at **magazine.caltech.edu/post/in-memoriam**



Allan Acosta

(BS ’45, MS ’49, PhD ’52), 1924–2020

Allan Acosta, Caltech’s Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering, Emeritus, who spent 50 years at Caltech and helped launch the Institute’s present-day mechanical engineering option, passed away on May 18, 2020. He was 95 years old. Acosta was a faculty member at the Institute in the Division of Engineering and Applied Science from 1954 until his retirement in 1993. He taught courses on fluid flow and heat transfer. His research group was a small collection of faculty with similar interests, including pioneering Caltech mechanical engineer Rolf Sabersky (BS ’42, MS ’43, PhD ’49), with whom he published the textbook *Fluid Flow: A First Course in Fluid Mechanics* in 1963. Acosta was recognized as an exceptional teacher and mentor, and was highly influential in shaping the education and training of many generations of students. He was an elected member of the National Academy of Engineering and a Fellow of the American Association for the Advancement of Science.



Louis Breger 1935–2020

Louis Breger, a professor of psychoanalytic studies, emeritus, at Caltech, and a psychotherapist who authored several books, passed away on June 29, 2020. He was 84 years old. Breger joined Caltech in 1970 and retired in 1994. His research centered on dreams, reformulations of psychoanalytic theory, psychotherapy process and outcome, personality development, and the application of psychoanalysis to literature. He authored numerous books, including two biographies of Sigmund Freud. His research on dreams used techniques to monitor people’s sleep throughout the night and showed that dreams are symbolic attempts to master emotional conflicts rather than wish fulfillments as Freud proposed.

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