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Catalyst

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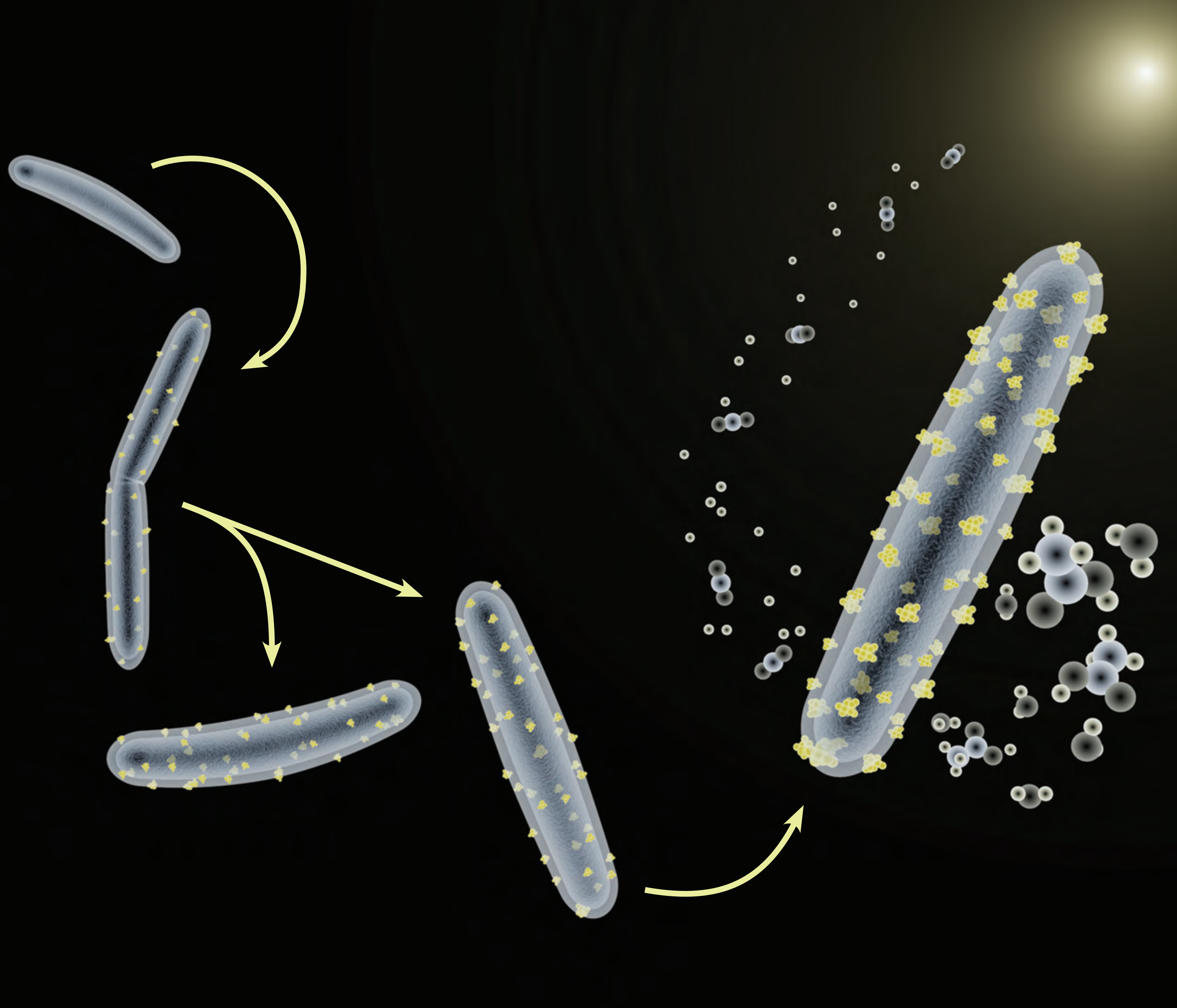

Artificial Photosynthesis

- 56 years of research, and counting
- Turning sunlight into fuel

Catalyst

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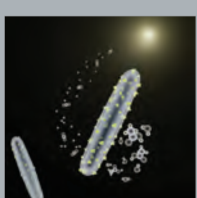

ON THE COVER

Moorella thermoacetica bacteria are shown developing cadmium sulfide nanoparticles on their cell membranes. These organisms use the nanoparticles as microscopic photovoltaic units to convert light to electrons, which in turn drive the production of acetic acid.
PHOTO: KELSEY SAKIMOTO

ALL TEXT BY MICHAEL BARNES UNLESS OTHERWISE NOTED.

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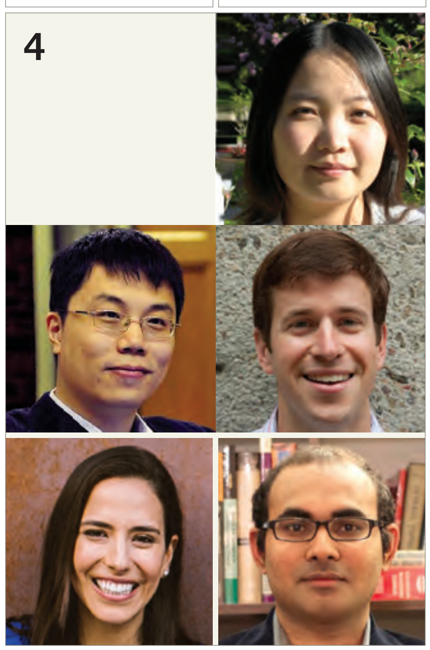

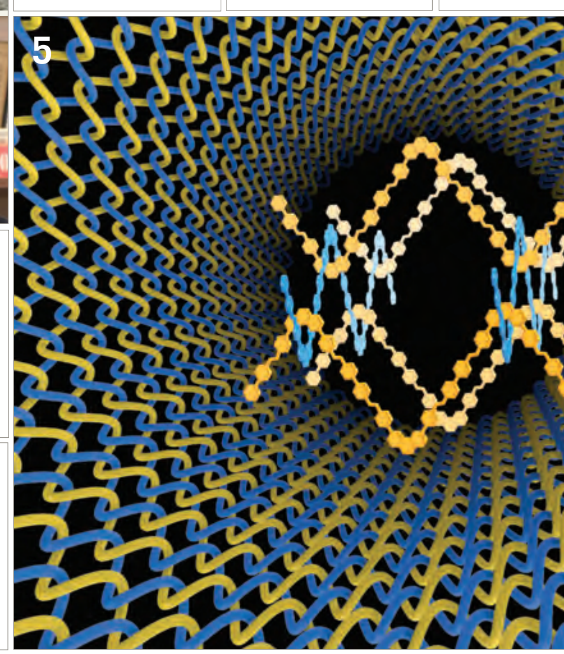

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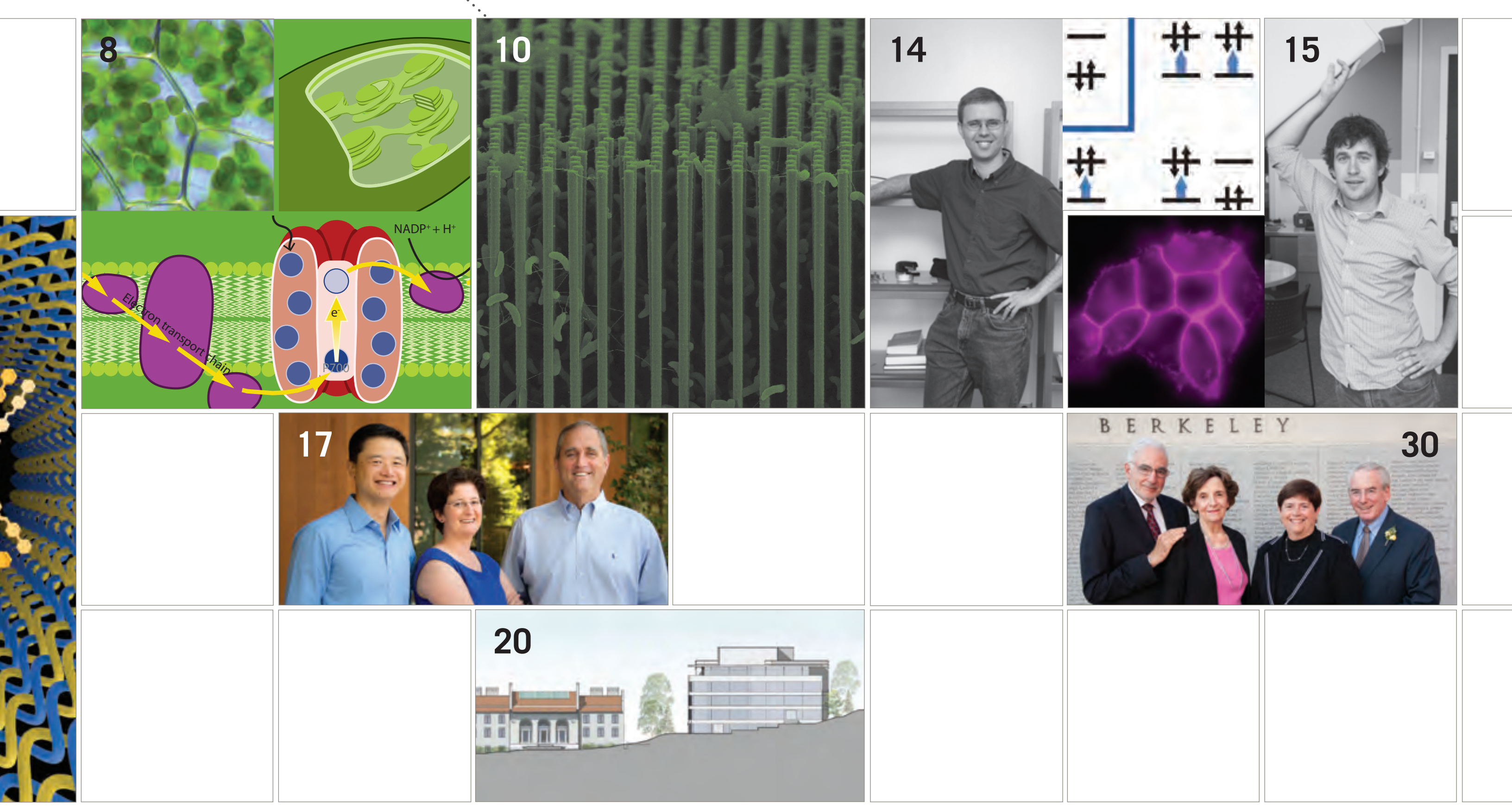


Reaffirming A Winning Formula

DOUGLAS S. CLARK
Dean, College of Chemistry
Gilbert N. Lewis Professor

In recent months, the College of Chemistry experienced an unforeseen development. In early February, Chancellor Nicholas Dirks announced the launch of a campus-wide strategic planning and analysis process*. This process, comprehensive in scope, included an academic realignment initiative designed to explore whether, given the reduction in State funding, the campus's current academic organization is best suited to support excellence in our research and education in future years. A primary motivation behind any restructuring and budgetary reform is to reinforce Berkeley's existing strengths and expand opportunities for multi-unit initiatives and academic collaborations.

As part of the analysis process, my colleagues and I began an active dialogue with campus. One of the options initially considered was a formal change in the status of the College of Chemistry, whereby the Department of Chemistry would move into the College of Letters & Sciences and the Department of Chemical & Biomolecular Engineering would join the College of Engineering.

The intrinsic merit of our College spans generations, and is evident from our historical achievements as well as our present strengths: our enrollment is at a peak, our academic and research programs are thriving, we are fundraising at record-breaking levels, and our global reputation for transcending boundaries remains unparalleled. Nevertheless, as news of the possible restructuring reached the College of Chemistry community, it generated considerable interest and concern.

The outpouring of support was truly remarkable. So many of you came forward in favor of the College's unique structure, emphasizing how important it is to our worldwide reputation, to the outstanding productivity of our renowned faculty and graduates, and to our strength as a fundraising and revenue-generating enterprise.

All's well that ends well, as we have reaffirmed that our current structure, which has been in place for nearly 150 years, still represents the best option for continued success. Thus, the College of Chemistry will remain intact as a single academic unit.

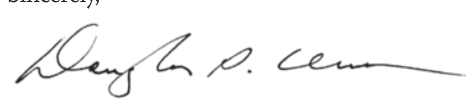
Not that we should not strive to be even better. Indeed, we welcome the opportunity to work with campus and other units to help devise creative ways for addressing Berkeley's structural deficit and exploit the multidisciplinary power of this great university. Our current plans include moving ahead with our visionary new building campaign (see pp. 20–21), and launching our innovative investment vehicle for philanthropic donors and financial investors, the Berkeley Catalyst Fund (see pp. 17–19).

I would like to take a moment to acknowledge some of the key players who contributed to this important process:

- Professor of Chemical & Biomolecular Engineering Alex Bell spearheaded a group letter from the College of Chemistry faculty;
- Alumnus Ron Silva, a member of the College's Advisory Board, crafted a group letter from a majority of our Board members;
- Alumnus, Professor Emeritus and Nobel Laureate Yuan T. Lee sent a letter of support, as did our five living Nobel Laureate alumni—Tom Cech, Robert Curl, Mario Molina, Kurt Wüthrich, and Ahmed Zewail;
- Professor of the Graduate School in Chemistry and National Medal of Science awardee Gabor Somorjai shepherded a letter from three other National Medalists in the College—professors Darleane Hoffman, Judith Klinman and John Prausnitz;
- prominent members of the campus community sent individual letters;
- alumni, colleagues and friends contributed numerous emails, letters and phone calls; and,
- perhaps most remarkably, chemistry undergraduate Jonathan Melville independently initiated a change.org petition** that garnered nearly 4,500 signatures and scores of heartfelt comments from students, parents, staff, alumni and friends across the nation, catalyzing articles in the international, national, state and local media***.

As dean, I am deeply grateful for the energy, devotion, and commitment shown by so many of you. Thank you. We took the important step of posing timely and difficult questions, while looking within and beyond the College, and worked together to determine the best outcome. I am tremendously proud to be the dean of this College as we head into the future, and I look forward to working with all of you to build upon its great foundation and secure its lasting excellence.

Sincerely,



*(see osi.berkeley.edu, search for "campus announcement")
**(see change.org, search for "college of chemistry")
***(see cen.acs.org, search for "college of chemistry")

(clockwise from top) **Students, faculty, staff, alums and friends gather to hear Dean Clark and other speakers convey the welcome news that the College will remain intact. Members of the Chris Chang lab enjoy the party. CoC undergrad Jonathan Melville toasts the College.**

NEW & NOTABLE

RESEARCH • VIEWS
DISCOVERIES • AWARDS

College of Chemistry alumni survey results

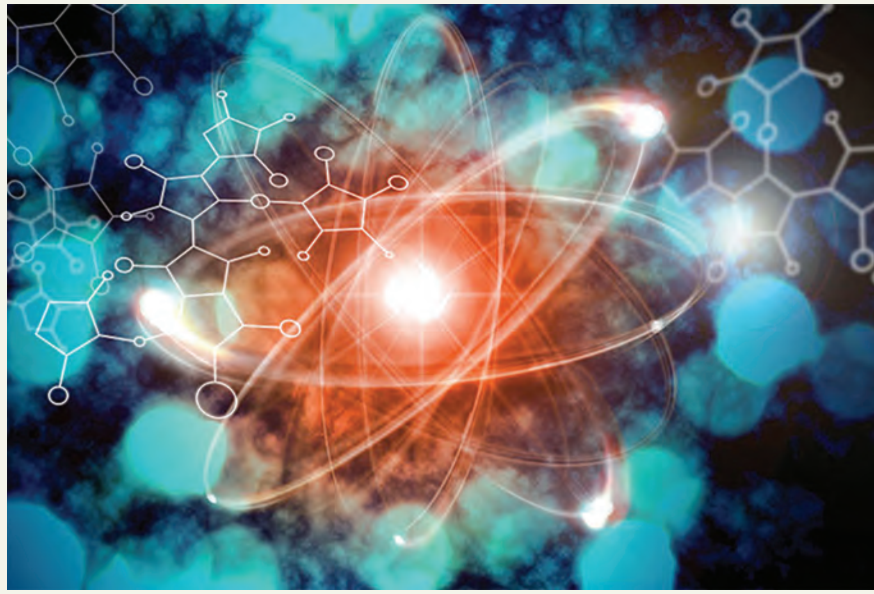
Many thanks to our alums who responded to the recent alumni survey. We were pleased to hear from so many of you. Here are a few highlights from the respondents:

48% are donors to the College of Chemistry.

76% have visited the college since they graduated.

83% read *Catalyst* magazine.

Suggested priorities for the college:
- Scholarships
- Sustainable chemistry
- Capital projects



Berkeley to lead nuclear security consortium

UC Berkeley is leading a new $25 million nuclear security and science consortium funded by the National Nuclear Security Administration (NNSA). The consortium members include eight universities and five national laboratories. The new consortium builds on the work of Berkeley's first $25 million NNSA consortium, funded in 2011. The late nuclear chemist Heino Nitsche (see p. 32) was one of the five faculty leads on the first project.

CHEMISTRY/LBNL

AWARD

Zhang

Miller

Xu

Three CoC researchers awarded Sloane Fellowships

CBE professor Wenjun Zhang and chemistry professors Evan Miller and Ke Xu have been awarded Alfred P. Sloane Foundation Research Fellowships.

The fellowships, awarded annually since 1955, recognize early-career scientists and scholars whose achievements and potential identify them as rising stars and members of the next generation of scientific leaders. Fellows receive $55,000 each to further their research.

CBE

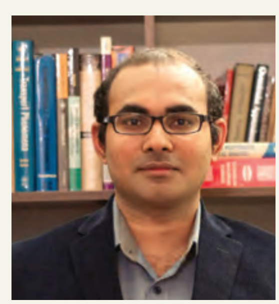
CBE welcomes two new professors

The Department of Chemical & Biomolecular Engineering welcomes its newest professors, Markita Landry and Kranthi Mandadapu.

Landry plans to explore the use of single-molecule techniques to expand the understanding of nanoscale biological interactions.

Mandadapu plans to focus his research on the thermal and mechanical behavior of polycrystalline materials and the dynamics and structure of biological membranes.

Landry



Mandadapu

CRISPR inventor calls for pause in editing heritable genes

A three-day international summit on the ethics of making permanent, hereditary changes in the human genome was held in December 2015, in Washington, DC. Berkeley professor Jennifer Doudna, the inventor of the CRISPR-Cas9 technology, organized a preliminary meeting in Napa, CA, and advocated for the follow-up meeting.

The conference, held at the National Academy of Sciences, was co-sponsored by the National Academy of Medicine and co-hosted with the Chinese Academy of Sciences and the UK's Royal Society. The summit brought together experts from around the world to discuss the scientific, ethical and governance issues associated with human gene-editing research.

CHEMISTRY

CHEMISTRY/LBNL

Alivisatos wins National Medal of Science

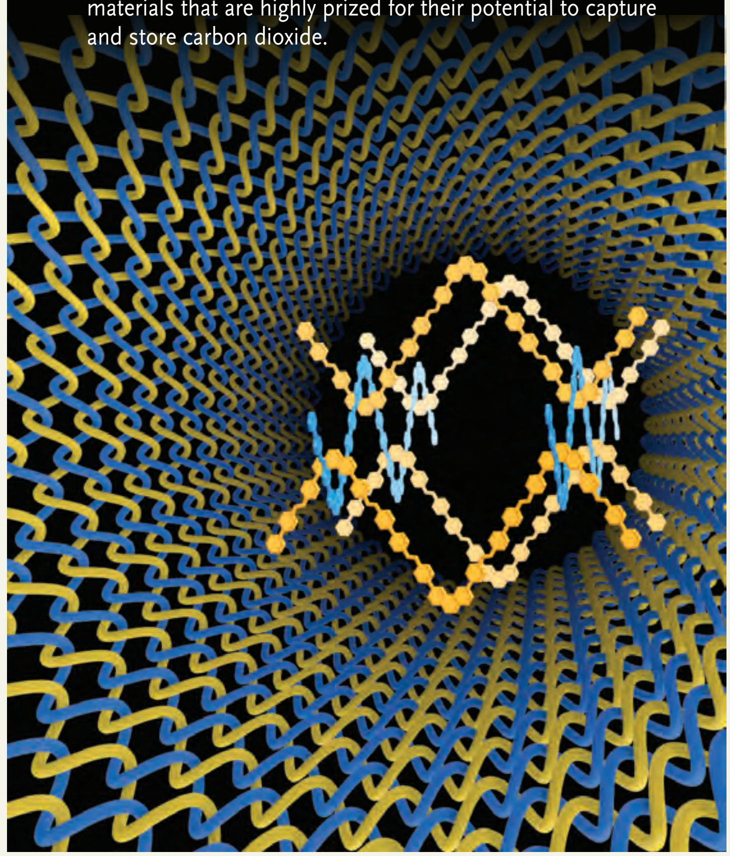
Paul Alivisatos, chemistry professor and newly appointed Berkeley vice chancellor for research, has been selected to receive the nation's top honor in science, the National Medal of Science. Alivisatos is among nine chosen to receive the medal. He is the former director of the Lawrence Berkeley National Laboratory. His successor as of March 2016 is physicist Michael Witherell of UC Santa Barbara.

CHEMISTRY/LBNL

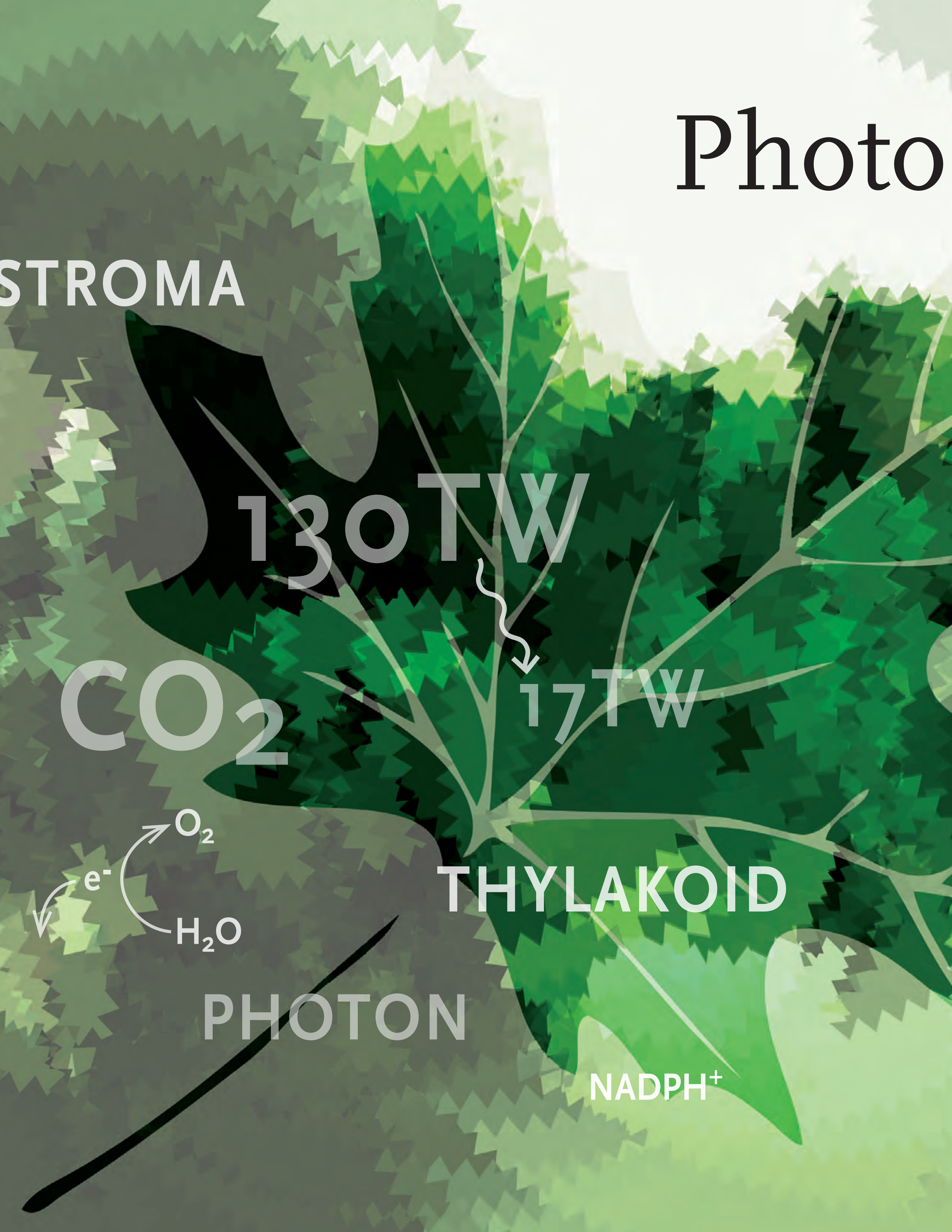
Yaghi weaves covalent organic frameworks

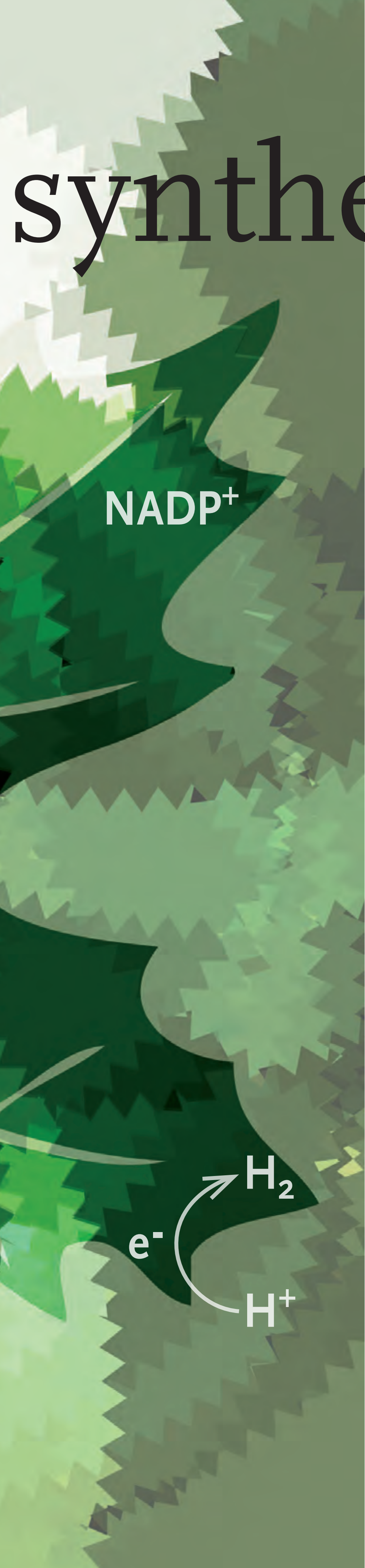
An international collaboration led by chemistry professor Omar Yaghi has woven the first three-dimensional covalent organic frameworks (COFs) from helical organic threads.

The woven COFs display significant advantages in structural flexibility, resiliency and reversibility over previous COFs—materials that are highly prized for their potential to capture and store carbon dioxide.



Photo





synthesis

IMPROVING ON NATURE

BY MICHAEL BARNES

The vast majority of the energy that humans consume comes from photosynthesis, which uses sunlight to turn carbon dioxide and water into simple carbohydrates. We eat the products of photosynthesis as food, and we burn the products of millions of years of photosynthesis as fossil fuels.

Although humans are beginning to have a dramatic effect on the Earth's biosphere, the average energy expenditure of humankind, 17 terawatts (17 trillion watts), is still dwarfed by the rate of energy produced via photosynthesis, about 130 terawatts. Yet by burning fossil fuels, we are pumping carbon dioxide into the Earth's atmosphere faster than plants, algae, cyanobacteria and other photosynthetic organisms can remove it.

As President Obama has noted, following the recent Paris climate talks and the record-breaking temperatures of 2015, global-warming skeptics are getting lonely. The question now is, what are we going to do about climate change?

The good news is that the solar energy reaching the Earth's surface averages about 100,000 terawatts, vastly more than either human use or the amount of energy produced via photosynthesis. The bad news is that we lack inexpensive, scalable ways to capture, store and transport that energy, especially in light of economic and population growth which may double energy use by the year 2050.

Here in the College of Chemistry, researchers are exploring artificial photosynthesis as a way to capture that energy. This issue of *Catalyst* features the work of chemistry professor Peidong Yang, who recently won a MacArthur Foundation "genius" fellowship. Yang sees his artificial photosynthesis breakthroughs as the culmination of years of research on nanowires and other nanoscale structures.

Even though photosynthesis has been studied in the college since the Nobel Prize-winning research of Melvin Calvin in the 1950s, it has not yet revealed all its secrets, some of which may be useful in solving the world's energy problems. Emeritus chemistry professor Ken Sauer has devoted his life to studying photosynthesis and, in the pages of *Catalyst,* he shares with us what he has learned—and what he still wants to know.

56 years of research, and counting

KEN SAUER

In 1960 Ken Sauer came to UC Berkeley as a postdoc in the lab of Melvin Calvin. One year after Sauer's arrival, Calvin received the 1961 Nobel Prize in Chemistry for his application of carbon-14 to his research on carbon dioxide assimilation in plants.

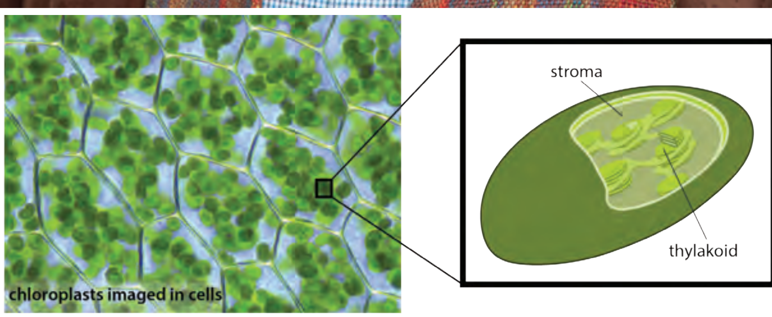
Sauer retired in 2001, 41 years and 240 papers later. He has continued to publish in retirement and, at age 84, remains active in the College of Chemistry and at LBNL. Sauer is the bridge between the current generation of photosynthesis researchers at UC Berkeley and the heyday of the Calvin research group.

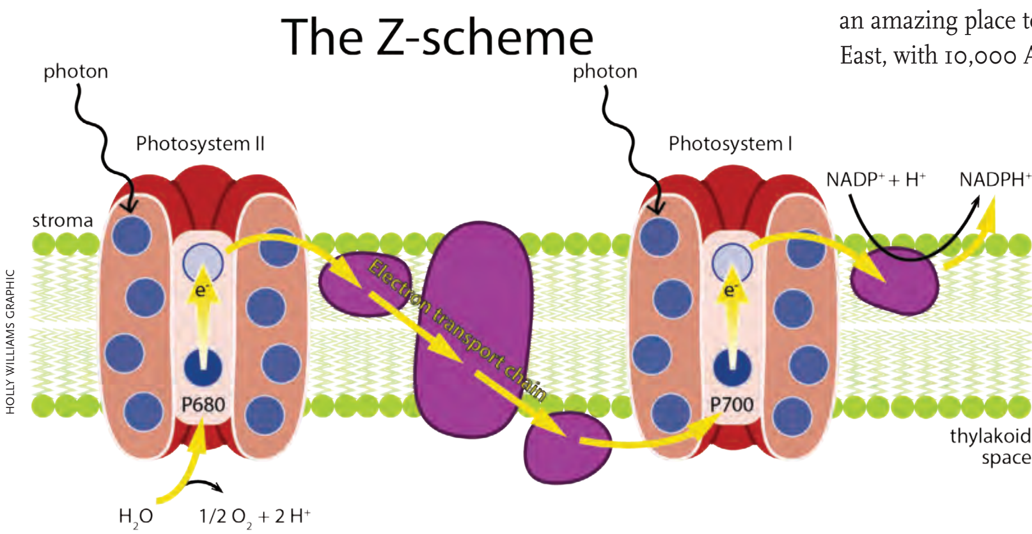
Sauer was born in Cleveland, OH, in 1931 and graduated from Oberlin College in 1953 with an A.B. in chemistry. That fall he moved to Cambridge, MA, to attend Harvard. His research mentor, George Kistiakowsky, had left Russia and immigrated to the United States in 1926.

Kistiakowsky was an explosives expert for the Manhattan Project in WWII. After the war he returned to the Harvard faculty and subsequently served as President Eisenhower's science adviser. His daughter, Vera Kistiakowsky, is a physicist who earned her Ph.D. at Berkeley in 1952.

Says Sauer, "At Harvard I made use of a technique called flash photolysis. During WWII powerful flashlamp sources were developed for military airborne photography, and many big capacitors became available as surplus items after the war. We used flash photolysis to study chemical dynamics initiated by brief, but intense, bursts of light, in much the same way as pulsed lasers are used today."

In 1957, the year before his Ph.D. was awarded, Sauer accepted a position teaching at the American University of Beirut, Lebanon. Says Sauer, "The founding of American University had occurred in 1860—even before that of UC Berkeley. In the late 1950s, Beirut was an amazing place to teach. It was the financial center of the Middle East, with 10,000 Americans living there.





- **Photosystems I and II are located near one another in a thylakoid membrane internal to the chloroplast—a green-colored organelle visible in the cells of plants and algae.**
- **PS II provides the water-splitting capability, which requires promoting four electrons using four absorbed photons to form and release O_2 from two water molecules and transferring four electrons to PS I.**
- **Following the absorption of more photons to provide the necessary energy, PS I is able to transfer electrons to ribulose bis-phosphate carboxylase (Rubisco), thereby reducing CO_2 ultimately to sugar and other carbohydrates. It was the accomplishment of unraveling the mechanism of this process that won the Nobel Prize for Calvin and his associates.**

"I met my wife Margie in Beirut while she was teaching in the American Community School. We met while singing, appropriately, in a performance of *Amahl and the Night Visitors*. We have continued to sing together in Bay Area choral groups to this day. From Beirut we travelled all over the region, often by motor scooter. Our oldest son, the first of our four boys, was born there.

"Although Lebanon was hard to leave, after three years I thought that it was time to return to the United States. Colleagues described Berkeley as the Beirut of the west coast of the U.S., so I applied and was offered a postdoctoral opportunity working with Melvin Calvin.

"By the time I arrived, most of Calvin's Nobel Prize-winning research had already been conducted. He had assembled a large group of grad students and postdocs during the 1950s to attempt to use carbon-14, which was first synthesized at LBNL in 1940, to understand the chemical pathways used by plants to conduct photosynthesis and assimilate carbon dioxide from the atmosphere."

Thousands of experiments were run—many making use of paper chromatography to separate and determine the identities of intermediates and products—before the nature of the carbon cycle in algae was revealed. The result was known as the Calvin cycle, although scientists often refer to it as the Calvin-Benson-Bassham cycle, in honor of Andrew Benson *(B.S. '39, Chem)* and James "Al" Bassham *(B.S. '45, Ph.D. '49, Chem)*, who co-discovered the cycle along with Calvin.

As a postdoc, Sauer co-authored his first article with Calvin in 1962. His early studies, carried out in collaboration with Roderic Park in Berkeley's botany department, involved pioneering research on the electro-optical spectroscopic properties of photosynthetic pigmented membranes from spinach chloroplasts.

In 1963 Sauer received an unsolicited offer to become a faculty member of the botany department. When Calvin got wind of this, he urged his colleagues to make a counter-offer of an assistant professorship in the chemistry department, which Sauer accepted. Comments Sauer, "The decision was actually easy to make. I knew very little about botany. I was trained as a physical chemist."

After his faculty appointment Sauer worked with Ignacio Tinoco and James Wang to initiate a course in physical chemistry for biology scientists—first designated Chem 109 and subsequently listed as Chem 130.

Sauer notes, "A Berkeley colleague, Bruce Mahan, had also been a student of Kistiakowsky, and for a time we both lived in the same group house at Harvard. It was Mahan who started the Chem 4 course at Berkeley, which became a model for similar courses at universities all across the country."

After the death of Mahan in 1982, Sauer inherited Chem 4 and continued teaching it until his retirement in 2001. He has served as an adviser or member of selection committees for the France-Berkeley Fund, the Study Abroad program and the Haas Scholars program.

By the time Sauer first came to Berkeley in 1960, photosynthesis was known to involve two light reactions, each acting in a chlorophyll-containing protein complex designated Photosystem I (PS I) and Photosystem II (PS II). The two photosystems, along with the electron transport chain that connects them, are known as the Z-scheme.

The Z-scheme was recognized conceptually at the time, but was not understood at the molecular level. During his three postdoctoral years in Calvin's chemical biodynamics research group, Sauer began to explore these photosynthetic light reactions, and he later spent most of his career exploring the mysteries of the Z-scheme.

For the last four decades Sauer has focused on a manganese-calcium-oxygen cluster, known as the oxygen-evolving complex, located in Photosystem II of plants, algae and cyanobacteria. He has developed sophisticated analytical devices to provide a more detailed picture of the nature of the components and their arrangement in the photosynthetic light reactions.

Sauer and his colleagues have been able to use advances in X-ray absorption spectrometry (XAS), a method that is particularly valuable for investigating the environment and involvement of metal atoms in biomolecules. Access to facilities like the Advanced Light Source at LBNL is invaluable to his research on studying metal centers in complicated redox-active metalloenzymes like PS II.

In the 1980s and 1990s Sauer teamed up with LBNL colleagues Melvin Klein and Vittal Yachandra in research that led to more than 20 papers. The threesome narrowed the range of possible structures and oxidation-state changes that were cycled in PS II to produce oxygen molecules and energetic electrons.

Klein died in 2000, and Sauer and Yachandra continued publishing with a younger colleague, Junko Yano, for another decade. The picture has steadily gotten clearer, but some significant details of the structure and function of PS II remain unresolved, and the research continues to this day.

Now 15 years into retirement, Sauer is taking a more macroscopic view of photosynthesis and how it may have evolved. The O_2-producing complex probably was functioning some time before the halfway point of Earth's 4.6-billion-year existence and has been largely conserved ever since.

"It's fascinating to me that there's been no significant change in more than 2.5 billion years," says Sauer. "Simple photosynthetic bacteria in the ocean and much more diverse land plants use essentially the same oxygen-evolving complex. How did it arise, and why has it continued essentially unchanged for so long?"

Sauer has studied manganese-oxide minerals using XAS and noted that many exhibit surface sites that are analogous to the photosynthetic water-oxidation complex. Says Sauer, "Primitive photosynthetic bacteria could have adapted the potentially active sites in the rocks to help oxidize water and use the bacterial genetically encoded proteins to surround and assemble this important photo-catalytic complex."

Ever curious, Sauer is excited about the dramatic increase in genomic information that is allowing researchers to trace the evolution of the huge variety of photosynthetic organisms during the last three billion years of life on Earth. He is happy to note the ongoing research of Graham Fleming, Naomi Ginsberg and David Savage in the college, along with that of other campus and LBNL researchers.

With continuing encouragement from Sauer, the Berkeley tradition of photosynthesis research is alive and well, and constantly evolving.

Turning sunlight into fuel

PEIDONG YANG

In September 2015, chemistry professor Peidong Yang was notified that he had won a prestigious MacArthur Fellows Program "genius" award.

Says Yang, "It was an amazing experience to win a MacArthur fellowship. I think it has to do with the nature of the award, which makes it very accessible to the public. The media interest has been almost overwhelming."

According to the foundation, the fellowships recognize "talented individuals who have shown extraordinary originality and dedication in their creative pursuits and a marked capacity for self-direction." Yang's research accomplishments in the months since the award are confirmation of the foundation's confidence in his scientific creativity.

Yang, 44, was born in Suzhou, China, near Shanghai. He attended the University of Science and Technology of China (USTC) in Hefei from 1988 to 1993, earning a B.A. in the university's five-year chemistry degree program.

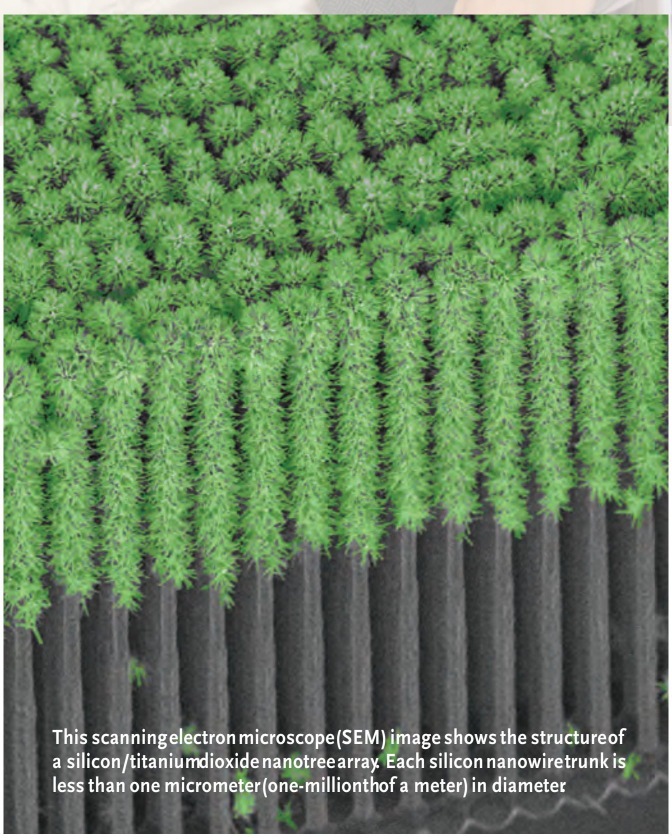
In 1993 Yang moved on to the research group of Charles Lieber at Harvard University, where he received his doctorate in 1997. Yang then came to California for a postdoc with Galen Stucky at UC Santa Barbara. There he studied nanostructures and high-surface-area silica. He joined the Berkeley faculty in 1999.

Since his arrival at Berkeley, Yang's research has blossomed, and he now oversees the country's leading research group in nanowire fabrication. These nanowires are long thin structures less than 100 nanometers in diameter, typically made of a semiconductor material. They have applications from fiber-optic communications and inexpensive solar cells to waste heat recovery and the production of carbon-neutral fuels.

For Yang, the MacArthur genius award is an affirmation of the importance of a task he set for himself 12 years ago—to create an artificial photosynthesis system using nanotechnology, catalysts and robust inorganic and physical chemistry.

Yang is seeking the direct conversion of sunlight to fuels, a process that stores the sun's energy in chemical bonds. This is known as artificial photosynthesis because it mimics the natural version, which allows plants to store solar energy as glucose and other simple carbohydrates.

Yang intends not only to mimic photosynthesis, but also to improve it. In order to grow, plants must take glucose and convert it to its polymer, cellulose. To assure growth even in the shade or on cloudy days, photosynthesis is optimized to work in low light levels, which wastes the majority of photons that fall upon the plants in bright sunlight.



This scanning electron microscope (SEM) image shows the structure of a silicon/titanium dioxide nanotree array. Each silicon nanowire trunk is less than one micrometer (one-millionth of a meter) in diameter.

Explains Yang, "Artificial photosynthesis devices would not have the same constraints that plants face. A robust synthetic system built with inorganic and biological components can be optimized to extract energy from all the photons that hit it. And because the system doesn't have to grow like a plant, it can use almost all the photons to make fuel and other chemicals."

Fortunately, planet Earth has photons to spare. The sunlit side of the Earth is constantly illuminated with more than 100,000 trillion watts of solar energy. If we could harness just a small part of that flow of energy, 17 trillion watts, we could meet the current demand of humankind.

While photovoltaic panels and windmills produce renewable energy without creating carbon dioxide, we still lack ways to reliably store their electrical energy for when the sun doesn't shine and the wind doesn't blow.

In addition, during the 20th century, humankind embarked on a building project of unprecedented scale—the infrastructure to produce, transport and burn liquid hydrocarbon fuels. It would be unwise to turn our backs on this infrastructure while at the same time attempting to meet the needs of our planet's growing population.

Artificial photosynthesis is the breakthrough that could bring the two pieces of the problem together—carbon-neutral "drop-in" fuels that could utilize existing infrastructure. But it is turning out to be a hard problem. "Evolution has had millions of years to perfect photosynthesis, while my lab has only been working on the problem for 10 to 12 years," Yang points out. "We've made great progress, but we have a long way to go."

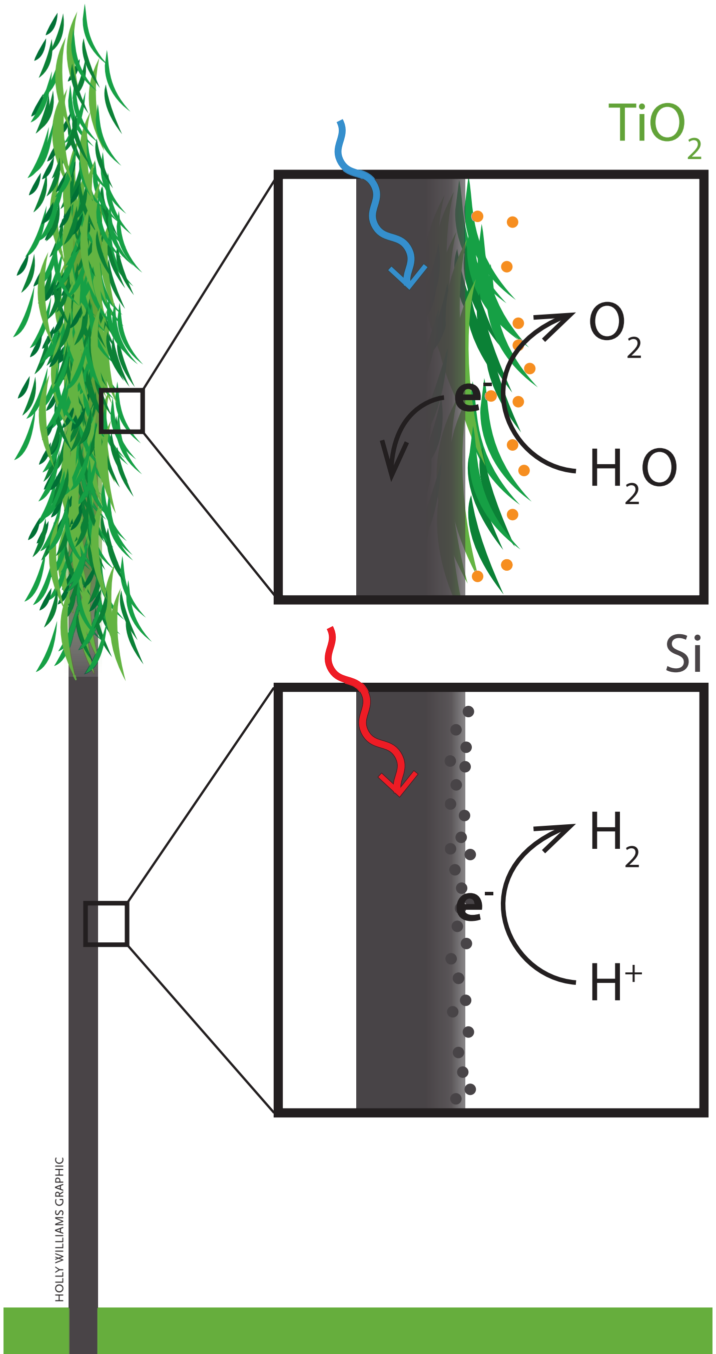
That goal moved much closer to reality in 2013 when the Yang lab constructed an integrated nanowire device to split water into hydrogen and oxygen. In Yang's device, water splitting is done by a forest of silicon nanowire "tree trunks" with smaller nanowire titanium dioxide "branches." The branches and trunks are coated with nanoparticle catalysts that make the reactions run more efficiently (see illustration).

Says Yang, "The efficiency of the system is still low, less than one percent, about the same as natural photosynthesis. But the beauty of this system is that we can test different semiconductor components and we can change the architecture of the system by varying the structure of the nanowires.

"However," Yang adds, "water splitting is only half of the story in photosynthesis. The other half is carbon dioxide reduction, which breaks the carbon-oxygen double bonds and frees the carbon atoms to be used to produce simple compounds like sugar and fuels. Finding an efficient and selective catalyst for CO_2 reduction is one of the biggest challenges in artificial photosynthesis."

CO_2 reduction is a tough problem for natural photosynthesis, too. Plants rely on a slow, nonselective enzyme known as Rubisco. Yang has sought a robust, selective, fast-acting inorganic analogue for Rubisco, and in 2014 his lab made an important first step.

In that year, the Yang lab created a new system for building nanoparticles that allowed researchers to hunt more effectively for the illusive CO_2 reduction catalyst. Explains Yang, "We don't really have enough fundamental understanding to design an outstanding



HOLLY WILLIAMS GRAPHIC

The Yang lab has constructed an integrated nanowire device that splits water into hydrogen and oxygen. Water splitting is done by a forest of silicon nanowire "tree trunks" with smaller nanowire titanium dioxide "branches." The branches and trunks are coated with nanoparticle catalysts that make the reactions run more efficiently.

When immersed in solution and illuminated with sunlight, energetic photons in the ultraviolet range create electron/hole pairs in the TiO_2 branches. The positively charged holes migrate through the semiconductor material to its surface, where they encounter water molecules. The holes strip electrons from water molecules, freeing O_2 gas and allowing protons to pass into the solution.

Meanwhile photons in the visible range create electron/hole pairs in the silicon trunk of the nanowire. Here it is the electrons that migrate to the nanowire surface, where they encounter the protons in the solution, reducing them to H_2 gas.

electrocatalyst from first principles. We are exploring the problem with gold-copper bimetallic nanoparticles of different compositions, which are well-defined platforms for learning more about catalytic activity." Through this effort the Yang group discovered a nanocatalyst with a composition of Au_3Cu that has the highest known mass activity for the electrochemical conversion of CO_2 to CO.

But overall progress on CO_2 reduction electrocatalysts has been slow, and Yang wasn't going to let the lack of a good inorganic catalyst impede his progress. Instead, he began working on hybrid inorganic/biological solutions. He knew that some single-cell organisms can reduce CO_2 very effectively.

In 2008, he started a program studying how bacteria would interact with semiconductor nanostructures. After demonstrating that these bacteria can happily interact with high-surface-area semiconductor nanostructures, Yang spent a few years perfecting his lab's techniques and then teamed up with College of Chemistry chemical biologists Michelle and Chris Chang. Together they began to create hybrid systems to make carbon compounds. This approach quickly began to bear fruit, and the year 2015 saw three major breakthroughs.

The first success started with the bacterium *Sporomusa ovata*. This organism is both an electrotroph and an acetogen—it uses electrons to reduce carbon dioxide to acetate, a simple organic compound with one carbon-carbon bond. Yang and colleagues integrated the *S. ovata* bacteria directly into a nanowire photovoltaic device that, like solar panels, produces electricity from sunlight. The microbes nestled securely between individual nanowires.

When illuminated, the hybrid device absorbed photons, creating energetic electrons that the *S. ovata* bacteria used to reduce CO_2. The end product, acetate, is a precursor to biofuels and other valuable chemicals.

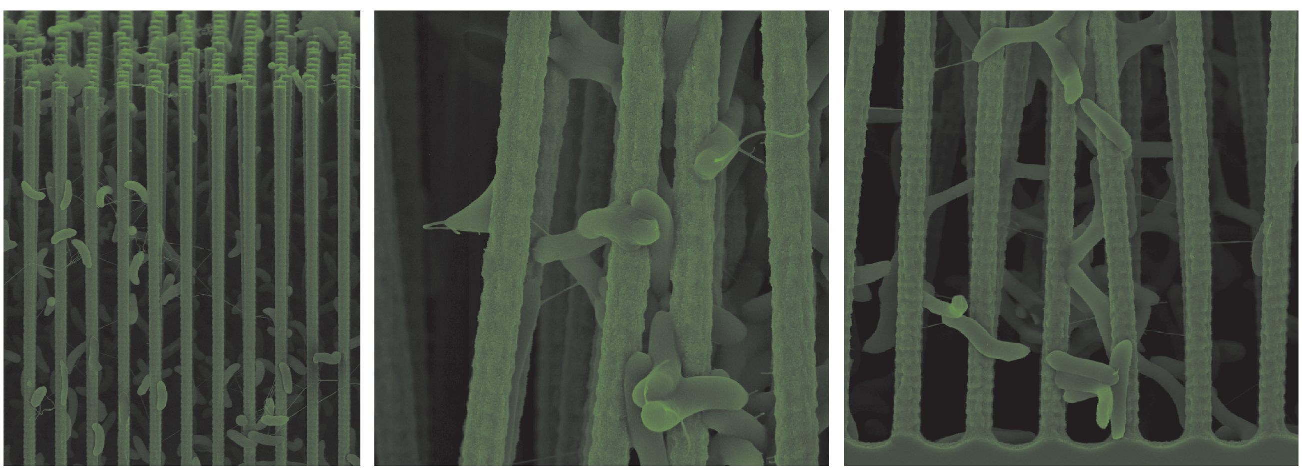
But Yang and colleagues didn't stop there. They next turned their attention to *Methanosarcina barkeri,* a single-cell organism that is a member of the domain of Archaea, the close cousins of bacteria. When fed both hydrogen and carbon dioxide, this organism can reduce CO_2 to methane, the main component of natural gas.

Based on their previous experiments and the Yang lab's expertise with nanoscale semiconductors and catalysts, Yang and colleagues constructed a light-driven device that split water into oxygen and hydrogen and fed the hydrogen, along with CO_2, to a solution containing *M. barkeri* organisms. The microbes churned out methane.

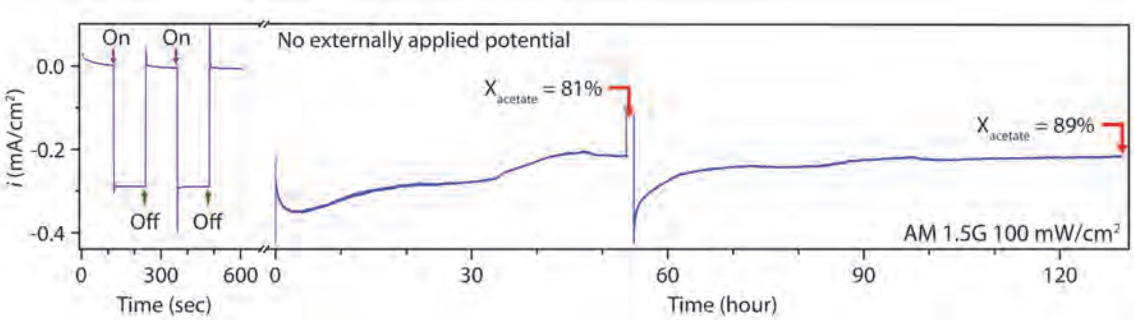
"This study represents another breakthrough in solar-to-chemical energy conversion efficiency and artificial photosynthesis," Yang explains. "And it is a system that can be scaled up. If we start with state-of-the-art solar panels and commercial electrolyzers, we can convert sunlight to hydrogen with almost 20 percent efficiency.

"By feeding this renewable hydrogen to microbes for the production of methane, we currently get a hydrogen-to-methane conversion efficiency of better than 50 percent. Putting the two together, the overall sunlight-to-methane energy conversion efficiency is about 10 percent—much higher than that of natural photosynthesis."

Yang's third and most recent breakthrough takes the integration of the inorganic and the biological to a new level. Instead of putting



Sporomusa ovata **bacteria nestle securely between individual nanowires of a photovoltaic device that, like a solar panel, produces electricity from sunlight. When illuminated, the hybrid device absorbs photons, creating energetic electrons that the bacteria use to reduce CO_2. The end product, acetate, is a precursor to biofuels and other valuable chemicals.**



(l.) **During the first 600 seconds the light is cycled on and off, showing that light produces electric current in the device.** (r.) **The amount of current absorbed by the bacteria is measured in milliamps per square cm. After 55 hours the reactor was stopped and chamber was sampled. The bacteria converted the electric current into acetate at more than 80 percent efficiency.**

microbes into inorganic light-harvesting devices, why not have bacteria grow their own semiconductor light-harvesting nanoparticles?

Although at first it sounds like science fiction, this is precisely what the Yang lab has accomplished. Yang's first breakthrough in early 2015 started with the bacteria *S. ovata*. Yang is now working with *Moorella thermoacetica,* which is also both an electrotroph and an acetogen—it uses electrons to reduce CO_2 to acetates, in particular hydrogen acetate (better known as acetic acid).

To produce cadmium sulfide nanoparticles, Yang grew *M. thermoacetica* in a glucose culture supplemented with cysteine, a sulfur-containing amino acid, and cadmium nitrate, $Cd(NO_3)_2$. Cadmium sulfide (CdS) nanoparticles precipitated and became embedded on the cell surface.

Cadmium sulfide is a well-known semiconductor that enables the microbe to conduct artificial photosynthesis. When light strikes the CdS nanoparticles, it creates electron/hole pairs, just like in a conventional semiconductor. The electrons produced by the nanoparticles reduce CO_2 to acetic acid via what biochemists call the Wood-Ljungdahl pathway within the bacteria, while the holes are quenched by grabbing electrons from cysteine molecules and oxidizing them to the related disulfide compound, cystine.

Notes Yang, "About 90 percent of the reduced CO_2 goes to producing acetic acid, while 10 percent is used for cell growth. The bacterial cells continue to reproduce, suggesting the possibility of a completely self-reproducing hybrid organism sustained purely by solar energy, assuming we can find a way to stabilize the concentration of cysteine and cadmium ions in the system."

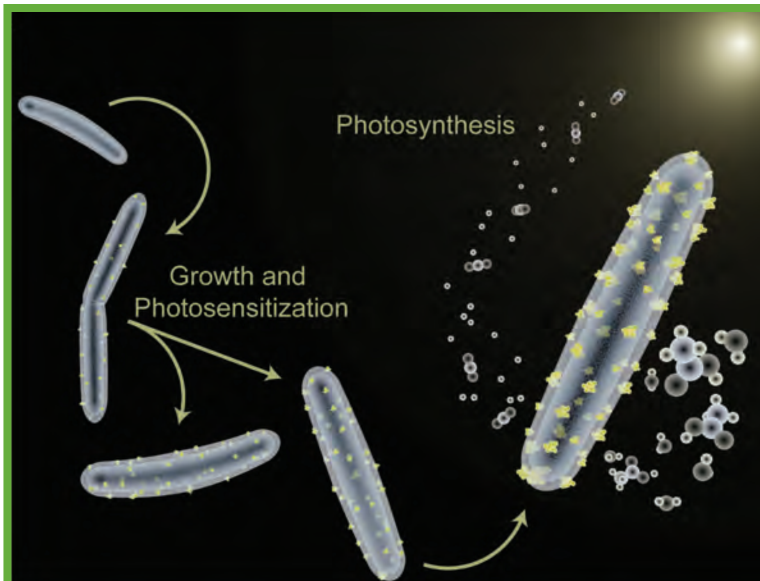
Evolution has provided Yang with a bacterium that can grow its own semiconductor nanoparticle light harvesters. But there is no reason to stop there. Genetic modification of yeast and bacteria has turned them into miniature factories for producing critical drugs like human insulin. These same techniques can also be applied to model organisms like *E. coli* to allow them to synthesize light-harvesting nanoparticles.

In addition, bioengineered metabolic pathways could produce a variety of chemicals and fuels. Such organisms would be miniature solar-powered chemical and fuel factories, but ones based on principles very different from natural photosynthesis.

"More importantly," Yang adds, "by working with these bacteria, we can actually learn the inner machinery of CO_2 reduction chemistry within them, and hopefully one day we can design and synthesize in the lab a robust inorganic electrocatalyst that would have the same activity and selectivity as the bacteria.

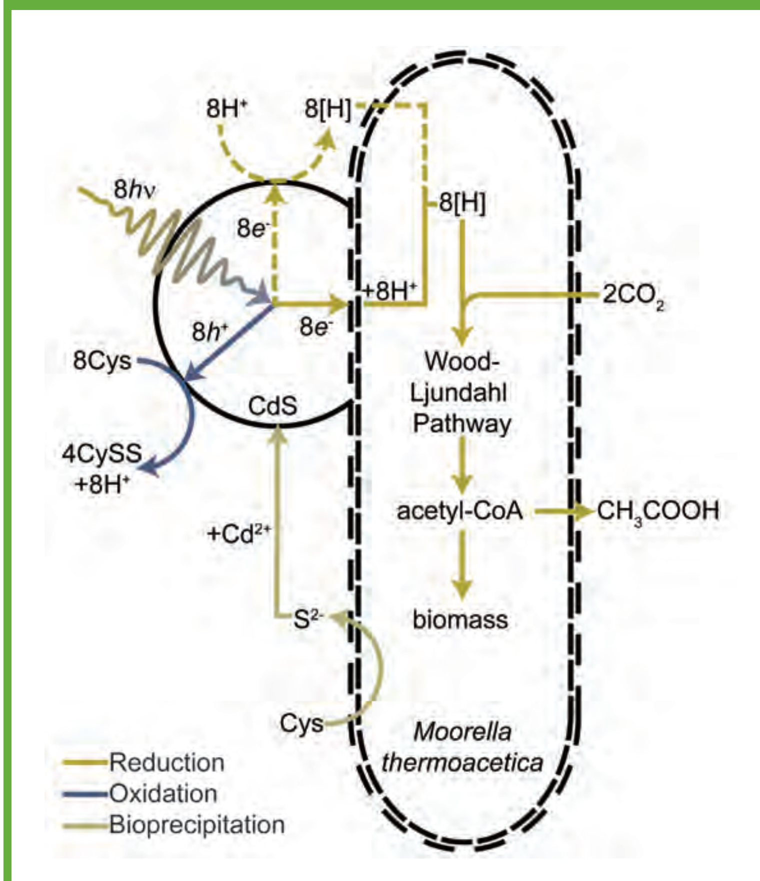
"Human population has surpassed seven billion," Yang says, "and will hit 10 billion by around the year 2050. By then we'll need to supply energy at a rate approaching 40 trillion watts. We won't be able to meet that challenge with fossil fuels without affecting the health and quality of life on the whole planet.

"Artificial photosynthesis has the potential to be a real alternative to fossil fuels. While we were inspired by the process of natural photosynthesis and continue to learn from it, by using nanotechnology to help improve the efficiency of natural systems we are showing that sometimes we can do even better than nature."



above: **The bacterium *Moorella thermoacetica* uses electrons to reduce CO_2 to acetates, in particular hydrogen acetate (acetic acid). Yang grew *M. thermoacetica* in a glucose culture supplemented with cysteine, a sulfur-containing amino acid, and cadmium nitrate, $Cd(NO_3)_2$. Cadmium sulfide (CdS) nanoparticles precipitated and became embedded on the cell surface. Cadmium sulfide is a well-known semiconductor that enables the microbe to conduct artificial photosynthesis.**

below: **In the green bioprecipitation pathway in the lower left of the diagram, cysteine provides sulfur ions which combine with cadmium ions to form cadmium sulfide semiconductor nanoparticles in the cell membrane of *Moorella thermoacetica* bacteria. In the gold reduction pathway, photons strike the CdS nanoparticles, producing electron/hole pairs. Two possible routes exist to generate reducing equivalents, [H] from electrons, either generated outside the cell (dashed lines) or inside the cell (solid line). In the black oxidation pathway, the holes are quenched by the oxidation of cysteine to the related disulfide compound, cystine.**



Chemistry welcomes
Eric Neuscamman and Evan Miller

ERIC NEUSCAMMAN, one of chemistry's newest assistant professors, succinctly summarizes his research with a simple question, "How do we predict how electrons glue things together?"

Neuscamman is an electronic structure theorist, a researcher in a branch of theoretical chemistry where questions about even simple molecules can, if not asked carefully, explode into computational nightmares. His job is to gain insight into fundamental topics while avoiding those nightmares.

He is the oldest of three children of a Chevron petroleum geologist and a college-educated stay-at-home mother. He was born in 1984 in Denver, CO, but spent his early years in Livermore, CA. When he was five years old the family moved to Beaconsfield, England, a town to the northwest of London, almost halfway to Oxford. "In England," says Neuscamman, "I was enrolled in an international elementary school. It had great teachers, and I remember it as a damp but positive experience."

His father was transferred back to Chevron headquarters, then in San Ramon, CA, so the family returned to Livermore, where Neuscamman graduated from high school in 2002 and where he lives today with his wife, Stephanie, and their two children.

For college, Neuscamman attended UCLA, where he spent his first two years studying chemical engineering. "But I grew dissatisfied," he says, "because I wanted to understand more fundamentally the physics of how electrons create molecules. I grew more interested in quantum mechanics and switched to physical chemistry." As a third-year student he studied NMR with Yung-Ya Lin, who had earned his Ph.D. at Berkeley in 1998 with Alex Pines.

Neuscamman had enough credits to graduate in 2006 with B.S. degrees in both physical chemistry and chemical engineering, with a

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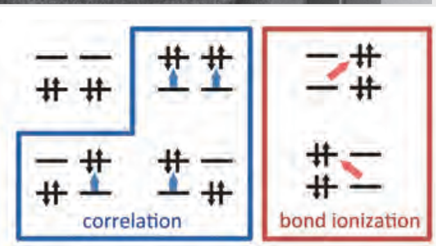


This diagram highlights the possible configurations of two bonds. Some models incorrectly assign all four electrons to a single bond, leading to unrealistic bond ionization.

EVAN MILLER knows a good thing when it he sees it. Some native Californians choose to head far away for college or grad school and come home with a renewed appreciation of the Golden State. Others seem to know how good they've got it and don't see any need to leave. Miller, a new chemistry assistant professor, falls into the latter group. He has created for himself an enviable academic background without ever leaving the state.

Miller was born in Long Beach in 1981. His father, a self-employed steel-rule die maker, soon moved the family to Atascadero, a town midway between Paso Robles and San Luis Obispo on Highway 101. Says Miller, "My folks wanted to move to the country. Since my dad did custom work for printing and circuit board companies, he could do his work from anywhere. We lived near the city limit, and my mom worked in town as a public school teacher."

Miller graduated from Atascadero High School in 2000. The school had an experiment-based chemistry lab course, and like many other College of Chemistry professors, he was first drawn to chemistry by his high school lab experience.

For college, Miller chose a little-known gem, Point Loma Nazarene University, a liberal arts college with 3,500 students. Tucked behind Sunset Beach National Park in San Diego, the campus is known for its spectacular ocean views and a popular local surf break. Miller marvels that he was able to graduate with a degree, given the proximity to world-class beaches.

He is quick to point out Point Loma's small but excellent chemistry department. "Our chemistry department had something like four full-time chemistry faculty and a strong tradition of undergraduate research. We didn't have a lot of resources, but we did a lot with what we had."

Miller worked with organic chemist Vic Heasley and graduated in 2004 with degrees in chemistry/biology and philosophy/theology. While at Point Loma he met a fellow student, Liz Palmquist. They married in 2005 and now have two young children.

continued page 16/column 2

Evan Miller's transmembrane potential sensor lights up the membrane of human embryonic kidney (HEK) cells.

…Eric Neuscamman continued

math minor. "Although I didn't pursue it," he says, "I'm thankful for my engineering background. Numerical optimization techniques have come in handy."

Next Neuscamman was off to Cornell University in upstate New York, an experience he described as, among other things, "a working education in buying proper winter clothing." There he studied in the group of Garnet Chan, whose research explored quantum many-particle systems by using numerical simulations.

Classic mechanics has its *n-body problem,* which Issac Newton and others struggled to solve in the late 1600s. Small planets and other objects travel around large stars in neatly defined elliptical orbits. However, when several bodies of similar size orbit around each other, their gravitational fields interact, making the calculations of their orbits much more complicated.

Likewise, quantum mechanics has its *many-body problem,* which arises in atomic-scale systems of interacting particles. Instead of planets occupying distinct positions in smooth orbits, electrons may be arranged in space in many different ways at once. The quantum mechanical challenge is precisely that many arrangements can exist simultaneously, and that the number of probable arrangements grows extremely rapidly with the number of electrons.

For Neuscamman, that's a problem. Keeping track of quantum interactions as more particles are added to a system makes simple models scale *factorially,* which means even the largest supercomputers can become hopelessly inadequate. Neuscamman has addressed this problem by borrowing an insight from the art of sculpting, where, as an old adage states, the sculptor simply starts with a large block of stone and chips away the unnecessary parts.

Says Neuscamman, "A straightforward approach to quantum chemistry fails due to the quantum many-body problem, in which the size of the Hilbert space grows factorially with the system size. In traditional quantum chemistry, the most common approach has been to start with a small subsection of Hilbert space and then to sparingly add more flexibility only as necessary to achieve accurate results.

"I've shown it may be more effective to pursue a subtractive strategy, in which an initially crude approximation that covers more of Hilbert space than necessary is cleaned up by deleting unnecessary pieces. Crucially, this paring down need not require inspecting the details of the system's factorial complexity and can thus be achieved at a polynomially scaling cost.

"Chemistry is ultimately about understanding and controlling collections of electrons," he adds, "and theoretical chemists make predictions that are useful for this purpose. If you're trying to make fuels from sunlight, for example, which of three expensive possible experiments do you choose? Theoretical guidance helps make more reliable predictions about which experiment will yield the most insight.

"Advances in electron structure theory are needed in order to improve our predictive power about chemical catalysis, molecular light harvesting and other critical applications of chemistry to the big problems society is facing."

…Evan Miller continued

"When I came to Berkeley," says Miller, "I was drawn to organic chemistry and chemical biology, but I had no idea about cutting-edge topics in chemistry, which is what made the chemical biology program so great for me. I was able to do rotations in a couple of labs before joining Chris Chang's lab in the spring. This was where I first discovered the idea of building chemical dyes to look at cells. Chris had also arrived in 2004, and it was so exciting to be part of a new lab. I wrote my thesis on making chemical indicators for the reactive oxygen species hydrogen peroxide to study the signaling roles hydrogen peroxide can play in cells."

In 2009 Miller moved back to San Diego for his postdoc. Unlike his Berkeley experience, where he helped start a lab group, at UC San Diego Miller moved into the established group of Roger Tsien. Tsien had shared the 2008 Nobel Prize in Chemistry for the discovery and development of the green fluorescent protein, and his lab was flourishing.

During his postdoc, Miller developed new fluorescent sensor molecules to measure transmembrane potentials in neurons and other cells. These fast changes in membrane potential, or action potentials, are an integral part of how brain cells communicate—or, in diseases like Alzheimer's, fail to communicate. The sensors are based on controlling fluorescence via a process called photo-induced electron transfer.

Fluorescence is a phenomenon that occurs when electrons, excited by light, relax back to lower energy states, releasing energy as photons. In the case of Miller's sensors, a fluorescent molecule is linked to another molecule that can, under the right conditions, drain away the excitation energy and quench the fluorescence.

"The trick," says Miller, "is to make the voltage potential across the cell membrane act as a switch which turns the electron transfer, and therefore fluorescence, on or off. In its normal state, a neuron's resting membrane potential accelerates electron transfer and quenches fluorescence. But if the neuron is active, the membrane potential is less negative and the electron transfer is allowed, and you see a signal from your fluorescent sensor."

Miller returned to the Berkeley chemistry department in 2013 as an assistant professor to develop new chemical fluorescent sensors. He has a joint appointment in the Department of Molecular & Cell Biology and is affiliated with the campus's Helen Wills Neuroscience Institute.

His research has attracted funding from sources interested in both basic research and fighting disease, including a recent Sloan Foundation Research Fellowship and new investigator awards from the March of Dimes and the Alzheimer's Association.

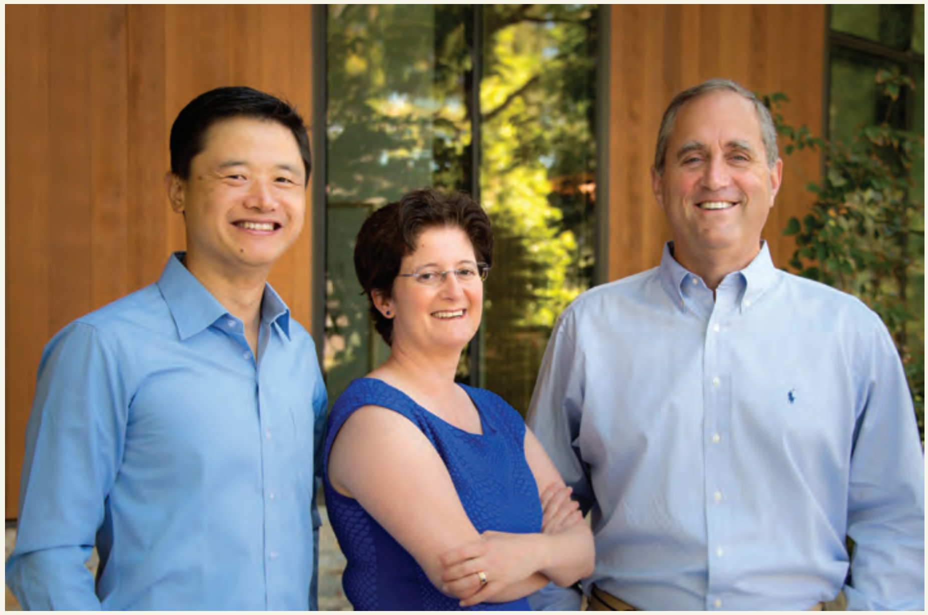
Notes Miller, "It's great to be back at Berkeley. Being part of the College of Chemistry as well as the MCB department is really the perfect mix, for me, of chemistry and biology interacting with one another."

VENTURE FUND WILL COMMERCIALIZE COC INVENTIONS

College alums launch Berkeley Catalyst Fund

At UC Berkeley, the days of business-as-usual are over. In February, Chancellor Dirks announced that, due to annual $150 million deficits, the campus would have to undergo a painful restructuring—not a typical short-term budget reduction, but a long-term revision in how the university does its job.

One of the Chancellor's changes will be "Making new investments to expand our fundraising capacity along with other new areas for external support." When it comes to innovative fundraising initiatives, the College of Chemistry is ahead of the game, thanks in part to the loyalty and efforts of two former students of Nobel Laureate chemistry professor Yuan T. Lee (*Ph.D. '65, Chem, with Bruce Mahan*).


JENNIFER TOWNHILL

Ted Hou *(Ph.D. '95,Chem)*, Laura Smoliar *(Ph.D. '95, Chem)* and Drew Lanza are the general partners of the Berkeley Catalyst Fund.

Laura Smoliar and Ted Hou both completed their dissertations in the research group of Lee in 1995. Since then, their lives and careers have taken parallel paths that have converged again with the founding of their business, Global Innovation Foundry, LLC.

The goal of the company is to bridge technology, markets and investments between the U.S. and Asia. As College of Chemistry alums with deep experience in both startups and large high-tech firms, Ted and Laura share similar backgrounds. Yet their experiences are also complementary. In recent years, Ted has worked with large telecom, solar and energy companies in China, while Laura's entrepreneurial experience has been in smaller and medium-sized display and photonics companies with key customers in Taiwan and Japan.

A high-tech startup must be able to negotiate a complex world where everything from sources of expertise to the locations for producing components can span continents, languages and technical fields. Global Innovation Foundry helps both startups and established companies to find their way in this complex world.

"We are not just match-makers or brokers who link up different companies and walk away," says Laura. "We form long-term relationships and serve as an international business development resource for the companies we advise." It is this expertise that Laura and Ted are bringing to the college.

For many years academia has struggled with how best to turn scientific breakthroughs into useful new products. Prior to 1980, patents and other intellectual property (IP) rights to inventions resulting from federally funded research remained with the government. But federal research agencies were not in the business of technology marketing, and the patents and other IP typically languished.

In the 1970s, two things changed. First, the rise of biotechnology meant that academic scientific discoveries could have immediate commercial potential as new drugs and other biomedical therapies. Second, U.S. companies were perceived to be losing the race for "competitiveness" to German and Japanese firms that innovated more rapidly.

In response, in 1980, Congress passed the Bayh-Dole Act, named for its sponsors, Republican Senator Robert Dole and Democratic Senator Birch Bayh. This act allowed universities and other organizations to retain patents and other IP rights to inventions flowing from federally funded research.

The Bayh-Dole act was greeted with enthusiasm at research universities. Many of them formed offices of technology transfer to handle the patenting and licensing of inventions from faculty and researchers. Some of these offices have been very successful at licensing—examples include Stanford's Office of Technology Licensing and Columbia University's Columbia Technology Ventures.

At Berkeley, the office of the Intellectual Property and Industry Research Alliances (IPIRA), headed by assistant vice chancellor Carol Mimura, handles both the patent processing and licensing as well as sponsored research contracts.

One of the campus's top inventors is chemistry professor Richard A. Mathies. During his years as the dean of the College of Chemistry (2008–13), Mathies began to consider a venture capital fund to help turn CoC inventions into useful products. Mathies had been involved in several startups, either as a founder or as a scientific adviser, and with the declining state support of UC, he felt it was time to consider new income sources for Berkeley. Campus administrators were receptive to the idea, but the critical set of skills necessary to create such a venture fund was lacking.

When Doug Clark became dean in 2013, he continued to look for a solution. This is where Ted and Laura came into the picture. With help from tax and legal experts, they reviewed the original proposal for a venture fund. Next they developed a model that would achieve the goals of the college while complying with legal considerations.

The result is a hybrid venture-fund model that is comprised of a for-profit venture fund and a separate philanthropic fund that is managed by the UC Berkeley Foundation. This arrangement will allow a substantial portion of the investment returns to flow back to the college. The for-profit fund, the Berkeley Catalyst Fund (BCF), is structured as a typical early-stage fund, and it is completely independent of the university.

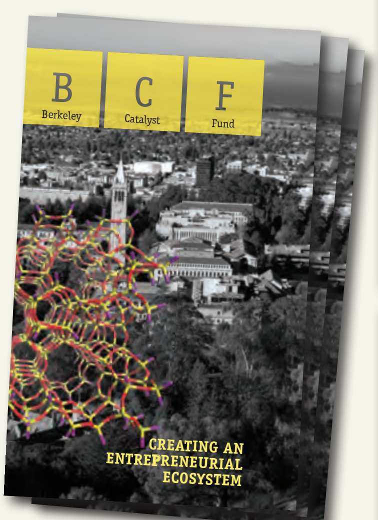
Ted and Laura are general partners, along with Drew Lanza, whom they recruited out of retirement. Drew was a founder of and executive at five Silicon Valley companies and a venture capitalist with Morgenthaler Ventures, where, for a decade, he ran the semiconductor and systems practices. Drew brings a wealth of experience and has generously shared his knowledge with all the stakeholders involved in the project, including IPIRA, the UC Berkeley Foundation, the Vice Chancellor of Finance and Administration, and the College of Chemistry.

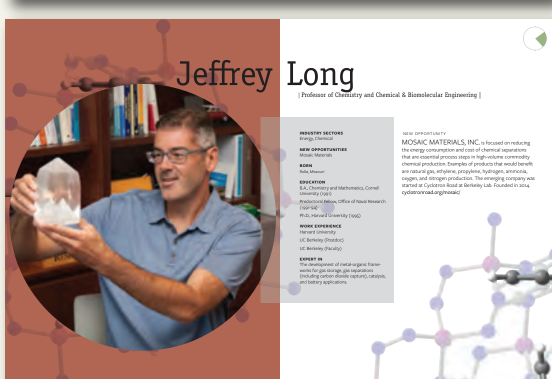
Drew has B.S. and M.S. degrees in electrical engineering from Stanford and served on the faculty there for many years. He also received an M.B.A. with honors from Harvard. Due to his family history, Drew is strongly attracted to the chemistry aspect of the fund. "My dad earned his Ph.D. in chemistry at NYU shortly after World War II," says Drew. "He moved the family out to California when he became the founding chief technical officer of Raychem, a Fortune 500 specialty materials company in Redwood City. When he joined, he was employee number six. The company grew to employ 10,000 people in over 80 countries."

Ted, Laura and Drew have structured BCF as a $25 million fund. It will initially invest in roughly 20 companies during a four-to-five-year period and will have a lifetime of approximately 10 years. The main source of startups will be the research of faculty, students, staff and alumni of the college and related Berkeley departments. CoC faculty members are excited by the possibilities, and 14 have been profiled to date in the current edition of the fund's brochure.

The college has also created a parallel philanthropic fund—the Berkeley Catalyst Philanthropic Fund (BCPF). Several alumni have started donating to the fund to help college faculty, students, alumni and staff commercialize technology emerging from their labs. Together, the BCF and the BCPF will enable college researchers to develop their discoveries and create new companies.

Says Laura, "The Berkeley Catalyst Fund has helped expand the conversation around philanthropy, especially with alumni in industry. Sometimes we bring new investors and donors to the college because of





The Berkeley Catalyst Fund brochure features the work of 14 College of Chemistry researchers.

A pdf version of the BCF brochure (12.4 MB) can be downloaded at berkeley.box.com/coc-bcf.

Ted Hou and spouse Sophie Wang at the 2015 Dean's Dinner.

Laura Smoliar and spouse Mark Arbore at the 2015 Dean's Dinner.

interest in the BCF/BCPF, but they decide they are more interested in funding a building or another project. We view it all as win-win for the college."

Knowing that successful relationships are built by face-to-face meetings, Ted and Laura encouraged Dean Clark and his wife Molly to travel to China and Japan last summer to meet some of the leaders of Asia's dynamic high-tech industries.

"It was a whirlwind tour," says the college's director of major gifts and alumni relations, Camille Olufson, who accompanied the Clarks for a portion of the trip. "The dean spent four days in Chengdu, four in Shanghai, three in Shenzhen, one in Hong Kong and three in Tokyo. Ted made the introductions in Shenzhen, and Laura took over in Tokyo. Doug also gave an invited talk in Tokyo, attended by many local companies and members of the Berkeley Club of Japan.

"Ted and Laura have been a huge asset for college outreach in Asia," adds Olufson, who has known them since their days as graduate students. "We are so grateful that they have been willing to be both ambassadors for the college and to share with us their technical and entrepreneurial expertise in helping to create and manage the Berkeley Catalyst Fund."

TED HOU was born in 1969 in Wuhan, China. As a child he lived in Guizhou Province and later attended high school at the Fuzhou No. 1 school in Fuzhou, Fujian Province. He graduated from the University of Science and Technology of China (USTC), in Hefei, Anhui Province, in 1989.

His wife-to-be, Sophie Wang, graduated in the same USTC class and also came to the College of Chemistry. They were married here in 1992 and have two children. Ted was a student of Y.T. Lee while Sophie was a student of Judith Klinman. Both earned their Ph.D.'s in 1995. Says Ted, "Since our Ph.D. advisers' last names, Klinman and Lee, were next to each other in the alphabet, to our surprise we found ourselves lined up next to each other for commencement."

Ted's postdoc took him to IBM's Almaden Research Center, where he was a staff scientist from 1996 to 1999. He spent the next decade in the fiber optics communication industry, working as the director for product line management at Oplink Communications, a rapidly growing company that went public in 2000.

Ten years later he was a manager for JDSU (formerly JDS Uniphase), one of the biggest fiber optics communications companies in the world.

In 2010 Ted switched to a new field, solar power. For two years, he worked in a variety of technology and marketing positions in Shanghai and Suzhou, China. He then returned to the United States to become the product strategy vice president for NRG Energy in Emeryville, CA.

Ted left NRG to found NEEM Scientific, a privately held early-stage startup that is creating novel nano materials for the consumer electronics, energy, environmental and healthcare markets. In 2014, Ted, along with fellow Y.T. Lee group alum, Laura Smoliar, started the Global Innovation Foundry to foster technology, market and investment alliances between the U.S. and Asian businesses and institutions.

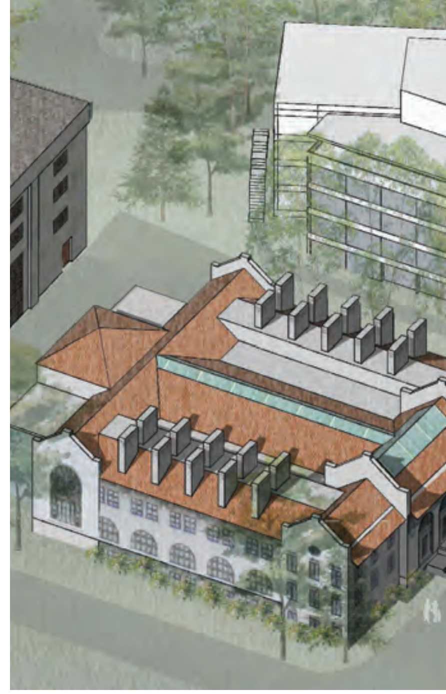
LAURA SMOLIAR was born in 1968 in New York City and later moved to a suburb of Detroit with her family. In 1986, Laura returned to Manhattan to attend Columbia College, where she performed undergraduate research with the late chemistry professor Brian Bent, a former student of Gabor Somorjai. (Bent earned his Berkeley chemistry Ph.D. in 1986). She graduated *summa cum laude* in 1990. "When it came time to apply to grad schools," she says, "I visited the labs of Somorjai and Y.T. Lee and decided Berkeley was for me."

In 1994, Lee returned to his home country of Taiwan to serve as President of Academia Sinica, an association of leading government scientific institutions. Laura spent her last year of graduate school with Lee in Taiwan, earned her Ph.D. from Berkeley in 1995, and returned to Taiwan for a postdoc as an Academia Sinica Fellow. She says, "My experience in Taiwan changed the course of my career, and I have worked collaboratively with companies and institutes in Asia ever since."

After her postdoc, Laura chose to work in Silicon Valley. She started her career with Seagate Technology, a leader in the data storage industry. She then worked in displays, lasers and other optical hardware technologies. Throughout these years, she worked closely with companies in Japan, especially Sony, Hitachi, Disco and NTT.

In 2005, Laura founded Mobius Photonics, which developed high-power fiber-based UV and green lasers. As CEO, she raised several rounds of financing from investors in the U.S. and Japan, and she exclusively licensed key technology from Harvard. The company was acquired by IPG Photonics.

Laura and her husband, Mark Arbore, owned their own engineering services firm, Peppertree Engineering, which specialized in outsourced product development that required deep expertise in optics, lasers and LEDs. The couple sold the company in 2013, and Laura later joined forces with Ted Hou to create Global Innovation Foundry, LLC in 2014.



Preliminary drawings, showing basic volume capacity and site placement between Hearst Memorial Mining Building and Stanely Hall

A VISION FOR THE FUTURE

The Joint Chemistry and Engineering Building

We are proud to share the news that the College of Chemistry, in partnership with the College of Engineering, is launching a long-overdue endeavor: constructing a brand new research building on the site of the old Donner Lab.

Our joint proposal for the building has been approved by campus administration. We are excited to be embarking on this vision for state-of-the-art chemical sciences and engineering research.

Early donor support has helped us to get to where we are now, positioned to move ahead into a major fundraising campaign.

Given the campus financial climate, we know that this will be challenging, but we also know the College must have new research space in order to continue to excel and lead in chemistry and chemical & biomolecular engineering. Chemical sciences research in recent decades has undergone a revolution. The field has broadened and deepened. Our researchers are transforming the fight against genetic disease, devising new materials, designing more efficient catalysts, and advancing sustainability practices. Research of this nature — sustained breakthrough research — requires a robust infrastructure that we just don't have. For some time, the College's infrastructure has been taxed by the demands of modern research. The new space will provide optimal conditions for pioneering work to unfold.

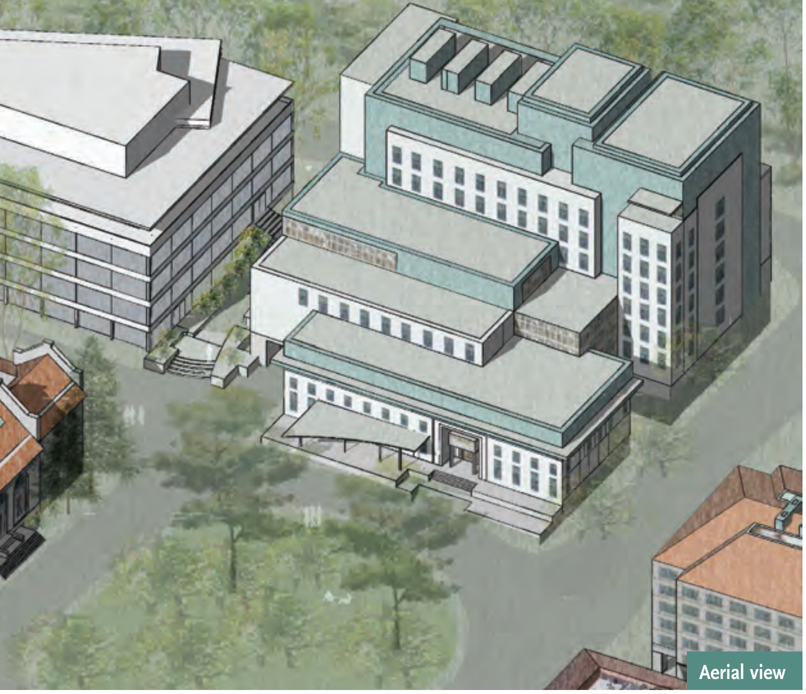
We believe that housing Chemistry and Engineering labs in the same building will not only be effective in terms of fundraising and optimizing campus space, but will also promote interdisciplinary collaboration. Chemists and engineers, by sharing the building's lab and office space, will be able to find new areas of collaboration and forge new synergistic research. Three potential themes for the building have emerged: translational chemical biology, advanced catalysis, and engineering for better health.

The new building project affords us a terrific opportunity to rally around our College and its commitment to top-level research and education. We are excited by the possibility — the Joint Chemistry and Engineering Building is starting to take shape.

Stay tuned for more info!

MINDY REX
Assistant Dean, College Relations & Development

RON SILVA ***(B.S. '77, Chem)***
Chair, CoC Building Project Committee



HISTORY OF COC CAMPUS

Chemistry has been offered by the University of California since its founding in 1868. The College of Chemistry itself was created as a unit within the University in 1872. It was housed—along with the other sciences—in South Hall, the first building to be completed on the Berkeley campus.

In 1890 a handsome brick building was constructed for the college on what is now the site of Hildebrand Hall. In time it came to be known as "The Old Chemistry Building," and when it finally fell to the wrecker's ball to make room for more modern facilities in 1966, its cupola was preserved. Now restored, the cupola sits on Chemistry Plaza above Giauque Laboratory.

The individual who was largely responsible for the rise of the college was Gilbert Newton Lewis, who became dean in 1912 and served until 1941. In order to accommodate the growth in faculty and students, the college acquired several other buildings during the Lewis years: the Chemistry Auditorium (built in 1913 and razed in 1959 to make way for Latimer Hall); the Freshman Chemistry Laboratory (built in 1915 and razed in 1962 to clear the site for the Physical Sciences Lecture Hall, now known as George C. Pimentel Hall); the Chemistry Annex, more popularly known as the "Rat House" (also built in 1915 and razed to clear the site for Hildebrand Hall in 1966); and the still-standing Gilman Hall (built in 1917).

The post-World War II years were a period of expansion and rebuilding: organic chemistry was strengthened, and chemical engineering became a bona fide program in 1945, leading to the formal establishment of the Department of Chemical Engineering in 1957 (the name was changed to the Department of Chemical and Biomolecular Engineering in 2010). As postwar enrollments soared, Lewis Hall was built in 1948, and enrollments largely continued to rise throughout the second half of the 20th century.

In response to the higher enrollments and the need for increasingly modern laboratory space, facilities for research and teaching were successively constructed: Giauque Hall (the Low Temperature Laboratory) in 1954 (renovated in the 1980s for Nobel laureate Yuan T. Lee), Latimer Hall in 1962, Hildebrand Hall in 1966, and the much-needed Tan Kah Kee Hall in 1997. The Loma Prieta earthquake of 1989 prompted a campus-wide reassessment of seismic safety, and comprehensive retrofits of Hildebrand, Latimer and Lewis Halls were completed in 2002.

HISTORY OF DONNER LAB

In 1936, endocrinologist John Lawrence took a leave of absence from his faculty position at Yale Medical School to visit his brother Ernest Lawrence at the new radiation laboratory on the Berkeley campus. Ernest Lawrence had established the lab in 1931 and, as its director, was instrumental in moving it to the hills above the campus in 1940, where it became the Lawrence Berkeley National Laboratory (LBNL).

Excited by the possibilities for using new isotopes in medicine, John Lawrence founded a program which later evolved into the Donner Laboratory and sparked the birth of a new field of medicine and research. Because of his lifelong contributions and pioneering work, John Lawrence became known as the "father of nuclear medicine."

The Donner Laboratory building was built in 1942 (a north wing was added in 1955). It was funded by William H. Donner, president of the Donner Steel Corp., who donated money to the university for work in nuclear medicine following his son's death from cancer. The Donner Lab was the world's first center for research in the uses of atomic energy in biology and medicine. Several of the well-known radioisotopes used in nuclear medicine were discovered there, including technetium-99m, carbon-14, fluorine-18, oxygen-15 and thallium-201.

During World War II, Lawrence and his colleagues began adapting nuclear medicine techniques for wartime uses. Donner Lab researchers used radioisotopes of inert gases to study decompression sickness experienced by pilots who flew at high altitudes. These tracer studies would help increase understanding of the circulation and diffusion of gases.

Following World War II, the main focus of the researchers continued to be on the physiology and biophysics of such diseases as polycythemia vera, multiple myeloma and leukemia, on the use of radioactive tracers for treatment, and on the development of improved imaging techniques.

Today the Donner Lab is outmoded. It has seismic deficiencies, and its infrastructure cannot meet modern research laboratory needs. Nearly 80 percent of the space in Donner is currently assigned to LBNL, which administers the building. LBNL and UC are in the process of transferring control of the building back to the campus so that it can be demolished to make way for JCEB.

In this 1943 photo in the Donner Lab altitude chamber, four sailors breathe a mixture of radiolabeled gases to help determine how to protect pilots flying at high altitudes.

In Memoriam

Friend of the college

KATHARINE (KATIE) STEWART SCHLINGER, a dear friend of the College of Chemistry, passed away on October 4, 2015, in Arcadia, CA, at the age of 92. Following a childhood in Alhambra, CA, she obtained an Associate of Arts degree in 1942 from Pasadena Junior College. She met chemical engineer Warren Schlinger while working at Caltech as the department secretary, and they married in 1947. Katie, who studied with voice coach Llewelyn Roberts, enjoyed a successful career as a soprano soloist and leader of the Carmel Bach Festival chorale, directed by Sandor Salgo. She directed the youth choir of her church, Oneonta Congregational Church, and was a soloist there for more than 25 years. She and Warren raised three children: Michael, Norman *(B.S. '75, Business)* and Sarah Lynne *(M.B.A. '82, Business)*. Katie was an active volunteer in community affairs and, with Warren, led a life filled with travel, golf, skiing, tennis and backpacking. Committed philanthropists, the Schlingers formed a family foundation in 1994 that has generously supported higher education both at Berkeley and at Caltech, Warren's alma mater. In 2001, they established the Warren and Katharine Schlinger Distinguished Professorship in Chemical Engineering, an administrative chair currently held by CBE chair Jeffrey Reimer.

Alumni

'41 **Consuelo Keller Tagiuri** *(B.A. Chem)*, the daughter of a Mexican chiropractor and a Swiss mining and metallurgical chemist, passed away on August 1, 2015, in Weston, MA, at the age of 93. Consuelo Keller studied chemistry, French and piano as an undergrad at Berkeley, graduating Phi Beta Kappa. She then earned an M.D. at UCSF. Following an internship in Puerto Rico and a psychiatry residency in Montreal, she and her husband, Renato Tagiuri of Milan, Italy, moved to Cambridge, MA, where Consuelo trained at the Massachusetts General Hospital Judge Baker Clinic and became the first Spanish-speaking child psychiatrist in the Boston area. In the 1950s, working at Children's Hospital, the Cambridge Guidance Center and Harvard Medical School, she co-authored seminal papers on child abuse and mental health issues. In the 1970s, she retrained to be able to administer neurological exams to her patients, having realized that some problems diagnosed as psychiatric were neurological in nature. She served as founding board member and consulting psychiatrist at the Gifford School for many years.

'44 UC Davis emeritus chemistry professor **Thomas L. Allen** *(B.S. Chem with Leo Brewer)* passed away on June 28, 2015, at the age of 91. A member of the Naval ROTC at Berkeley, he served in WWII, then earned a Ph.D. in chemistry at Caltech. He joined the UC Davis faculty in 1949, where he remained—except for one year at Chevron Research—until his retirement in 1993. His main fields of teaching and research were inorganic and physical chemistry; he taught the introductory courses in general and analytical chemistry, the junior-level courses in inorganic chemistry and physical chemistry, and the graduate course in quantum chemistry. He and Raymond M. Keefer co-authored *Chemistry: Experiment and Theory*, a general chemistry textbook published in 1974 (second edition, 1982). An active member of the Academic Senate at Davis, Allen served as chairperson of the Universitywide Committee on Educational Policy in 1969–70, where he led a successful fight against the imposition of tuition fees on UC students.

'45 **Edward L. "Ed" King** *(B.S. '42, Chem; Ph.D. '45, Chem with Wendell Latimer)*, emeritus chemistry professor at the University of Colorado Boulder, passed away on September 1, 2015, in Boulder, CO. Following his undergrad years, he remained at Berkeley, first to earn his Ph.D. in chemistry, doing research on the aqueous solution chemistry of plutonium, and then to spend a year as a research associate on the Manhattan Project. After working at Harvard as a postdoc and instructor (1946–48), he joined the faculty of the University of Wisconsin-Madison. In 1963, he moved to CU Boulder, where he spent the remainder of his career, retiring in 1986. While at the UW and CU, King conducted research in the field of solution chemistry of inorganic substances. He authored two books, *How Chemical Reactions Occur* (1964, translated into Spanish and Japanese) and *Chemistry* (1979), an advanced college-level introduction to the field.

'48 **James N. "Jim" Shoolery** *(B.S. Chem)*, a pioneer in the development of nuclear magnetic resonance spectroscopy, passed away on September 24, 2015. Shoolery received his Ph.D. from Caltech in 1952. He served in the U.S. Navy (1943–46) as a radar operator. In 1952, he joined Varian Associates and helped build the first commercial NMR spectrometer. Throughout the next decades, he developed the procedures for using NMR for chemical analysis and guided the development of improved NMR spectrometers. He wrote "NMR at Work," a long-running series on the back cover of the *Journal of the American Chemical Society*, and *A Basic Guide to NMR* (1972). In the course of his career, he gave thousands of lectures and published more than 160 papers. His biography is available online at Chemical Heritage Foundation.

'51 **Alan William "Bill" Boyd** *(Ph.D. Chem with William Gwinn)* died December 9, 2015, in Fontainebleau, France. He grew up in Vancouver, B.C., earning an M.Sc. at the University of British Columbia in 1945. During a distinguished career in radiation chemistry, he became a leader on radiation dosimetry. He worked as a senior physical research chemist at Atomic Energy of Canada Limited in Chalk River, Ontario, from 1951–80, with sabbaticals at Harwell Laboratory in England (1958–59) and CEA Saclay, France (1974–75). After retiring he worked for the United Nations International Atomic Energy Agency in Vienna, Austria (1980–85).

'58 **Ralph J. Fessenden** *(Ph.D. Chem with James Cason)*, an emeritus professor of organic chemistry at the University of Montana, passed away on October 4, 2015, in Missoula, MT. Fessenden began his higher education with a track scholarship to the University of Illinois, where he excelled in running the 440-yard distance and, in 1954, placed fourth at the USA Track and Field Championships. At UI, he studied chemistry, obtaining both his bachelor's and master's degrees. He and his wife, Joan, then moved to Berkeley, where she earned her master's degree *(M.S. '56, Chem)*, and he earned his Ph.D. in organic chemistry. After teaching at San Jose State University, Fessenden moved with his family to Missoula, MT, to join the faculty at UM, where he remained until retirement and where he developed the reputation as an extraordinary classroom teacher. Ralph and Joan co-authored several chemistry books, publishing their first book in 1971. They were internationally known organic chemistry authors; their books have been translated into six languages. Joan predeceased Ralph in 1991.

'61 **Richard A. "Dick" Keller** *(Ph.D. Chem with William Gwinn)*, a Fellow at Los Alamos National Laboratory, died on September 1, 2015, in Los Alamos, NM. Born in Pittsburgh, PA, Keller had lived in Los Alamos with his family since 1976, distinguishing himself in the field of analytical chemistry. His most notable contribution was his pioneering of single molecule detection, a technique he and his collaborators applied to DNA sequencing as part of the Human Genome Project. He received the American Chemical Society Division of Analytical Chemistry Award for Spectrochemical Analysis in 1993. Much of his work was the result of interdisciplinary collaboration, at his initiative, between physical and biological scientists.

'63 **David W. Seegmiller** *(Ph.D. Chem with Kenneth Street)* passed away on September 15, 2015, in Albuquerque, NM. Seegmiller studied chemistry at Brigham Young University before entering grad school at Berkeley. He served in the U.S. Air Force from 1958 to 1985, retiring as a colonel. His service included 18 years as a faculty member of the Air Force Academy, Colorado, where he spent time as head of its department of chemistry and biological science. As a researcher, he was chief of the High Energy Laser programs for the Air Force, overseeing research in chemistry, nuclear reaction, high-energy lasers and high-energy batteries. His Air Force postings included the role of Chief Scientist for the European Office of Aerospace Research and Development (EOARD), based in London, UK (1976–78). Beginning in 1985, he worked as a senior scientist for Schafer Corporation until full retirement in 2003.

'72 **Michael S. "Mike" Zisman** *(Ph.D. Chem with Bernard Harvey)* passed away on August 30, 2015, at the age of 71. Zisman, a senior scientist in the Accelerator Technology and Applied Physics (ATAP) Division at LBNL, was well known as a designer and builder of high-energy accelerators. While a grad student at Berkeley, he worked at LBNL's 88-inch cyclotron. Following a postdoc, he joined LBNL's scientific staff and remained there for the duration of his career, developing and refining his interest in accelerator physics. His expertise contributed significantly to the design and success of numerous high-energy accelerators over the course of his career, during which time accelerators became a vital infrastructure—not only for many areas of basic research but also for numerous applied fields. In recent years Zisman was key in establishing a new government program: the Accelerator Stewardship Program at the Department of Energy's Office of High Energy Physics. This program supports fundamental accelerator science and technology development and disseminates accelerator knowledge and training to the broad community of accelerator builders and users. For a detailed synopsis of Zisman's contributions, see atap.lbl.gov/Michael-s-zisman-1944–2015/

Between June and December 2015, we learned of the deaths of 41 CoC alumni.

For a complete list, please visit: **berkeley.box.com/chem-memoriam-sp2016**

COMPILED BY KAREN ELLIOTT

ANNUAL REPORT

of private giving 2015

In my role as Dean, I have come to understand the profound importance of the College of Chemistry community of alumni, donors and friends. We are able to succeed because of the strength and backing of this community—our faculty relies on you, our students need you, and the vigor and reputation of our college is enhanced through your steadfastness.

Thanks to your help, in 2014–15 we maintained the superb quality of the teaching and research in the college—we supported and hired outstanding faculty, provided scholarship and fellowship awards to our wonderful students, launched interesting programs and renovated old facilities. We are forging ahead in 2016, meeting financial and higher-education challenges with innovation and energy: building an entrepreneurial ecosystem, developing creative revenue generation and establishing the New Frontiers Fund to provide the resources for our exciting Joint Chemical and Engineering Building project. Without donors like you, we could not begin to achieve what I am certain will be accomplished in the years to come.

It is no coincidence that the College of Chemistry is such an exemplary institution—we are supported by an exemplary community! I am deeply grateful for your support.

donors *to the* college

The first three donor clubs listed—the California Benefactors, the Blue and Gold Society and the 1868 Society—are cumulative clubs. Donors' lifetime giving to the College of Chemistry determines their club level. The remaining clubs are annual—the club level shows each donor's giving during the 2014-15 fiscal year.

Cumulative Clubs

Cumulative Clubs include each donor's total giving through June 30, 2015.

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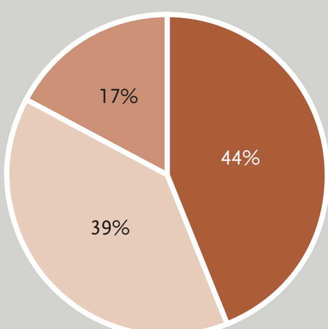

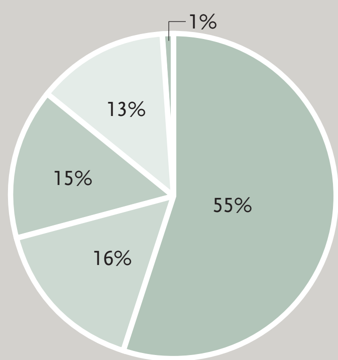

Sources of Gifts

Individuals	$6.3 M	44%
Corporations/ Corporate Foundations	$5.7 M	39%
Private Foundations/ Nonprofit Organizations	$2.5 M	17%
Total	$14.5 M	100%

Designation of Gifts

Capital Projects	$8.0 M	55%
Student Support	$2.3 M	16%
Research	$2.1 M	15%
Unrestricted/other	$1.9 M	13%
Chairs	$0.2 M	1%
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MALLORY PICKET

GREEN CHEMISTRY IN ACTION

The Berkeley Center for Green Chemistry (BCGC) is celebrating the conclusion of another successful Greener Solutions course, an interdisciplinary project-driven graduate class in which students work with corporate clients to develop greener solutions to specific sustainability challenges.

During the fall 2015 course, the fourth year it has been offered, students worked with the software company Autodesk to develop safer and more sustainable resins for 3D printing. They also worked with the corporation Method Products to develop laundry detergents that work effectively in cold water and low-agitation wash cycles.

BCGC staff and faculty, including Marty Mulvihill, Meg Schwarzman, Tom McKeag and Heather Buckley, teach the Greener Solutions course. The instructors guide the students by teaching them green chemistry design principles and how to incorporate knowledge from public health and other disciplines to solve problems.

The course is built on the idea that human health and environmental sustainability should be considered from the beginning in the design and manufacturing of a product. During the fall semester the students worked in groups and consulted frequently with their industry clients, developing their professional skills. The students started by studying biomimetic design and learning how to look to nature for inspiration. This biological inspiration was evident in several of the solutions proposed for 3D printing and laundry detergents.

In December, nine graduate students from several different campus departments presented their results to an audience that included EPA officials, Autodesk and Method employees and campus faculty. The two student teams, one working for Autodesk and the other for Method, each presented several ideas for how to address their clients' sustainability goals.

Two particular bio-organisms inspired the Autodesk team—the mussel and the oyster. Both are marine invertebrates that must turn adhesive liquids into solids in their underwater habitat. The team's challenge was to translate the chemistry of natural products used by mussels and oysters into new resins that reconciled the performance requirements of 3D printers with the need to find more benign chemical formulas.

Method was looking for something entirely different—a low-temperature laundry detergent for oil-stained clothes. Removing oily stains from clothes takes chemical, thermal and mechanical energy. Alternatives to harsh detergents, hot water and vigorous agitation not only increase the usable life of clothing, but also reduce energy use, one of the biggest costs of laundry operations.

The Method team crafted specifications that included the use of existing washing machines, cold water and biodegradable, low-toxicity compounds. The solutions they proposed ranged from natural enzymes to an entirely new product idea—objects with oil-adhesive surfaces that could be added during the wash cycle to attract grease from clothes.

Autodesk, Method and the other participants at the presentation were enthusiastic about the student proposals. Some of the class members may continue working with their industry clients outside the scope of the class. Billy Hart-Cooper, a Ph.D. student in the college *(Ph.D. '15, Chem)*, worked with Method as part of last year's Greener Solutions course and now works with them as an independent consultant. Another Greener Solutions alum, Justin Bours, helped this year's students with their projects. He has been hired by Autodesk.

The Greener Solutions program received welcome support from their two corporate clients, Autodesk and Method Products, as well as from the sustainable chemical company BioAmber. To support BCGC's work, gifts may be sent to the UC Berkeley Foundation and designated for the College of Chemistry, Berkeley Center for Green Chemistry.

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(l. to r.) **Martin and Karen Weiner join their cousins Agnés and Alan Mendelson as the Mendelsons are honored at the Builders of Berkeley event.**

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Martha Boccalini (center) receives the Glenn T. Seaborg Award for Nuclear Chemistry on Heino Nitsche's behalf at the March 2015 American Chemical Society conference.

AMERICAN CHEMICAL SOCIETY

A GIFT FOR GRADUATE LIFE

When chemistry professor Heino Nitsche died suddenly on July 25, 2014, it was a powerful loss for his wife, Martha Boccalini. But even in her grief she realized Heino's death also left a big hole in the lives of his students. Martha has kept in touch with them, and recently she reached out to provide assistance to the students and their colleagues through a generous gift to the Chemistry Graduate Life Committee (CGLC).

The CGLC is a joint student-faculty committee with the mission of improving the life of chemistry graduate students. It provides peer mentoring, plans social events, advocates for graduate student wellness and coordinates recruiting weekends. The CGLC also sponsors the weekly Friday afternoon "ChemKeg" on the plaza, an event that Heino relished attending.

Martha and Heino married in 1989, while he was a group leader at LBNL. When Heino returned to his native Germany in 1993 to head a nuclear science institute, Martha accompanied him. The couple came back to the Bay Area in 1998 for Heino's new appointment at LBNL and the College of Chemistry.

Martha is a talented artist and calligrapher (see art above). In the last several months, she has learned more about nuclear chemistry and the work of Heino and his colleagues.

In March, 2015, Martha attended the national conference of the American Chemical Society, where, in Heino's memory, she received the Glenn T. Seaborg Award for Nuclear Chemistry. Heino was recognized for the "first chemistry of bohrium and hassium, the first confirmation of element 114, and fundamental behavioral studies of actinides in the environment."

In September, Martha attended the 2015 Migration Conference in Santa Fe, NM. The biannual Migration Conferences provide an international forum on chemical processes that control the

migration behavior of actinides and fission products in natural aquifer systems. Heino was honored at the conference banquet.

Richard Wilson, one of Heino's first students, helped solve a vexing problem for Martha—what to do with his beloved 1983 Mercedes Benz 280E. Says Martha, "We had the car shipped to Germany for our stay there, and then back with us to the Bay Area. Even though it was 33 years old, I couldn't bear the thought of scrapping it or seeing it being driven around town by a stranger."

She contacted Wilson, who is now a research scientist at Argonne National Laboratory near Chicago. He was delighted to take the car, which brought back many fond memories for him. Says Wilson, "Heino was more than a doctoral adviser, he became a trusted confidant and friend. I don't want to say that he was like a father, I have one of those, but he was pretty darn close."

One of Heino's last students is Jennifer Schusterman, who is now a postdoc at Lawrence Livermore National Laboratory.

Notes Schusterman, "I feel very lucky to have had Heino as my Ph.D. adviser for four years. He truly embraced being a mentor to his students. He made sure that we knew the fundamental experimental methods, but also pushed us to expand our creative thinking and challenge ourselves."

Through Martha's generosity to the college, the legacy of Heino's caring for students will continue.

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INVESTING IN RESEARCH SUPPORT

In 1911, prior to joining the College of Chemistry as a faculty member and dean, G.N. Lewis suggested to UC President Wheeler that the university fund the construction of a new chemistry building to include laboratories, offices and a machine shop.

Lewis also recommended increased funding both to hire additional faculty, assistants, a machinist and a glassblower, and to purchase research and shop equipment. Only after Wheeler agreed, did Lewis come to Berkeley and begin his lifelong task of creating the best chemistry and chemical engineering research institution in the world.

The college shops quickly became a critical resource for scientific discovery, and remain so today. For more than a century the shops have helped design, develop and construct research equipment and laboratory facilities. Today the shops provide R&D support totaling more than $2 million annually in labor and material recharges.

But maintaining this tradition of excellence is becoming harder and harder. As the state of California has begun to disinvest in the University of California, short-sighted budget cuts have devastated the college shops and many other research support centers on the Berkeley campus.

It has been 18 years since the college shops last received state funding for upgrading technology and replacing equipment. In the shops, equipment has long exceeded its useful life. Some of the equipment dates back to WWII, and some of that was military surplus when purchased. Shop machinists continue to replace worn bearings, rebuild vacuum tube-controlled equipment and repair computer motherboards on milling machines.

In this era of budget cuts, the college shops have not been able to take advantage of advances in technology like 3D printing, laser and plasma cutting, electronic discharge machining, and water jet cutting. Says shops manager Norman Tom, "We spend too much of our time figuring out how to use broken and obsolete equipment instead of facilitating the innovations of our researchers."

To address these challenges, Dean Douglas Clark has committed to establishing the Center for Excellence in Research Innovation Support (CERIS). CERIS will rebuild and advance the college's R&D support infrastructure.

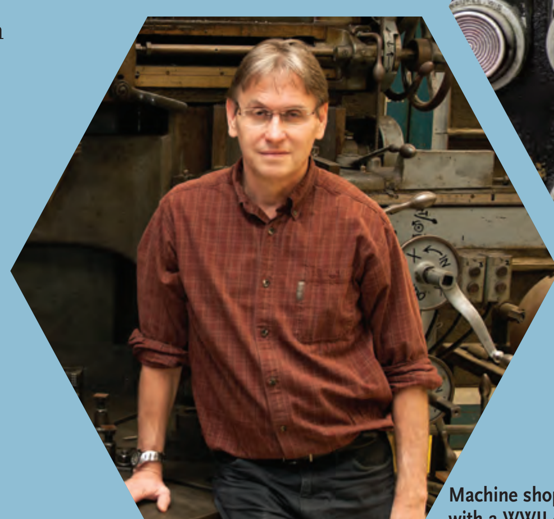
The college has begun fundraising efforts for purchasing modern shop equipment, upgrading technology and replacing obsolete equipment. In addition to serving the college, shop technical services will be offered to other campus users, private industry and the community.

As an integral part of the campus research innovation ecosystem, CERIS will offer state-of-the-art shop technical support to experimental research, campus innovation initiatives, incubators and startups.

CERIS has also established a partnership with an education outreach program in Engineering. Shop staff will work with engineering undergraduates in work-study positions. These engineering students will have an opportunity to apply their classroom learning in a real-world environment in support of cutting-edge research.

Through CERIS, the college will build upon the Lewis-era legacy of supporting excellent research with excellent shops and provide a vital missing piece in the campus research innovation ecosystem. Technical support will be considered an investment in research success, rather than another expense to be cut. CERIS will set the standard for creating innovation through strategic long-term investment in research support.

For more on CERIS, see **twitter.com/CERIS_UCB**



Machine shop manager Eric Granlund with a WWII-era vertical lathe.

PLANNED TECHNOLOGY UPGRADES ($1.9 MILLION TOTAL)

- Water Jet
- 3 Axis Vertical Machining Center (VMC)
- 5 Axis VMC
- VMC Tooling
- CNC Lathe
- CNC Lathe Tooling
- CAD /CAM Software
- CAD/ CAM Hardware
- Fused Deposition Modeling 3D Printer
- Stereolithographic 3D Printer
- Direct Metal Printing 3D Printer

MAJOR RESEARCH ADVANCES MADE POSSIBLE BY COLLEGE OF CHEMISTRY SHOPS

- Giauque (Nobel prize)
  Low Temp Lab equipment
- Y. T. Lee (Nobel prize)
  Crossed molecular beams machine
- G. Pimentel
  Mars Mariner 6 & 7 IR spectro-photometers
- NASA
  Mars MAVEN project in conjunction with Space Sciences Laboratory
- G. Somorjai
  SEM and STM for surface chemistry and catalysis
- R. Mathies
  DNA sequencing, Human Genome project, lab on a chip
- D. Clark
  bioassay chips and drug screening
- A. Pines
  advanced NMR and MRI applications

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Benjamin Ide Wheeler Society

The following have communicated to us their intention to include the College of Chemistry or the University of California, Berkeley in their estate plans through some form of planned gift.

Raul E. Acosta and Selma Gluck-Acosta
David and Beverly Altman
Charles E. Auerbach
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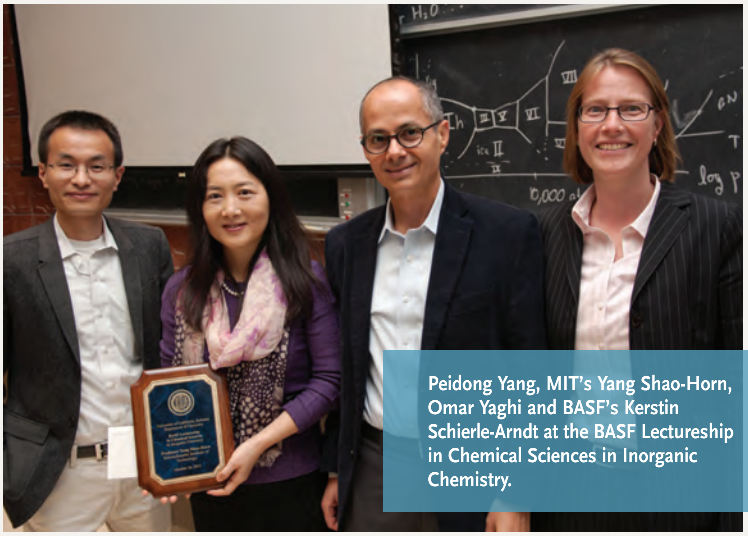

Peidong Yang, MIT's Yang Shao-Horn, Omar Yaghi and BASF's Kerstin Schierle-Arndt at the BASF Lectureship in Chemical Sciences in Inorganic Chemistry.

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2014–15

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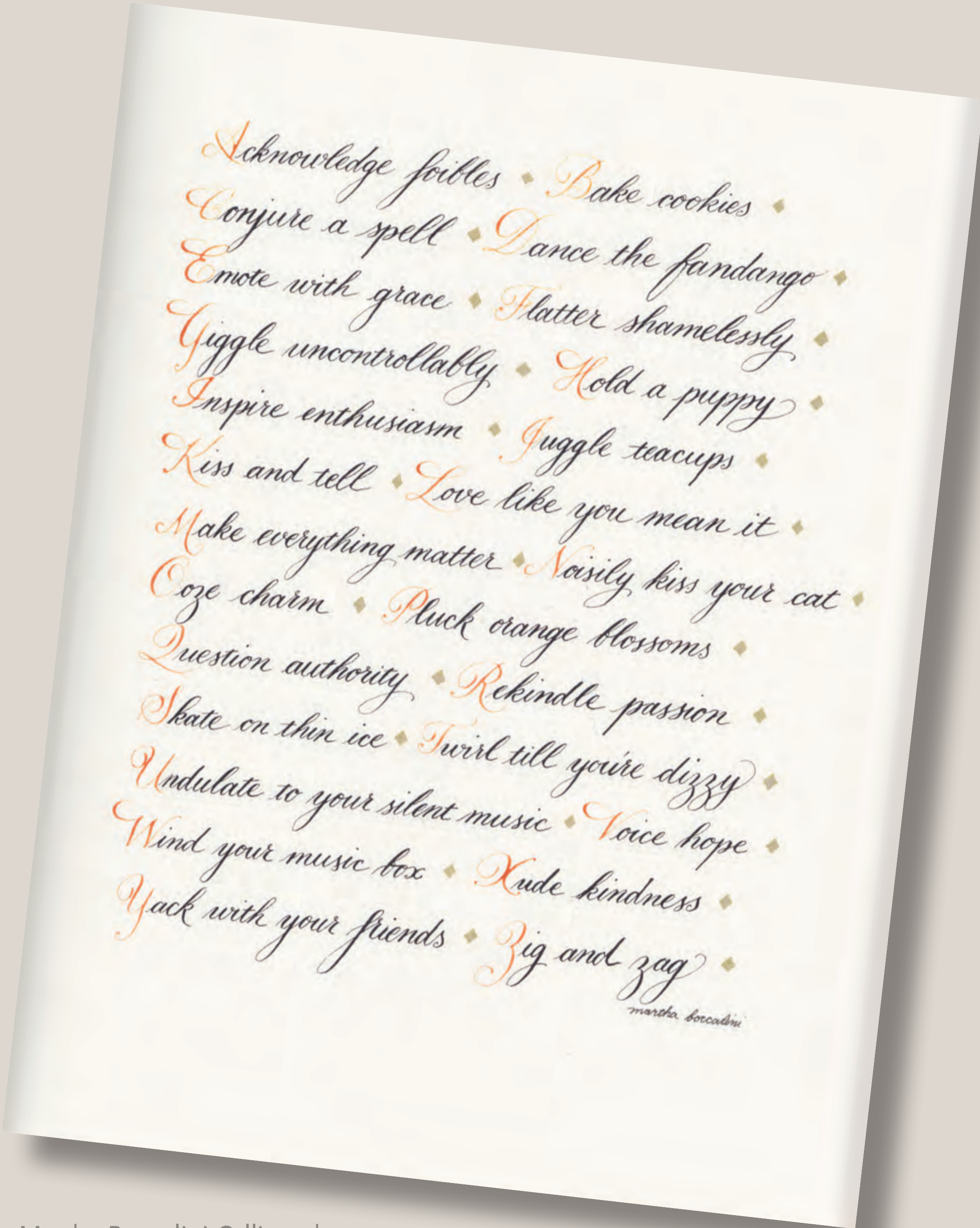

Martha Boccalini Calligraphy

In addition to her skill as a fine artist, Martha Boccalini is an accomplished calligrapher. She created this piece to be displayed in the office where her late husband, chemistry professor Heino Nitsche, met with his students.

After their group photo on the plaza, members of the Hartwig group crammed into the freight elevator to return to their lab upstairs in Latimer Hall. Fortunately, the elevator's weight limit is 5,000 lbs.

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Cal Day
April 16 **11:00 a.m.–2:00 p.m.**
This campus-wide open house will feature various activities and presentations in the College of Chemistry.

Check **calday.berkeley.edu** closer to the date for more info.

Berkeley Lectures in CBE
April 25 & 27 **4:00 p.m.**
Banatao Auditorium, Sutardja Dai Hall
Professor Jens K. Nørskov of Stanford University will present two lectures.

Wednesday's lecture will be followed by a reception in the atrium.

College of Chemistry Commencement
May 14 **2:00 p.m.**
Zellerbach Hall

+ For more information on events, visit **chemistry.berkeley.edu/events,** or email **coc_events@berkeley.edu**

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GINZA, TOKYO, 2008 / ARTIST: ALEXANDRE HERVÉ

The college recently sponsored a photo contest to provide artwork for our conference rooms. We'll display some of the finalists here. Hervé is currently a postdoc at LBNL.

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