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Catalyst

Fall 2015 Volume 10 • Issue 1
COLLEGE OF CHEMISTRY • UNIVERSITY OF CALIFORNIA, BERKELEY

A tale of two technologies

BIOFUELS AND BATTERIES

- The quantum world of Birgitta Whaley
- Meet CBE's new faculty members

Catalyst

COLLEGE OF CHEMISTRY
UNIVERSITY OF CALIFORNIA, BERKELEY

ON THE COVER

An agave plant in the UC Berkeley botanical garden. Dozens of species grow in Mexico and the American Southwest. Agave has tremendous potential as an energy crop for California's semiarid climate.

ALL TEXT BY MICHAEL BARNES UNLESS OTHERWISE NOTED.

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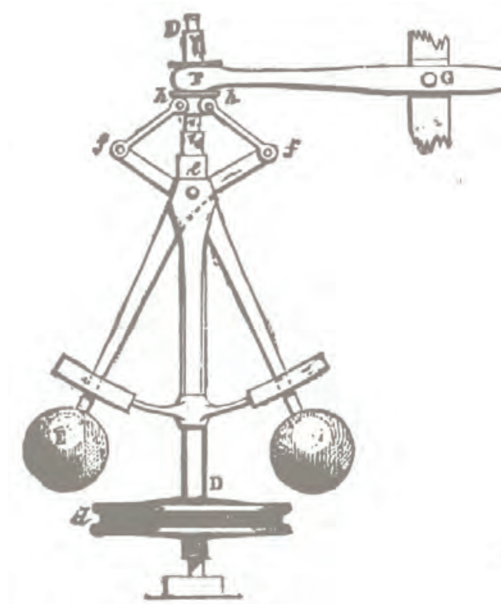

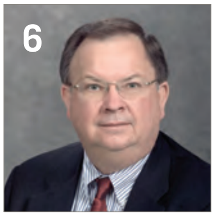

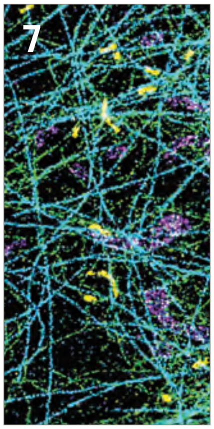

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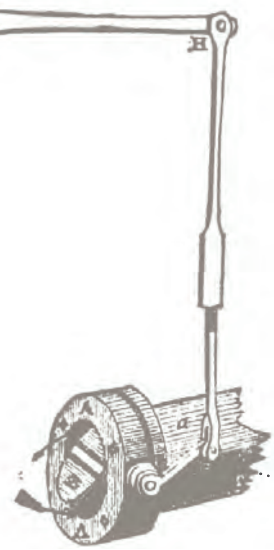


A Formula for Growth in Challenging Times

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

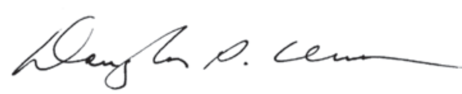
Last spring the Committee of Two, consisting of UC President Janet Napolitano and Gov. Jerry Brown, agreed to eschew a proposed tuition hike in return for a modicum of increased State support for UC[1]; however, neither option makes up for drastic cuts in State funding over the past decade.

As pointed out by my predecessor Rich Mathies in a previous issue of *Catalyst* (v. 7.1), in 2012 less than 11 percent of Berkeley's revenue came from the State of California (in 2003, state funds accounted for about 40 percent of the total budget). Dealing with, and indeed prospering within, the new fiscal reality requires a multifaceted strategy for managing and generating income to support the College in fulfilling its basic educational mission and maintaining its position as a preeminent institution of research and education in the chemical sciences and engineering.

With new challenges come new opportunities, and the College of Chemistry is rising to the occasion through new initiatives and bold ambitions. In partnership with the College of Engineering, we are about to launch a fundraising campaign for a new building that will enable revolutionary research at the interfaces of chemistry, biology, engineering, and medicine.

We are actively pursuing the development of funding programs to encourage entrepreneurism and translate discoveries from our laboratories into successful commercial ventures that will benefit society, spur the economy, and generate revenue for the College. And we are expanding our activity in continuing education, along with exploring new professional degree programs along the lines of the highly successful Product Development Program in the Department of Chemical and Biomolecular Engineering. All of these initiatives have distinct upsides, all have the potential to stabilize the financial footing of the College, and all have benefited greatly so far from the support and involvement of our alumni.

Indeed, the support of our alumni has never been more important to our success. We are striving to develop new financial strategies across campus and within the College of Chemistry, and each involves renewed engagement and collaboration with our largest and most diverse asset: our graduates. It is an unprecedented opportunity for all of us to contribute to—and share in—the continued prosperity of a uniquely prosperous institution.



[1]The revised State budget provides UC with a 4 percent increase to its base budget for each of four years beginning in the upcoming fiscal year; however, given the current distribution of revenue, the 4% equates to a 1.7% increase to UC's core educational budget.

A view from Stanley Hall, with the old Donner lab building in the lower right. The new Joint Chemistry and Engineering Building will replace the old Donner, which is too small and cannot be renovated to meet modern research standards.

Seeking the elusive steady state

Seeing the last issue of the CoC magazine on my desk gave me pause to think about its title:

Catalyst \ˈka-tə-ləst\
def. (according to Webster)
1: a substance that enables a chemical reaction to proceed at a usually faster rate or under different conditions (as at a lower temperature) than otherwise possible
2: an agent that provokes or speeds significant change or action

The chemistry of life is in fact all about controlled catalysis of reactions. As we all learn early in chemistry studies, a reaction must be downhill in free energy to occur spontaneously. Unlike the chemical context, where we often want equilibrium to be reached to produce a desired product, in biology equilibrium is only approached upon death of the organism. Keeping life going is all about sustaining a near steady-state with energy and matter flowing in and out at nearly balanced rates. In Biophysical Chemistry we try to teach about how nature manages to accomplish this while carrying on with remarkably complex large-scale activities of many kinds.

Since I have taught Biophysical Chemistry for many years, the concepts are now ingrained in me with the biology context. However the *Catalyst* magazine made me realize that I now fall into definition 2: for the Department, it is necessary for me to facilitate change, and as in the biological context it is necessary not just to speed change or action but also to try to control it. The concept of steady-state is also again the key: in spite of significant fluxes in and out of people, material and funds, we must try to balance in and out quite carefully.

As Chair I have needed to understand the fluxes. The numbers are substantial. We have ≈ 150 undergraduate majors in Chemistry and Chemical Biology in and out each year, interesting to note that Chemistry has been gradually decreasing but Chemical Biology has increased to compensate quite closely—a case of a natural steady-state as these fluxes are hard to control. With graduate students the numbers are smaller, ≈ 70 per year, and we do actively manage admissions to try to keep the total number constant and maintain the balance between synthetic and non-synthetic chemistry, while maintaining the high quality of graduate students we get.

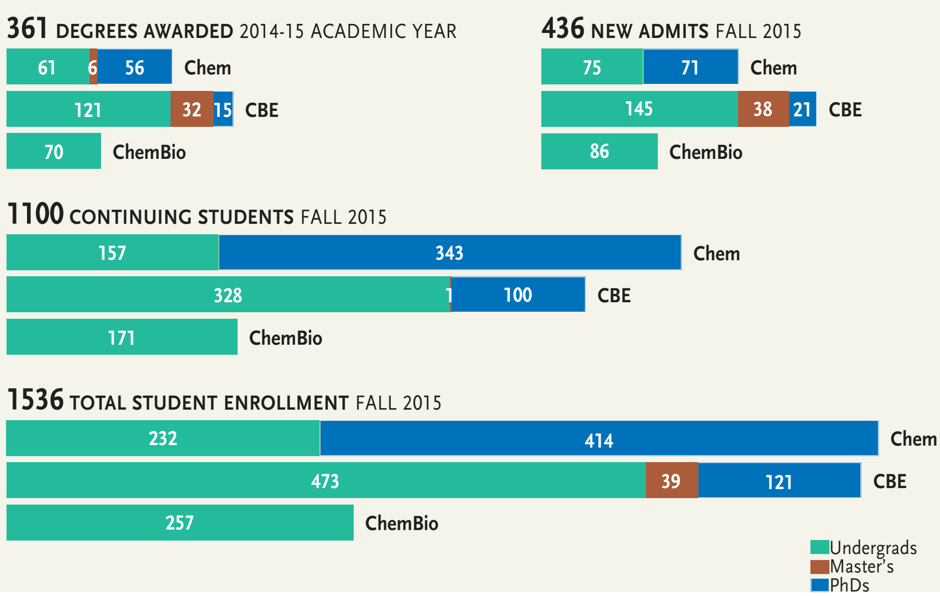
In spite of our efforts there are fluctuations, but the system is elastic enough to accommodate. The number of postdocs is regulated by funding of the faculty and individual postdoc grants, but is also significant with well over 100 in the Department. Faculty numbers are smaller but are still a challenge to sustain. We expect to need two faculty hires each year to fill slots opened by retirements and other departures. Each needs justification to the campus, the assembly of resources and space, and of course a major effort to identify the very best candidates possible. Here the generosity of Chemistry alumni has been a major help in making it possible to create attractive offers (thank you!); we have had a very good success rate in attracting top prospects.

DAVID E. WEMMER
Chair, Department of Chemistry
Joel Hildebrand Distinguished Professor

Part of the steady state is turnover. On the faculty side Gabor Somorjai, Charles Harris and David Chandler decided to formally retire at the end of this academic year, though we anticipate their continued participation in many aspects of the Department's life. On the staff side an early retirement benefit program induced several Department office staff to take this step. All part of 'life' in the Department, and the challenge of sustaining its leading position in Chemistry. I hope I have sufficient catalytic power to maintain steady state—and I thank all of those who help in this endeavor.

BY DAVID E. WEMMER

COLLEGE OF CHEMISTRY: **THE FLUX OF STUDENTS**



Op-Ed: CBE's value transcends politics

JEFFREY A. REIMER
Chair, Department of Chemical and Biomolecular Engineeering, Warren and Katharine Schlinger Distinguished Professor

It is surprising to me that elements of the political left and political right have chosen these times to assault the public research university. As exemplified by Governor Scott Walker from Wisconsin (but by no means exclusive to him), UC Berkeley is elite, expensive, and predisposed towards intellectual inquiry as opposed to job and skills preparation. As stated in the *New York Times* (Politics, Julie Bosman, February 16), "...[Walker holds a view] popular among many conservatives: that state universities have become elite bastions of liberal academics that do not prepare students for work and are a burden on taxpayers." California's own Governor Jerry Brown has lifted the veil on the trending liberal view of public research universities, arguing that neither the faculty nor the students are representative of California, that we are not teaching enough students, and that we are not seeking lower cost alternatives. Governor Brown, who seems to be abandoning Clark Kerr's Master Plan, has suggested "increasing the number of hours faculty spend teaching, moving classes online, encouraging students to finish their degrees in four years or less and make it easier for community college graduates to transfer to UC campuses (AP, 2/18, Armario)."

Clark Kerr on the Oct. 17, 1960, cover of TIME magazine. As UC president, Kerr formulated the Master Plan for Higher Education in California, which became a model for universities across the United States.

So how is all this playing out in CBE@ Berkeley?

It is certainly true that employers of our students (our "constituents") frequently tell us that the immediate skills needed for productive new hires are lacking. Interestingly enough, these job-specific skills used to be taught to new employees by their employer; but time and attention to that training either decreases corporate shareholder value, detracts from the frenzy of starting a company, or presents other capitalism-compromising issues. So our constituents ask that those skills be outsourced to the university such that student tuition and taxpayer dollars pay for it. CBE@Berkeley has not been very receptive to that outsourcing project for many reasons, not the least of which is that the immediate skills needed by our employers tend to be ephemeral (a CBE elective in Total Quality Management, anyone?). Our curriculum is aimed at helping students learn how to do any job, and to be adaptable in a changing environment. I can safely say that my colleagues would recommend a course reading Jane Austen, James Joyce, or Gabriel Garcia Marquez over a course in preparing Material Safety Data Sheets. "Culture eats strategy for breakfast" (attributed to Peter Drucker) suggests that our remarkable students need to focus on compelling authors that inform our culture rather than today's business strategy. Indeed, the real difficulty we face with liberals and conservatives may lie in the fact that public research universities do not easily hew to either the pressures from top-down political action or the forces of the marketplace.

Enrollment in CBE@Berkeley continues to avalanche this decade. In Fall of 2004, enrollment in our introductory course was 54 students. In Fall of 2012 it was 183. The State of California has given no additional resources to accommodate this explosion of students. Indeed, the only way we function is by innovating to do more with less, largely at the expense of faculty time in general, and the freedom to do research in particular. We are, however, fortunate compared to many other departments to have a faithful and responsive alumni that have provided time, talents, and treasure to ameliorate the problems with the double-edged sword of increased enrollment and decreased state support. Gifts from Chevron and Dow, for example, have upgraded teaching labs with new equipment. The time and talents of Berkeley alumni Henrik Wallman, Ravi Upadhye, Keith Alexander, Carlo Alesandrini, Marjorie Went, Paul Bryan, Steve Sciamanna, Dean Draemel, Greg Schoofs, and Colin Cerretani engage and uplift out students. But no amount of alumni time and support can return the time lost by professors to compliance, certification, and finance administration imposed by those upstream from us. I dare liberals like Governor Brown and conservatives like Governor Scott Walker to follow over a hundred CBE students into K-9 schools around the Bay Area, teaching engineering to students that look like neither governor. I dare them to come to Gilman Hall and follow any of our faculty through days that often start before sunrise and end well after sunset. I dare them to follow us working with minimal or no support through the myriad of paper policies that politicians have left for us, to work with us side-by-side while challenging adolescents to learn mass transfer, and to experience with us the onslaught of peer review and the dysfunction of overwrought bureaucracy in order to obtain modest research funds.

I offer another challenge from CBE@Berkeley. I beg governors Brown and Walker to come to our commencement and watch our graduates and their families weep with joy at achieving a degree from one of the most demanding programs in the world. Many of these families are first-generation Californians, and many are realizing a dream that began oceans away.

Finally, no small amount of media attention has been devoted to the UC budget. Kevin McCarthy, the Democrat from Sacramento who heads the Assembly budget subcommittee reviewing UC spending, said [regarding UC budget], "...even with new money coming into the budget, there's not enough money to go around. What are California taxpayers getting for that?" (*CC Times*, 3/14/2015, Katy Murphy). I'll answer that. As of this writing, UC Berkeley was just labeled as the best public university in the world (number 6 overall, *Times of Higher Education*), Berkeley was #3 in "Best Undergraduate Engineering Programs," and CBE@Berkeley was ranked number 2 in the U.S. (*US News*, 2015 rankings).

BY JEFFREY A. REIMER

CHEMISTRY

Grad student named ACS fellow

Chemistry graduate student Leah Rubin Shen moved to Washington, DC, this summer for a one-year adventure as one of two American Chemical Society Congressional Fellows. The ACS program places two Ph.D. fellows each year as staff members in the office of a senator, representative or committee. It is part of a broader effort administered by the American Association for the Advancement of Science (AAAS) that puts more than 30 scientists in Congress each year.

AWARD

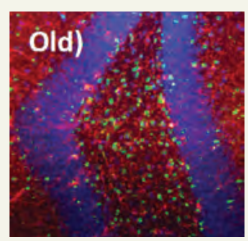
Shank receives DOE Enrico Fermi Award

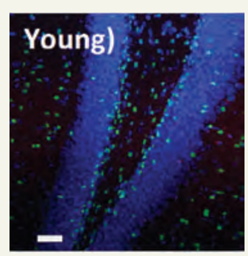
LBNL

Advisory board member Charles "Chuck" Shank has been named by President Obama to receive an Enrico Fermi Award, one of the federal government's oldest and most prestigious awards for scientific achievement. Shank, who served as LBNL director from 1989 through 2004, is an emeritus chemistry professor.

CBE

Drug perks up old muscles and aging brains



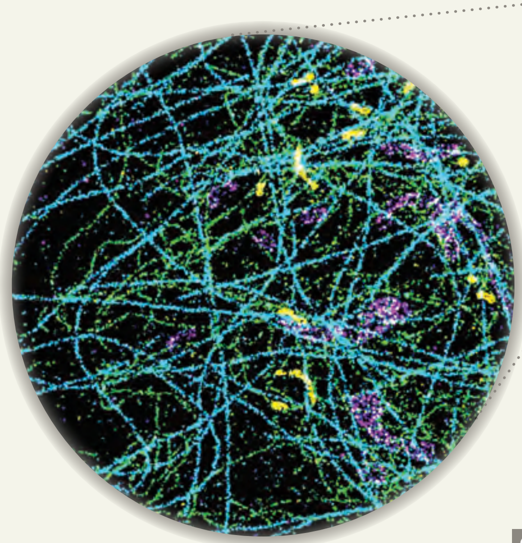


CBE professor David Schaffer has discovered that a small-molecule drug simultaneously perks up old stem cells in the brains and muscles of mice, a finding that could lead to drug interventions for humans that would make aging tissues throughout the body act young again. Says Schaffer, "That is good news, because if every tissue had a different molecular mechanism for aging, we wouldn't be able to have a single intervention that rescues the function of multiple tissues."

According to Schaffer's colleague, bioengineering professor Irina Conboy, the new drug interferes with the activity of a growth factor, TGF-beta 1, that depresses the ability of stem cells to renew tissue. "Based on our earlier papers," says Conboy, "the TGF-beta 1 pathway seemed to be one of the main culprits in multi-tissue aging."

NEW & NOTABLE

RESEARCH • VIEWS
DISCOVERIES • AWARDS



CHEMISTRY

Xu lab develops new super-resolution microscope

The research group of chemistry professor Ke Xu has invented a new technology to image single molecules with unprecedented spectral and spatial resolution, thus leading to the first "true-color" super-resolution microscope. Xu has dubbed the innovation SR-STORM, or spectrally resolved stochastic optical reconstruction microscopy.

CHEMISTRY AWARD

Sarpong wins RSC award

NIKI STEFANELLI

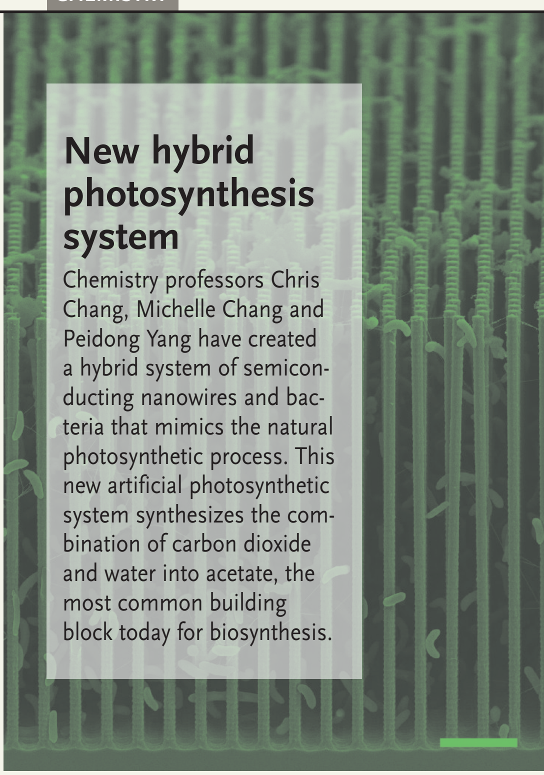
Chemistry professor Richmond Sarpong is the winner of the Royal Society of Chemistry's Synthetic Chemistry Award for 2015. "I am very grateful for this award, which recognizes the creativity, passion, and tireless efforts of my talented coworkers. I am very much indebted to them for all our successes," says Sarpong.

CBE

PDP program expands

CBE's Product Development Program (PDP) continues its growth as it welcomes its largest class ever—38 new master's degree students for the Fall 2015 semester. The program has outgrown its original location in Gilman Hall and has moved into new, expanded facilities on the fourth floor of Latimer Hall.

CHEMISTRY



New hybrid photosynthesis system

Chemistry professors Chris Chang, Michelle Chang and Peidong Yang have created a hybrid system of semiconducting nanowires and bacteria that mimics the natural photosynthetic process. This new artificial photosynthetic system synthesizes the combination of carbon dioxide and water into acetate, the most common building block today for biosynthesis.

ORDINARY STRANGENESS

Birgitta Whaley on how quantum mechanics will soon be a part of your life

It was an odd place for a UC Berkeley chemistry professor—PianoFight, a bar/performance space in San Francisco's Tenderloin district, on a July evening. Yet that is where Birgitta Whaley found herself, powerpoint slides on the screen, giving a lecture on quantum mechanics to a surprisingly attentive and appreciative audience.

Whaley's talk, "The Quantum Strangeness Beneath Our Everyday World," was sponsored by Wonderfest, a Bay Area educational non-profit. Says Whaley, "I think it's important for professors to reach out to the public. At the PianoFight talk, I wanted to stress to the listeners that quantum mechanics is not just a theoretical curiosity. More and more, devices based on quantum mechanics are becoming part of our lives."

A hip bar in a sketchy San Francisco neighborhood is a long way from where Whaley was born in 1956 in Barnehurst, Kent, southeast of London. Whaley's father was a British civil servant who had served in Army Intelligence in Germany immediately after WWII and who became a well-known and respected translator of the poetry of J. W. Goethe.

Her mother, originally German and with a background in history, German literature, English and philosophy, was a language teacher who taught German and French in the local schools. The couple met after the war in Tübingen, a 7th-century university town in the southeastern state of Baden-Württemberg, west of Bavaria. Whaley grew up in England but spent many childhood summers in Germany.

"I took five years of chemistry and four years of physics in high school, in addition to higher mathematics," Whaley says. "By the end of high school, I was already gravitating to the mathematical end of chemistry. I started at Oxford in 1974. I took courses for the first three years and did research in the fourth year on semiclassical quantum dynamics."

Whaley graduated in 1978 with a B.A. in chemistry. Before enrolling in a Ph.D. program, she spent one year as a Kennedy Fellow at Harvard University. She then attended the University of Chicago, where she earned her Ph.D. in 1984 in the research group of John C. Light.

Whaley's postdoctoral appointments took her to Israel for two years, first as a Golda Meir Fellow at Hebrew University in Jerusalem, then on to a position at Tel Aviv University. In 1986 she joined the College of Chemistry faculty.

Since 2004 she has co-directed the Berkeley Quantum Information and Computation Center, which brings together researchers from several fields to work on fundamental issues in quantum algorithms, quantum cryptography and quantum information theory. More recently she has turned her focus to different aspects of quantum biology and what we can learn from the natural world to help make better quantum devices.

And that brings us back to that hip bar/performance space in a sketchy neighborhood in San Francisco, where on a Monday night, Whaley prepared to explain to the audience how quantum mechanics has become part of our everyday world.

"I like to talk about MRI scans, since they involve two aspects of quantum mechanics, superconductivity and nuclear spins," says Whaley. The intense magnetic fields produced by MRI (magnetic resonance imaging) machines depend on superconducting magnets. In superconducting materials, electrons are correlated in such a way that they can travel without resistance. With zero resistance, even at low voltages, an immense amount of current can be pumped in the windings of the coils of the superconducting magnets, creating fantastically powerful magnetic fields.

These magnetic fields in turn align or "flip" the quantum spin states of protons in water molecules. The protons are then exposed to a radio frequency (RF) field, which alters their spin. When the RF field is turned off, the protons realign with the magnetic field and give off an RF signal of their own that determines the nature of the tissue and its location.

In MRI, the protons align with the powerful magnetic field in either an up or down state. But protons and other sub-atomic particles can also exist in superimposed states, where the particles can be in two states at the same time. In quantum computing devices, these particles capable of existing in superposition are called quantum bits or "qubits."

Unlike the standard binary bit of classical computer science, the qubit can take on infinitely many values. Quantum computing with qubits can in theory speed up some calculations—finding factors of extremely large numbers, or rapid searches through immense databases—by several orders of magnitude.

Says Whaley, "You can now buy a computing device that appears to exploit quantum effects, although the jury is still out as to whether it is a true quantum computer. On certain complex optimization problems, it is predicted to be able at least to keep pace with, and sometimes go faster than, the best classical computers. Prototypes of these quantum computers are currently being made by D-Wave systems in Vancouver, BC." (see: www.dwavesys.com).

When Whaley turns to discussing quantum entanglement, the conversation takes on the air of science fiction—except that the

Birgitta Whaley explores the hidden realms of quantum mechanics in her Gilman Hall office.

devices based on them are already in use, and more are coming in the next decade.

The states of electrons, photons and other subatomic particles can become correlated in ways that appear classical as well as in ways that have no classical analog. When one or more particles engage in a specific non-classical correlation where the correlated particles can be separated by large distances, they are said to be entangled. Einstein referred to this counterintuitive feature of quantum mechanical correlations as "spooky action at a distance." In 2012 researchers reported in *Nature* magazine that they had set a new record by separating an entangled pair of laser photons by more than 88 miles, distributing them between the islands of La Palma and Tenerife.

There is a special advantage to transmitting information by sending entangled photons. Unlike conventional communication, if quantum-encoded information is intercepted, the information itself is changed. This makes quantum communication an ideal mechanism for transmitting secret keys in cryptography. The weakness of any cryptographic system is that no matter how sophisticated, an eavesdropper may intercept the key transmission and discover the identity of the key. However, if quantum key distribution is used to transmit the key, any eavesdropper can be detected and the corresponding key rejected.

Says Whaley, "The Swiss national elections employ quantum cryptography in the Canton of Geneva to protect the dedicated line use for counting its ballots. In Europe, firms are using quantum key distribution over fiber optic cables to send secure information between their offices."
(see: www.idquantique.com).

Researchers at the University of Bristol and Hewlett-Packard are working to incorporate quantum key distribution in cell phones with a small laser that can act as an ATM card, sending a secure code to a bank machine. This technology should become available in the next few years. Auto and house keys may be designed along the same lines.

In 2007, Whaley read a paper that opened her eyes to the world of quantum biology. It was co-authored by Berkeley chemistry professor Graham Fleming and suggested that the light-harvesting mechanism of photosynthetic organisms relies on quantum mechanics to funnel energy to reaction centers with efficiencies close to 100 percent. There is also tantalizing evidence that some birds may navigate with help from quantum mechanics.

Says Whaley, "The remarkable thing about these natural systems is that they maintain the coherence of the quantum entanglement for several picoseconds or more at normal temperatures, something that we have not figured out how to do in artificial systems. With luck we can use biological quantum systems as engineering models. That bodes well for the future of quantum computers."

As the evening wound down at the PianoFight session, Whaley left her audience with some big questions. "We know quantum coherence plays an important role in photosynthesis, which led to the oxygenation of Earth's atmosphere and the evolution of higher life. If quantum effects didn't exist, would life on Earth have evolved differently? How much does life itself depend on quantum mechanics?" These are questions that Whaley and her colleagues are beginning to explore.

A tale of two technologies

By Michael Barnes

Judging from the headlines, this is the best of times for batteries and the worst of times for biofuels. The all-electric Tesla Model S is a media darling, while the Environmental Working Group agrees with the American Petroleum Institute that federal ethanol biofuel mandates should be scaled back.

If you scratch the surface of these stories, a different reality emerges. College of Chemistry researchers are at the forefront of innovation in both batteries and biofuels, and the stories they tell are far more nuanced than those of the headlines.

CoC researchers affiliated with the BP-funded Energy Biosciences Institute are deeply disappointed by the energy company's decision to reduce funding for the institute. However, their disappointment and frustration stem not from EBI's lack of success, but just the opposite.

CoC researchers, along with their EBI colleagues, have made several significant discoveries. New CBE professor Ali Mesbah (see p. 19), an expert on process control, is looking forward to bringing a new level of sophistication to biofuels production (and many other areas).

Meanwhile, the lithium-ion batteries used to power electric vehicles are problematic. In many applications—jet aircraft, automobiles, laptops and cell phones—lithium-ion batteries have overheated, causing damage and fires and at least one well-documented case of fatalities.

To address this lack of inherent safety, CoC researchers are working on safer designs both in their labs and in startup companies based on their innovations. Another new CBE professor, electrochemist Bryan McCloskey (see p. 21), is exploring new battery designs to extend the range of electric cars.

If you are interested in easily digestible headlines and sound bites on batteries and biofuels, you are reading the wrong magazine. But if you are interested in the glorious ambiguities of the frontiers of research, jump into the stories in this issue of *Catalyst*.

BIOFUELS

The hardest problem

When Nobel Laureate Steven Chu became the director of Lawrence Berkeley National Laboratory (LBNL) in August 2004, he sat down with staff members and listened to their ideas about the role the lab could play in addressing the world's problems.

He got an earful about climate change, and concluded that the lab had the tools and the motivation to confront the hard problems he learned about. For Chu, one of the hardest problems was finding energy-dense, carbon-neutral transportation fuels to replace fossil fuels.

With that goal in mind, he championed the establishment of the Energy Biosciences Institute (EBI) in February 2007, which brought together UC Berkeley, LBNL and the University of Illinois to lead a $500 million, 10-year biofuel research effort funded by the energy company BP. By 2014, EBI was utilizing the skills of more than 100 professors and LBNL scientists along with 250 graduate students, postdocs and technicians.

But after only seven years of the 10-year contract, BP announced at the end of 2014 that it was terminating its funding for the major portion of EBI's research portfolio—cellulosic biofuels. No doubt the decision was based on the damage to BP's bottom line from plummeting oil prices and the cost of the 2010 Gulf Coast oil spill cleanup. But the other reality, as Chu had realized a decade earlier, is that biofuels are hard.

EBI's new building near the northern edge of the Berkeley campus now feels a bit like a high-tech ghost town. EBI has already phased out its work on cellulosic biofuels, which was a large part of its research portfolio. BP did give enough notice to allow dozens of postdocs to finish their research, and some lab groups are still working in the building. EBI is being restructured to keep working on its other projects, with reduced funding from BP and with, the institute hopes, new funding from other companies interested in renewable energy.

For now BP will shift its biofuel efforts to Brazil, where it has well-established biorefineries based on sugarcane. It's a shift that doesn't sit well with Heather Youngs, EBI's senior analyst and the executive editor of *Bioenergy Connections,* the institute's magazine.

"Of course we're grateful for all the funding BP has provided during the last seven years, but BP's decision to end research on cellulosic feedstocks is short-sighted. The cane fields of Brazil can't begin to supply the raw materials for a worldwide biofuel industry large enough to put a dent in CO_2 emissions. Sources other than sugarcane and corn will have to be developed."

Here in California, the Global Warming Solutions Act of 2006 (AB32) and Executive Order S-3-05 require that the state reduce its greenhouse gas emissions to 80 percent below 1990 levels by 2050, while accommodating the growth in its economy and population.

According to the California Council on Science and Technology (CCST), a nonpartisan, impartial think tank established by the California legislature, achieving the state's ambitious 2050 goals will require a major revision in the state's energy production and use, including the production of cellulosic biofuels here in California.

The CCST report, *California's Energy Future,* assumes electrification of much of the transportation sector and home and business heating, which will require a doubling of electricity production with nearly zero emissions. Replacements for natural gas will be required for heavy industries and for smoothing out electricity generation from intermittent renewable sources like wind and solar. Most autos, light trucks and railroads will be electrified. However, liquid fuels will still be required for aircraft, ships and long-haul trucks.

Since California's climate is too dry for either sugarcane or corn, biofuels will need to be based on cellulosic biomass. These cellulosic biofuels are derived from grasses, crop residues, wood waste, municipal garbage and other sources. Along with Youngs, EBI director Chris Somerville participated in the CCST study and together they wrote the section on biofuels in 2013. Says Somerville, "For California's climate, *Agave americana*, a relative of the blue agave used for making tequila, has real potential to be grown in semiarid areas as an energy crop."

Cellulose is a major component of biomass and is the most abundant biopolymer on the planet. It is a polymer of the simple sugar glucose. It's difficult to believe that a cotton t-shirt is made of one of the two components of table sugar, or sucrose. A molecule of sucrose is a disaccharide made up of one atom each of glucose and fructose. It dissolves easily in water, and humans are fond of its sweet taste.

Cellulose is constructed in plants from the glucose they make from water and carbon dioxide via photosynthesis. It is tough stuff. It doesn't dissolve in water. It doesn't taste sweet. Humans can't digest it.

Toss an old t-shirt in your back yard, and it may take months or years to degrade. That's because over millions of years, plants evolved complex crystalline structures of cellulose that form tight hydrogen-bonded layers. They are almost impervious to weather and the attacks of bacteria and fungi that would like to get at those simple sugars. Cellulose's structure also makes it hard for humans to get at those simple sugars.

The process of making and using biofuels is like a fast-motion movie of plants growing, but in reverse. Start with plants, grind them up, treat them to release cellulose and break it up into its constituent glucose atoms, process it into a fuel and burn it, producing carbon dioxide and water and releasing the sun's energy that allowed the plant to grow in the first place.

Unlike burning fossil fuels, producing and burning biofuels does not make radical changes to the Earth's carbon budget. Burning fossil fuels removes carbon that has been stored underground for millions of years and moves it into the atmosphere in a geological instant. Burning biofuels just recycles carbon between plants and the atmosphere on an annual cycle.

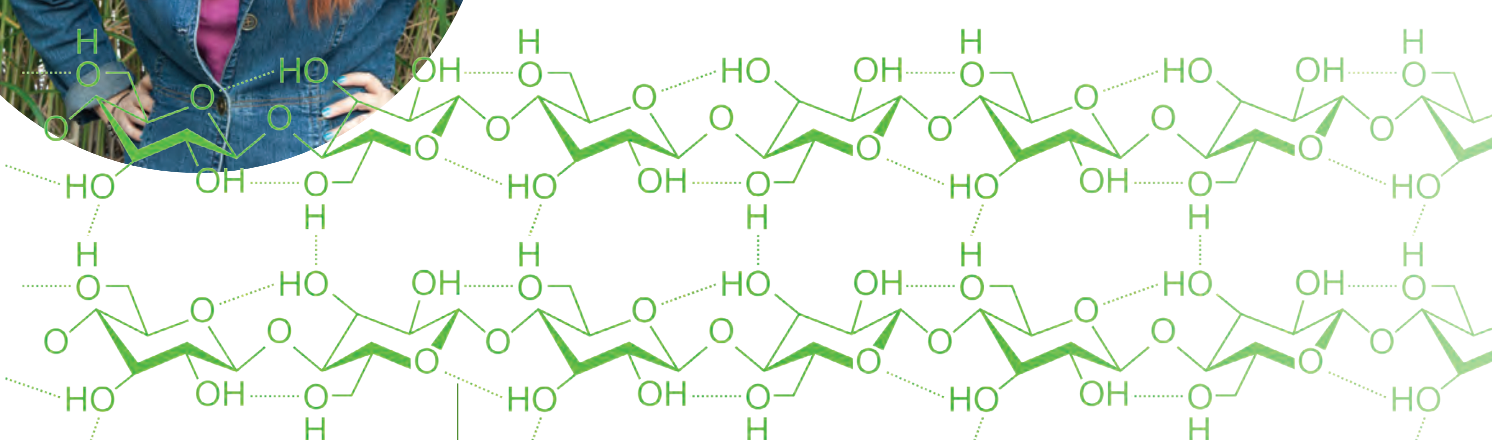
The production of cellulosic biofuels can be broken down into two phases. First, cellulose must be degraded to its constituent sugars, and second, the sugars must be converted to fuel. The first phase, cellulose-to-sugar, has proven to be the most difficult, and BP has thrown in the towel. EBI, with help from College of Chemistry researchers, has had more success with the second phase—sugars-to-fuel—and BP is still interested in pursuing that work. Several College of Chemistry researchers have devised ways to produce biofuels more efficiently. Three interesting innovations stand out.

In addition to cellulose, biomass consists of hemicellulose and lignin. While cellulose is a polymer of glucose—a hexose sugar which contains six carbon atoms—hemicellulose is a polymer of pentose sugars, which contain five carbon atoms. Lignin is a molecule that helps provide structural strength to plants and is less digestible for bacteria and fungi.

The varieties of yeast used for fermentation, including baker's yeast and brewer's yeast, are all different strains of *Saccharomyces cerevisiae*. Unfortunately, these yeasts are picky eaters. They'll ferment glucose, but not pentose sugars. One way to increase the efficiency of fermentation and biofuel production would be to breed yeast that also consumes pentose sugars. That is precisely what chemistry professor Jamie Cate has accomplished.

Many fungi, including *Neurospora crassa*, will happily break down hemicellulose to get at the pentose sugars. Cate and EBI colleagues added five genes from *N. crassa* into the yeast genome, allowing the yeast to ferment pentose sugars. But they didn't stop there. One of the byproducts of breaking down biomass is acetic acid (hydrogen acetate). The acetate ion is toxic to yeast and limits the productivity of fermentation.

HEATHER YOUNGS
EBI senior analyst



Cellulose

Benjamin Schwessinger and Jeemeng Lao examine switchgrass plants at DOE's Joint BioEnergy Institute in Emeryville.

LBNL

According to their January 2015 article in *ACS Synthetic Biology,* Cate and colleagues integrated the fermentation pathways of both hexose and pentose sugars and an acetic acid reduction pathway into one *S. cerevisiae* strain for the first time using synthetic biology and metabolic engineering approaches. The new strain produces 24 percent greater yield than the earlier strain.

The ethanol created by yeast is currently mixed with gasoline at up to 10 percent by volume, although "flex fuel" vehicles can run on blends that contain up to 85 percent ethanol. Ethanol is not a perfect fuel. Its energy density is low compared to gasoline, it readily absorbs water, and it is difficult to transport via pipelines. Most fuel ethanol in the United States is transported by rail, which has led to at least one deadly accident.

Ethanol may be most useful as a bridge fuel for autos and light trucks as they become electrified in the next several decades. The vehicles that cannot easily be electrified—ships, heavy trucks and jet aircraft—require fuels for which ethanol is not a substitute. These vehicles require more complex, longer-chain hydrocarbon "drop-in" fuels, fuels that can be processed and shipped using the world's vast existing petrochemical infrastructure.

If you're looking for a different biofuel, you could start with a different organism. That's what College of Chemistry professors Doug Clark, Harvey Blanch and Dean Toste did. They went back through the history of industrial fermentation to one of the first organisms used, *Clostridium acetobutylicum,* or the Weizmann organism (See *Catalyst* v. 5.1, p.12).

During WWI, industrial chemist Chaim Weizmann developed a process using *C. acetobutylicum* to produce acetone, a solvent necessary for making the artillery propellant cordite for the British military. Weizmann's process was also known as the ABE process, an acronym for acetone-butanol-ethanol, the three fermentation products.

Clark, Blanch and Toste gave this old process a modern twist by bioengineering the bacterium to produce a higher ratio of butanol and then using standard industrial heterogeneous catalysts to perform repeated rounds of alkylation, building up long-chain hydrocarbons suitable for replacing gasoline, diesel and jet fuels.

The ABE process was used commercially in the United States as late as the 1960s, and into the 1980s in South Africa, so there is a long history of industrial-scale ABE fermentation. As Toste notes, "While the chemistry portion is less proven on scale, it relies on heterogeneous catalysis, a mainstay of industrial chemistry today." Industrial-scale biofuel production via ABE fermentation could be possible in just a few years.

Perhaps the most remarkable aspect of this modern ABE process is its carbon yield—up to 90 percent of the carbon in the sugar feedstock will find its way into the final fuel product. Like Cate's bioengineered *S. cerevisiae,* the *C. acetobutylicum* used by Toste, Blanch and Clark is not a picky eater. It happily consumes a wide variety of the sugars available from the breakdown of cellulose and hemicellulose and will produce up to a gallon of fuel from 16 pounds of sugars.

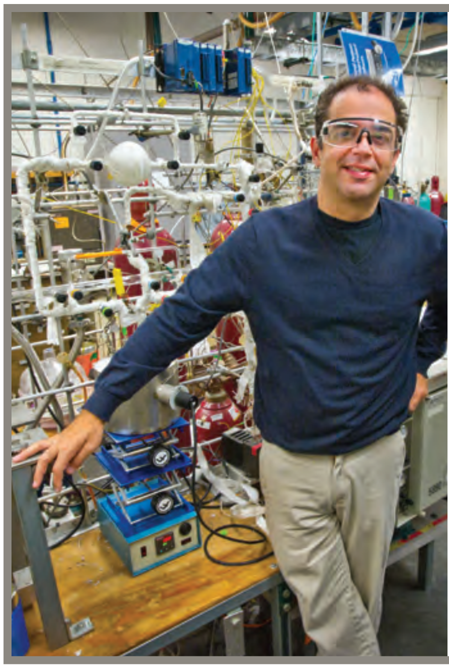
Buoyed by the possibilities of more efficient conventional and ABE fermentation, College of Chemistry professors have taken their research one step further. Toste joined forces with Alex Bell and EBI colleagues to produce an integrated model of how a sugarcane biorefinery could put together conventional fermentation, ABE fermentation and catalytic techniques to produce a suite of high-value jet fuels and lubricants.

Bell and Toste's process also produces lubricant molecules containing 33 carbon atoms. These are very similar to the benchmark synthetic lubricants poly-α-olefins, which are in high demand for automotive engine oils. While Toste and Bell are optimistic that their bio-lubricants will have similar properties to poly-α-olefins, they note that their products represent a class of compounds that have not yet been tested as lubricants.

Toste, Bell and EBI colleagues also conducted a life-cycle analysis that compared their production process to that of similar petroleum-based fuels and lubricants. Depending upon the desired mix of final products, greenhouse gas emissions were reduced anywhere from 57 to 87 percent, figures that are as good or better than using sugarcane to produce ethanol.

The model could also be tweaked to produce different sets of products based on other sources of biomass, including switchgrass, miscanthus and other energy grasses that can be grown in the United States on soil not suitable for food crops. Ironically enough, that is precisely the sort of research BP has defunded at EBI.

Biofuels remain a hard problem, both technically and politically. No one understands this better than the college's emeritus professor Harvey Blanch, who recently retired. He was affiliated with EBI and was the chief scientific officer for DOE's Joint BioEnergy Institute (JBEI) in Emeryville. Blanch was a veteran of the first renewable



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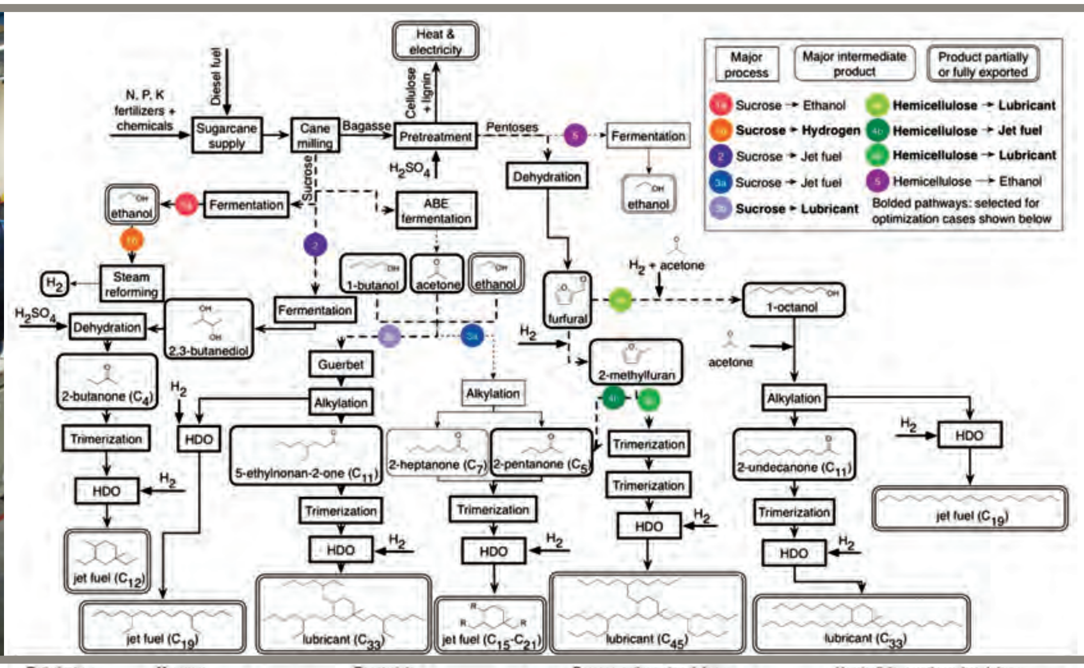


Optimization	Maximize	Constraints	Sucrose pathway breakdown	Hemicellulose pathway breakdown
A	Net GHG reduction	Zero acetone & H_2 imports/exports	1a: 30%; 3b: 70%	[illegible]; 4b: 78%
B	Jet fuel output (MJ)	Zero acetone & H_2 imports/exports	1b: 18%; 2: 82%	4b: 100%
C	Lubricant output (kg)	Zero acetone & H_2 imports/exports	3b: 100%	[illegible]

DEAN TOSTE
Chemistry professor

LBNL

CHRIS SOMERVILLE
EBI director

energy effort after the Arab oil embargo in the 1970s. He watched those research efforts fade when the Reagan administration came to power in Washington, DC, in 1980.

With the reduction of EBI's budget, a second round of efforts seems to be stumbling, although research at JBEI and other DOE labs will continue. Blanch is fond of pointing out that Saudi Arabia can profitably pump oil even at prices below $10 per barrel. With increasing competition from fracked oil in the United States, the Saudis have announced that they will no longer attempt to control price by restricting their output and instead will pump to maintain their market share. Low oil prices will probably be the norm for many years to come.

Sadly, low oil prices mean much less enthusiasm for renewable energy research, especially if that research is funded out of the profit streams of energy companies. Long-term research funding will require more patient funding sources, otherwise it will be the actions of Saudi Arabia and other big, low-cost producers that will drive renewable energy research budgets. The perverse incentives are obvious.

In a recent lunchtime talk to college staff, College dean and EBI-affiliated faculty member Doug Clark was philosophical. He stressed that the innovations and knowledge generated by EBI will not remain locked up inside BP headquarters. EBI generated hundreds of peer-reviewed papers in scientific journals, and the public has access to all that work.

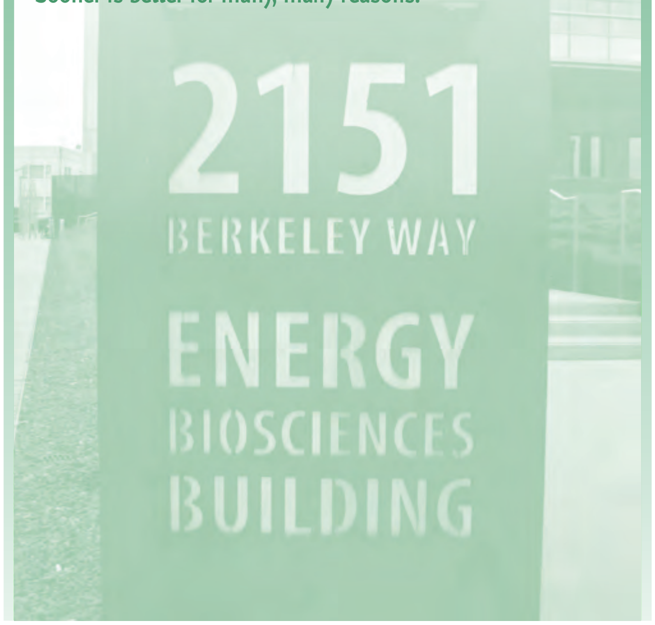
Says Clark, "EBI has made progress on many fronts. The College of Chemistry should be proud of its role in these accomplishments. Climate change is not going away, and alternatives to fossil fuels will only become more important. College researchers will remain committed to meeting the challenge of developing clean and sustainable energy."

THE ENERGY BIOSCIENCES INSTITUTE IS OPEN FOR BUSINESS

Energy Biosciences Institute director Chris Somerville is actively seeking new research partners. Says Somerville, "EBI has built an exceptional pool of scientific and engineering talent and research capabilities in liquid fuels, biomaterials, green chemistry and industrial biotechnology.

"BP has been impressed with the progress made by the College of Chemistry and other EBI-affiliated researchers, so the company will continue to fund EBI by an amount of about $5 million annually. BP is encouraging and assisting in the recruitment of additional industry partners. We'd like to get enough research partners to support a $20 million annual budget, including cellulosic biofuel research."

Notes Somerville, "By the time all the papers from the first tranche of EBI funding are published, we will have produced almost 1,000 scientific and engineering papers. For the sake of the future, sooner or later this research will be restarted. Sooner is better for many, many reasons."



BATTERIES

Hazards under the hood

BY ALEXANDRA DEL CARPIO

On September 3, 2010, a United Parcel Service Boeing 747 cargo plane took off from Dubai International Airport. Within 22 minutes an in-flight fire erupted, filling the cockpit with smoke and obstructing the pilots' visibility. After a failed emergency landing, the plane crashed, killing both pilots. A three-year investigation concluded that 880 pounds of lithium-ion batteries (LIBs) held in the cargo container had caused the fire. Had the fire occurred on a passenger flight, hundreds of lives could have been lost.

There have been other incidents in which LIBs have caught fire while being loaded or unloaded from cargo holds of jet aircraft. Even more dangerous are battery fires in the electrical systems of new jet aircraft. In 2013, the Federal Aviation Agency grounded the new Boeing 787 passenger plane after several incidents of overheating and fires in its LIBs. Closer to the ground, two battery fires in the Tesla Model S, both from impacts with highway debris, forced Tesla to weld a titanium plate to the undercarriage and raise the suspension of the vehicles.

Although the instances of fire are relatively rare, LIBs continue to compromise the safety of cargo planes, electric vehicles, cell phones and laptops. Professor Nitash Balsara of the Department of Chemical and Biomolecular Engineering wants to change this.

LIBs are the rechargeable battery of choice due to their ability to store large amounts of energy with relatively little weight. Inside, however, they contain a highly volatile and highly flammable organic solvent. This is fine if the battery works as it should, but battery failure—whether due to manufacturing defects or external abuse—is unavoidable and can result in an uncontrollable rise in temperature that vaporizes the solvent and pressurizes the battery. Scaled down to the size of a cell phone or laptop, the results are often minor, but when scaled up to a car or an airplane, the results can be catastrophic.

With each incident come greater safety precautions. Cargo planes now require fire-proof containers, while passenger planes no longer transport LIB cargo at all. Companies interested in large battery-powered devices have gone to great lengths to engineer sophisticated control systems that prevent disaster, increasing the level of complexity and price of the resulting product. Even so, the safety risks linger.

"It's an amazing statistic that only one in ten million cell phone batteries fails," says Balsara. "However, that kind of statistic—when extrapolated to a car—will give a failure rate of one in 10,000, which in my view makes it unacceptable."

Typical LIBs are composed of a liquid solvent electrolyte that is sandwiched between positive and negative electrodes. This electrolyte is the flammable component that Balsara wants to replace. Rather than developing complicated battery packs that work around this critical flaw, replacing the electrolyte with a non-flammable version would make the batteries inherently safe. This has been a dream for years, but a practical non-flammable electrolyte has proven to be elusive. Recently, researchers from Balsara's group at Berkeley, in collaboration with Professor Joe DeSimone's group at the University of North Carolina at Chapel Hill (UNC), have found a promising alternative to flammable electrolytes—perfluoropolyethers (PFPEs).

PFPEs have a similar structure to other non-flammable polymer electrolytes currently in development for LIBs, but possess a very unique and alluring property—even in contact with a flame, PFPEs do not ignite. In fact, PFPEs do not even vaporize below 200°C. This is in stark contrast to conventional LIB electrolytes, which produce flammable vapors at temperatures as low as 24°C. (75°F.).

The key to these nonflammable properties lies in the high fluorine content of the polymer backbone, but it comes at a heavy price. Alone, commercial PFPEs are useless as an electrolyte because the fluorine atoms decrease the polymer's ability to dissolve positively charged lithium ions. The ions are the workhorses in LIBs, shuttling between the electrodes during charging and discharging. By chemically altering the PFPE structure to incorporate a component that interacts favorably with the lithium ions, the Balsara lab was able to more than double the concentration of ionized lithium salts. But the researchers were not sure the ions would flow freely between the electrodes.

"There are tons and tons of polymers that dissolve salts but have zero conductivity—the ions are just stuck," explains Balsara. The flow of ions under an electric field, known as their conductivity, is an important criterion to help determine the viability of a new material as an electrolyte. It turns out that the conductivity values in the PFPE system are fair, albeit two orders of magnitude lower than conventional electrolytes.

Conductivity, however, is only part of the story, as lithium salts are composed of both positively charged lithium cations (Li+) and negatively charged anions, but only the flow of Li+ is important for batteries. In the PFPE electrolyte, the anion is largely immobile, while Li+ flow is responsible for most of the current. This is an unexpected result, as Li+ in conventional electrolytes typically accounts for less than half of the current. According to theoretical calculations, this is very promising because it may increase battery life and offset the relatively low conductivity of PFPE electrolytes.

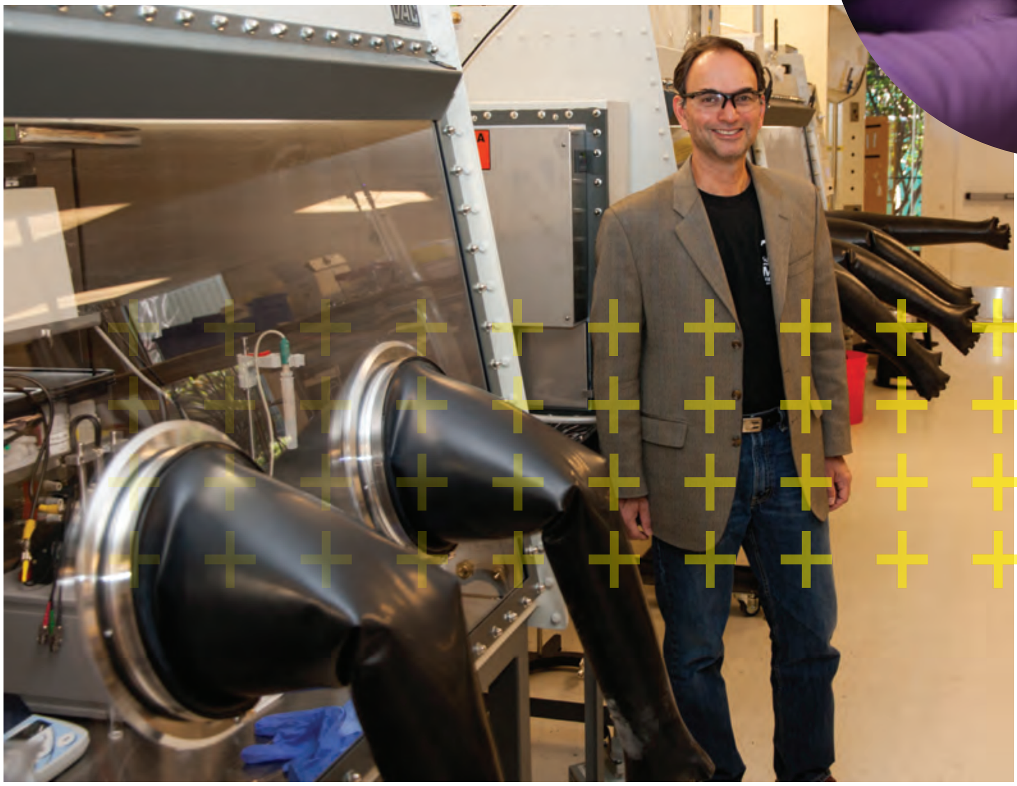
These PFPEs studied by Balsara and DeSimone are not yet ready for consumer use, and much more work will be required to increase their conductivity and successfully incorporate them into working batteries. The two researchers decided the best way to make batteries with PFPE electrolytes a reality was to found a startup, which they named Blue Current.

"There comes a point in your R&D when you think that something is important enough that you want the answer quickly," says Balsara. "Things can happen a lot faster in startups than they can happen in academic labs." Among campus researchers, Balsara is not alone in this type of reasoning. More than 162 Berkeley-licensed startups have been created since the mid 1990s. At Berkeley, it is not uncommon for professors to straddle the fence between research and industry.

Carol Mimura is the Assistant Vice Chancellor for Intellectual Property and Industry Research Alliance (IPIRA). The job of IPIRA is to determine if campus inventions require patent protection, and whether companies would want to license the intellectual property. The potential of inventions cannot always be determined simply by reading a patent or licensing agreement. Academic inventors often have a depth of understanding of a new technology that can assist a new company. Sometimes inventions can only be commercialized through the passionate drive of the inventor.

In these situations the best way to get inventions to market is to license to a faculty startup. Some new technologies, according to Mimura, "are something that existing companies feel are too risky, too uncertain, to commercialize." Big companies can't invest the time and money required to bring every nascent technology to market, and academia is often incapable of bridging the gap. This is where faculty startups like Blue Current come in.

Mimura cautions, however, that university startups face many challenges. Professors making the transition from academia are often unfamiliar with entrepreneurship or have become too accustomed to the everyone-for-themselves culture at top-level research institutions. "It's difficult for many career academics to transition directly into startups, work well in teams, and be flexible with changing directions," she



NITASH BALSARA
CBE professor

says. “They tend to hold on too strongly to the original idea or are not open to what their board is telling them because they are used to being top dog in the lab.”

Raising money is another major hurdle. Angel investors who invest in risky startups not only help solve this issue, but also come with experience and contacts that can help make their investments fruitful. Mimura calls it “smart money.”

Balsara and DeSimone were able to bypass many of these challenges. DeSimone had connections to angel investors who were interested in Blue Current, and both he and Balsara had previous experience founding startups stemming from research in their laboratories. With smart money in their pockets and experience under their belts, the two professors decided to add another company to their portfolio. Blue Current was born.

The company’s focus will not be on answering theoretical questions regarding the mechanism of ion transport through the electrolyte, but instead on developing a working device. One of their biggest challenges will be integrating their electrolytes with commercially relevant battery electrodes. “Once you incorporate these new electrolytes into a battery, they have to play nice with the electrodes,” explains Alexander Teran, the chief battery engineer at Blue Current and an alumnus of the Balsara lab. In particular, it is necessary to form a stable solid-electrolyte interface (SEI) between the electrolyte and the electrodes. The SEI prevents electrolyte decomposition, increasing the amount of current that the battery can handle and preventing failure.

Sacrificial additives, which get consumed during the first charge to form the SEI layer, are a logical solution, but the trick lies in figuring out which additives to use and how much. “There’s a lot of work to be done to understand how these PFPE materials, which are very different from conventional electrolytes, behave with regards to the SEI layer,” says Teran.

Improving conductivity through the electrolyte is also on the to-do list, and industrial battery testers that can test 128 prototypes at a time help Blue Current determine the optimal parameters. This equipment is a luxury that Teran’s colleagues in academia usually don’t have access to. Conversely, Blue Current does not have the luxury of taking the time to unravel the subtleties underlying transport mechanisms of the electrolyte.

Although further experiments will be required to improve the PFPE system, Teran and Balsara are optimistic that Blue Current will overcome the typical challenges that plague other battery startups. One advantage is their narrow focus on the electrolyte. Another is the compatibility of the PFPE system with current LIB chemistries, which will make switching to Blue Current’s new electrolytes straightforward. “There are other battery startups with technology that might be really interesting, but it involves completely reinventing how the batteries are manufactured,” explains Teran. “You basically have to rebuild the battery from scratch.”

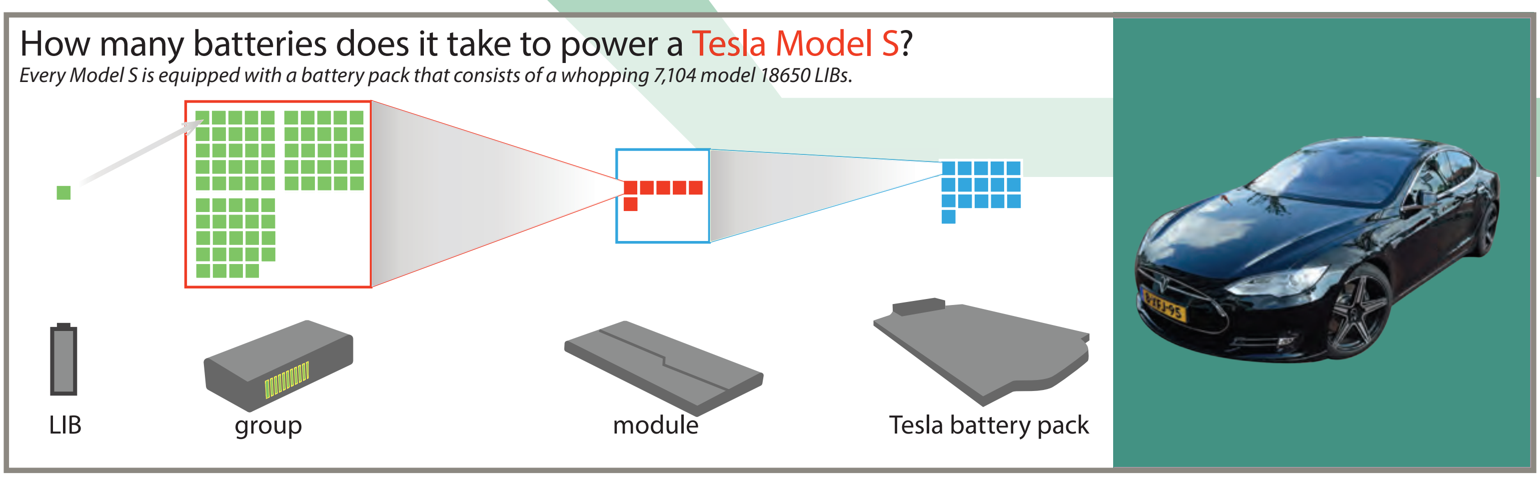
Not only does the compatibility of Blue Current’s electrolyte allow Teran to test his batteries using standard, off-the-shelf materials and components, but it also makes the technology more attractive to battery manufacturers. These companies will be able to seamlessly incorporate Blue Current’s new electrolyte. This is a key advantage, since Blue Current needs to gain attention from established companies in order to test their electrolytes on a larger scale and ultimately commercialize their work.

Convincing end users like Boeing and Tesla of the value of the technology is also important, since these companies can sway their battery suppliers to work with Blue Current. These big companies are, after all, the ones that would benefit most from the inherent safety of non-flammable electrolytes.

According to Balsara, the 7,000 batteries in a Tesla each have their own temperature-measuring device, and the car is equipped with the equivalent of two refrigerators to cool down any battery that goes above temperature. “Tesla spends a lot of money and time making a dangerous product safer, but if we can make these battery packs inherently safe, we can eliminate a lot of extra monitoring equipment and make them cheaper as well,” he says.

Blue Current still has some work to do before making this a reality, but Balsara hopes that his integration of the complementary approaches of academia and industry will lead to a better battery that will benefit everyone with a safer and greener ride.

A previous version of this story appeared in Berkeley Science Review*, a magazine produced by Berkeley graduate students.*



DESIGN: HOLLY WILLIAMS; DATA: TESLA MOTORS; MODEL S: WIKIMEDIA COMMONS

Groups are created by wiring 74 LIBs in parallel. Then, six groups are wired in series to create a module, 16 of which comprise a battery pack. Fully charged, the pack supplies 85 kWh of energy. Compare this to your standard laptop, which operates on less than 0.1 kWh of energy. See graphic on p. 22 for more on model 18650 LIBs.

Ali Mesbah

ASSISTANT PROFESSOR OF CHEMICAL AND BIOMOLECULAR ENGINEERING

[Process Systems and Control]

Ali Mesbah was born in Tehran, Iran, in 1983. His parents were both professors, his mother in chemical engineering and his father in international politics. After earning his B.S. in chemical engineering from the University of Tehran in 2004, Mesbah moved to the Netherlands to enroll in a master's program in chemical engineering at Delft University of Technology.

Says Mesbah, "My two-year program involved one year of courses and one year of research. My M.S. research was purely experimental. I synthesized zeolite membranes for gas separation in membrane reactors. The work was successful, and I was offered a chance to pursue the research as a Ph.D. student. But pure experimental research was not my thing—I found myself drawn to theoretical research involving mathematics."

Mesbah decided to switch to control theory. Says Mesbah, "My mother, a chemical engineering professor, told me I was taking a big risk, but I was driven by intellectual curiosity. I earned a graduate degree in systems and control theory from the Dutch Institute of Systems and Control, and then a Ph.D. in 2010 from Delft University of Technology.

"I wrote my thesis with advisers Paul Van den Hof and Herman Kramer on nonlinear model predictive control of batch crystallization processes. This was a distinct achievement for process control research since my results were applicable to industrial-scale crystallization processes. My thesis research taught me that theoretical developments should make a difference in real world systems."

For his first postdoctoral appointment, Mesbah stayed at Delft University, where he perfected theoretical tools for autonomous maintenance of model-based control systems. "I briefly worked in South Africa," he mentions, "where we validated tools at plant scale using one of the largest plant simulators in the world."

For his second postdoc, Mesbah moved on to MIT and the lab of chemical engineer Richard Braatz. Mesbah worked with the Novartis-MIT Center for Continuous Manufacturing, a research collaboration aimed at transforming pharmaceutical production. The center develops new technologies to replace the pharmaceutical industry's conventional batch-based system with continuous manufacturing processes.

Continuous manufacturing allows the use of smaller production facilities with lower costs that minimize waste, energy consumption and raw material use. It also allows continuous monitoring of drug quality rather than post-production, batch-based testing.

At MIT Mesbah designed a bench scale model for thin-film processing. Thin films, medications that dissolve in the mouth, eliminate solids process handling. Dry chemicals are difficult to handle in continuous processing. In addition to thin films, Mesbah developed a plant-wide model predictive control system for an end-to-end continuous pharmaceutical manufacturing pilot plant, the first for continuous processing in pharmaceuticals.

Mesbah joined the CBE faculty in 2014. "Here at Berkeley," he says, "the primary thrust of our research is to make fundamental advances in the area of systems analysis techniques and control theory for complex chemical and biological systems. It's a big shift from my work at MIT.

"Complex systems have three features—highly non-linear dynamics, uncertainties of a probabilistic nature and systems composed of several sub-systems. My modeling techniques stress first principles, the physical and chemical bases of systems. I am usually opposed to data-driven modeling approaches that treat real-world systems as black boxes that churn out numbers to be analyzed. Model validation and understanding the underlying principles are very fundamental to my work.

"I strongly believe in application-relevant theory, in contrast to theory for the sake of theory—I attempt to validate the theoretical developments for real-life applications. In particular, I work on life science and energy applications. The ultimate aim is to facilitate high-performance and cost-effective operation of complex systems.

"The main applications that my research group is working on are stochastic modeling of cell-signaling pathways in biological cells, stochastic predictive control of atmospheric-pressure plasma for biomedical applications such as wound healing, and advanced control of biochemical processes for conversion of biomass to drop-in biofuels."

THE ORIGINS OF CONTROL THEORY

Control theory confronts problems that, if not quite as old as the wind itself, are at least as old as wind-powered machinery. Today, control theory is a modern branch of applied mathematics, one that allows chemical engineers to optimize the operation of complex batch and continuously operating processes. But control theory's roots lie in a simpler and much older problem—grinding good flour.

In Europe, during the several centuries preceding the development of steam engines in the late 1700s, most grain milling was done by water and windmills. In a water-powered mill, it was easy to control the speed of the grinding stones simply by adjusting the rate of water flow. But the wind doesn't flow as steadily as water. When the wind lulled, the milling stones inside windmills would literally grind to a halt, ruining the consistency of the flour.

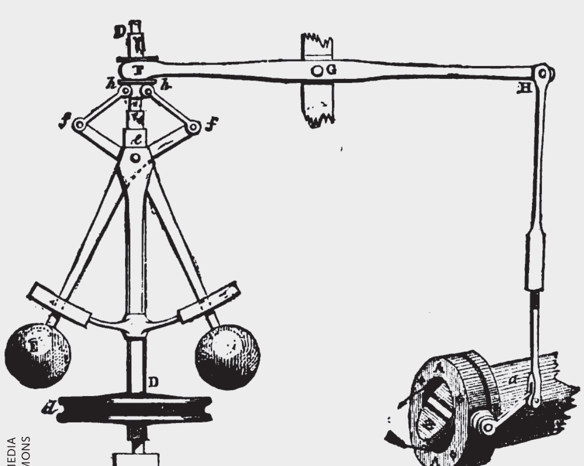


FIG. 4.—*Governor and Throttle-Valve.*

WIKIMEDIA COMMONS

Around 1788, English inventors patented centrifugal ball governors to compensate for shifting wind speeds. Scottish inventor James Watt, who was then perfecting the steam engine, took note of these governors at the suggestion of his business partner Matthew Boulton, and installed them on their company's steam engines.

Governors were a big help in regulating the speed of steam engines, but they could themselves be unpredictable. In some cases, the governor was ineffective, and if the load dropped suddenly, the governor would not prevent the engine from running away. In other cases, the governor lagged and overcompensated, causing oscillations in engine speed that could either dampen or grow larger over time.

The problems with governors caught the attention of one of the most brilliant scientific minds of the 1800s, mathematical physicist James Clerk Maxwell. In 1868, Maxwell published a paper simply titled "On Governors." In it, he described the laws of motion of governors by using differential calculus. In these differential equations, the variables and their rates of change appear together. As any second-year calculus student can attest, these equations can be fiendishly difficult, or even impossible, to solve explicitly.

Maxwell's paper laid the foundation for control theory. Today, control theory has a variety of applications from aircraft autopilots to robotics, and for chemical engineers, plant operations. A modern continuously operating plant can require the use of several feedstocks, a variety of sub-processes operating at different temperatures and pressures, many monitoring points and controls, all to produce a final product that requires extremely high consistency. These plants are vastly more complex than early steam engines, and they require control systems based on correspondingly complicated mathematical modeling techniques.

Ali Mesbah is the first control theorist to be hired in the Department of Chemical and Biomolecular Engineering since Alan Foss, who joined the faculty in 1961 and remained at Berkeley as an emeritus professor until his death in 2006.

Foss published a short but provocative essay in 1973 titled "Critique of Chemical Process Control Theory." In this paper Foss laid out a succinct summary of a proper theory for chemical process control. He identified the theoretical features necessary for a chemical process control approach to be of practical value.

The paper inspired a new generation of process control theorists and practitioners in academic and industrial chemical engineering. A key result was the development of model predictive control (MPC), a theoretical framework that has been remarkably successful in a wide variety of applications.

Ali Mesbah is now using MPC as a foundation for his novel research into dynamics and control of complex chemical and biological systems. Alan Foss would have been happy to see his ideas return home.

Bryan McClosky

ASSISTANT PROFESSOR OF CHEMICAL AND BIOMOLECULAR ENGINEERING

[Electrochemical energy storage, molecular and ionic transport through polymers]

Bryan McCloskey was born in Ft. Collins, CO, in 1981. His father was a Larimer County water-quality engineer and his mother taught in the federal Head Start Program for pre-kindergarten children.

For a brief period in his academic career, it appeared that McCloskey might follow in his father's footsteps. As a Ph.D. he focused on molecular transport through microporous polymeric membranes, with a particular emphasis on membranes for water purification. But as a postdoc he was drawn away from water purification to new lithium-battery technologies.

McCloskey prefers to blaze his own trail. "My brother studied forestry and is now a master arborist, but in school, I never had much interest in the bio side of science. And although Ft. Collins, located about an hour north of Denver, is a great place for winter sports, I only skied once. When I was 15 I was captivated by a young golfer named Tiger Woods, and I decided golf was for me. I liked the technical aspect of it."

After graduating from high school in 1999, he headed to the Colorado Schools of Mines in Golden, CO, for his undergraduate studies. "CSM was the right place—it is passionate about engineering and has a fantastic department for undergrad ChemE education, so that's where I went. I majored in ChemE with a minor in economics. Since 7th or 8th grade I wanted to do ChemE because I liked the combination of chemistry and math, but I really had no idea what a ChemE professor did."

McCloskey learned what professors did by working with two, Thomas McKinnon and Andrew Herring, on combustion and soot formation. McKinnon was known for having perfected a technique to make a new form of carbon, C60 "buckeyballs," from soot. McCloskey's primary task was to use mass spectroscopy to study the formation of volatile aromatic compounds resulting from the pyrolysis of biomass chars, which he says is "a fancy way of saying we were studying the composition of second-hand cigarette smoke."

McCloskey earned his ChemE B.S. in 2003 and enrolled at the University of Texas at Austin for his doctorate. He joined the research group of chemical engineer Benny Freeman (who earned his Ph.D. with Morton Denn at Berkeley in 1988). The Freeman lab focuses on polymers and polymer membranes for gas separation and water purification.

"Austin is an aesthetically pleasing city," says McCloskey. "I have fond memories of living there and getting out into the hill country, especially cliff diving at Pace Bend Park and BBQ at the famous Salt Lick." During his Ph.D. studies, it seemed McCloskey would devote his career to water purification, much like his father had. In the Freeman group he worked on membrane separations and water purification, earning his doctorate in 2009.

For his postdoc, he moved to IBM's Almaden Research Center in San Jose, CA. Says McCloskey, "I had worked with IBM staff scientists on water-purification membranes as a grad student, and they mentioned the possibility of a postdoc at their Almaden lab. I originally planned to study how to use membranes to keep water out of lithium-air batteries, but the group was working on electrochemistry more generally, and I gravitated toward that.

"Almaden Research center is a fantastic place. I really enjoyed working on the lithium-air battery as part of IBM's Battery 500 project, which had the goal of designing a battery that could power an automobile for 500 miles. I had all the resources I needed at IBM to learn on the job." McCloskey was a postdoc at Almaden from 2009 to 2011, then stayed on as a Research Staff Member at IBM until November 2013 and subsequently joined the CBE faculty in January 2014.

Lithium-air batteries attempt to combine the best characteristics of two existing battery technologies, zinc-air batteries, and lithium-ion rechargeable batteries. Zinc-air batteries are the tiny batteries used in hearing aids. They have high energy density because they get one of the reactants, oxygen, from the air, so it doesn't take up space inside the battery.

Conventional rechargeable lithium-ion batteries power devices from cell phones to electric cars. They can be recharged hundreds or even thousands of times, and they also have relatively high energy densities. If researchers could combine the best attributes of both in the lithium-air battery, the result would be a very compact, energy-dense rechargeable battery.

Says McCloskey, "Lithium-air is being studied because of its high theoretical energy density. However, the rechargeability is the big concern—it's very difficult to get it to recharge a few times, let alone thousands of times. Most of my research at IBM focused on characterizing the rechargeability limitations in the battery, and it is clear to me that a breakthrough will be necessary to provide the stability to allow it to compete with lithium-ion."

Batteries still have a long way to go in order to compete with the energy density of fossil fuels. One gallon of gasoline, which can be pumped into a car in just seconds, has the energy equivalent of 33.4 kWh (kilowatt-hours) of electricity. The Tesla Model S has an 85 kWh battery, which stores the equivalent of about 2.5 gallons of gasoline. To be fair, the Tesla's electric drive train is so efficient that with a full charge it can get 265 miles of range at freeway speeds, or the equivalent of more than 100 miles per gallon.

Charging time is another issue. If a conventional auto needs an additional 25 miles of range, a driver can pump the necessary fuel in just a few seconds. For a Telsa Model S, adding that much range with a conventional 110-volt, 12-amp household circuit can take 6-7 hours. If an electrician can provide you with a 240-v, 80-amp circuit, that time is reduced to 25 minutes. A public supercharging station can bring that time down to around 3 minutes. But as a rule, when it comes to energy transfer rates, gasoline has batteries beaten by two to three orders of magnitude.

Notes McCloskey, "These are the some of the problems my research group would like to help solve. In general, we are searching for the fundamental breakthroughs in electrochemistry that will take us beyond lithium-ion batteries."

McCloskey has a joint appointment with LBNL, as part of the Electrochemical Technologies Group in the Division of Energy Storage and Distributed Resources. His role at LBNL has taken him back to Golden, CO, not only the home of his alma mater, but also that of the DOE National Renewable Energy Lab (NREL). He says, "Ironically enough, I only learned of NREL after attending the Colorado School of Mines for a few years. Now I am very familiar with the lab's work—I just had a proposal funded with a scientist at NREL as a co-PI.

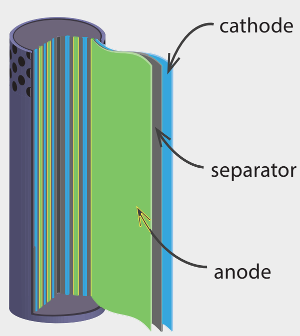
"The synergies between the College of Chemistry and the national labs are obvious. When nature lobs us hard big problems, we have to respond with big science, and working with the national labs allows me to do that."

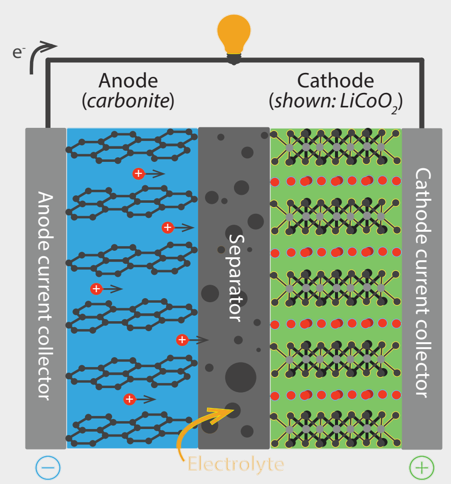
The science behind lithium-ion batteries

The most commonly used LIB is the 18650. These batteries are used in laptops and Tesla vehicles.

Inside, thin sheets of the anode, cathode, and separator materials are wrapped into a "swiss roll".

The separator is a microporous polymer membrane whose pores are filled with liquid electrolyte.





Lithium cations move towards the cathode when the battery is discharging, and back towards the anode when charging.

DESIGN: HOLLY WILLIAMS; BATTERY: LEAD HOLDER; LIGHTBULB: SIMPLEICON.COM

Class of 2015

What will they be doing after commencement?

In the spring, some of the students who planned to walk in the May 2015 commencement ceremony shared their plans with us:

"Since my job is a mixture of Computer Science and ChemE, I plan on learning more CS by getting a master's in CS. I may transition completely into the CS field as well."
—Aman Agrawala *(B.S. ChemE)*

"I will continue researching in the lab I am currently a member of for another year and apply to medical school during the 2017 AMCAS cycle."
—Renan Aparicio *(B.S. ChemBio)*

"After finally graduating with my Ph.D., I'm going traveling in Africa for two months (Cape Town to Nairobi—bungee jumping at Victoria Falls along the way). Following this trip will be adventures of a similar scale in South America. After half a year of traveling, I will be moving to London, UK, at the start of 2016 to begin a job consulting with McKinsey & Company. Once I learn some business and professional skills, I aim to return to working in the renewable energy field (but this time not from the lab bench)."
—Meera Elizabeth Atreya *(Ph.D. ChemBio)*

"Planning to study bioengineering as Ph.D. student."
—Atrouli Chatterjee *(B.S. ChemE)*

"I plan to get my Ph.D. in chemical engineering focusing on the theoretical and experimental aspects of electrocatalysis for photoelectrochemistry. I plan on securing a job in academia where I can serve as a leader in equity and inclusion in STEM and serve as a role model for Latino scientists."
—Steven Chavez *(B.S. ChemE)*

"Gap year (lab research, hospital volunteering)."
—Qidi Chen *(B.S. ChemBio)*

"I will take summer classes. I want to explore more statistical mechanics, so get into research for a year. If I still don't like research, I will just take classes at edX and educate myself in computer science or finance."
—Tony Cho *(B.S. ChemBio)*

"Serving in Mozambique through Peace Corps (maybe)."
—Tiffany Chung *(B.S. ChemE)*

"I will be returning to my hometown of Bakersfield, CA, to start my career as a petroleum engineer for a major oil company!"
—Joseph Leo Cooney *(B.S. ChemE)*

"I'm applying for internship/research positions as I intend to strengthen my skills in those areas before applying to postbaccalaureate programs. After a postbac, I intend to get into med school. My ultimate goal is to use my background in chemistry, my minor in Global Poverty and Practice, and (soon hopefully) medicine to reach out to countries in dire need of quality and affordable health/medical care."
—Zire Nasol Co-Untian *(Ph.D. Chem)*

"Will attend School of Pharmacy at UCSF starting Fall 2015."
—Lisha Deng *(B.S. ChemBio)*

"I plan on heading off to graduate school to earn a Ph.D. in chemistry!"
—Vivian Dien *(B.S. Chem)*

"I plan on going backpacking for a month after graduation and then going into the industry to work. After a few years of work, I might decide to extend my education by going to grad school or maybe even pursuing an M.B.A."
—Sumin Dong *(B.S. ChemE)*

"I want to go to pharmacy school or work in a pharmaceutical company."
—Kimsirey Em *(B.S. Chem)*

"Find a job, presumably in a non-ChemE field. Go for a statistics master's degree."
—Xue Fan *(B.S. ChemE)*

"I'll be starting a job with General Motors as a test engineer in the hybrid and electric propulsion division this summer and looking into a master's in energy systems engineering at the University of Michigan."
—Ian Forsman-Kendall *(B.S. ChemE)*

"Travel, Job, Grad School."
—Michael Forsuelo *(B.S. ChemE)*

"My goal is to remain involved in research concerning the generation of biofuels from otherwise untapped substrates."
—Brett Garabedian *(B.S. ChemBio)*

"I look forward to becoming an uncle and meeting the newest member of our family, Ollie, when he is born this upcoming summer. In the fall I will begin graduate studies on my path to a Ph.D."
—Martin Gelenter *(B.S. ChemE)*

"I will be going for a graduate program in chemistry."
—Rahul Goel *(B.S. ChemE)*

"I am so looking forward to spending some time with my family in India and then joining Honeywell UOP in September to continue on an interesting and exciting journey in the world of catalysis."
—Sarika Goel *(Ph.D. ChemE)*

"In August will be participating in an adult chamber music camp (http://college.interlochen.org/chambercamp), playing the piano. In September, I will be leaving for Chile and Argentina, where I will be visiting a former colleague who is now a professor, attending a biochemistry meeting, and traveling in Patagonia and Argentina. After that I will be back in the U.S. looking for an apartment and settling in for my postdoc."
—Daniel Goldman *(Ph.D. Chem)*

"I am joining the Vlachos lab at the University of Delaware as a postdoctoral researcher!"
—Konstantinos A. Goulas *(Ph.D. ChemE)*

"I will continue my research in organometallic chemistry beginning in the Fall of 2015 at the University of Pennsylvania as a Ph.D. student."
—Lauren Grant *(B.S. Chem)*

"I am entering a one-year coursework-based master's degree program at Stanford (M.S. in Environmental Engineering and Science)."
—James Edward Hake *(B.S. ChemE)*

"Probably work in energy-related industry, gaining experiences and skills necessary for my own startup in the future."
—Jun Hur *(M.S. ChemE)*

"Take one or maybe two years to gain more research experience and apply for graduate school."
—Loc Huynh *(B.S. Chem)*

"New job upon graduation: Engineering Program Manager at Apple."
—Crystal Jain *(B.S. ChemE)*

"Ph.D. in organic chemistry."
—Esther Jang *(B.S. Chem)*

"After graduation the plan is to join a Bay Area company in the exciting field of clean technology!"
—Arthur Quentin Dominique Marie Kegels *(M.S. ChemE)*

"Not sure about plans yet, but I have applied to both the Peace Corps to be a youth empowerment volunteer in Fiji, and also to the Biochemical Science and Technology master's degree program at National Taiwan University."
—Kathleen Keh *(B.S. ChemBio)*

"Graduate studies in chemistry and chemical biology at TSRI."
—Esther Kim Kemper *(B.S. ChemBio)*

"New job - research assistant in the Environmental Systems Dynamics Laboratory in Berkeley."
—Aayush Khurana *(B.S. ChemE)*

"Going for master's degree! Not in ChemEngineering Major!!!!!"
—Youngkyou Kim *(B.S. ChemE)*

"Going to work with my dad in industry!"
—King Jason Navarro Lam *(B.S. Chem)*

"I will take a gap year. After that, I plan to apply for grad school. In six years from now, I hope I can begin to work in the industry for small molecules synthesis."
—Thanh Le *(B.S. ChemBio)*

"A new job."
—Shuai Li *(B.S. ChemE)*

"I will be doing a postdoc until I start my faculty position in chemical engineering."
—Karthish Manthiram *(Ph.D. ChemE)*

"I intend to enroll in law school for Fall 2015. Although science will always be with me, I won't ever be doing it again."
—Christopher Marth *(Ph.D. Chem)*

"I will be researching kinase inhibitors in the Shokat lab at UCSF this fall. During the summer, I will be relaxing with outdoor adventures!"
—Elizabeth McCarthy *(B.S. ChemBio)*

"I will be immediately pursuing a master's degree, followed by a Ph.D. My dream is to ski in the morning and research in the afternoon."
—Alec William Michels *(B.S. ChemBio)*

"I am spending this summer working for GM in their battery division, then I'll be returning to Cal for one year to complete a master's degree in Materials Science and Engineering!"
—Morgan Monroe *(B.S. ChemE)*

"I am interested in finding a job as an atmospheric chemist."
—Tiglath Moradkhan *(B.S. ChemBio)*

"I'll be an environmental engineering Ph.D. student focusing on atmospheric organic chemistry and its implications for global climate change and human health."
—Josh Moss *(B.S. ChemE)*

"Continuing my studies at Princeton University for a Ph.D. in chemistry!"
—Michael Nechayev *(B.S. Chem)*

"Doing master's degree at Berkeley in Material Science."
—Han Ee Ong *(B.S. ChemE)*

"I'm going to Disneyland!"
—Patrick Vincent Nicolas Palad *(B.S. ChemE)*

"I will finish my study in the summer and work in the chemical engineering industry

in the States before returning to Indonesia for good."
—William Agung Prabowo *(B.S. ChemE)*

"Graduate studies in chemistry."
—Jake Precht *(B.S. Chem)*

"Grad school!"
—Rostam Razban *(B.S. Chem)*

"I will continue to be a graduate student until December."
—Peter Robinson *(Ph.D. Chem)*

"I'm going to apply to graduate school next year to pursue a doctorate in chemistry, perhaps in inorganic chemistry."
—Steven Noel Ruiz *(B.S. Chem)*

"M.B.A. at Berkeley."
—Ivan Salim *(B.S. ChemE)*

"Find a job."
—An Shi *(M.S. ChemE)*

"After graduating from Cal, I plan to continue working at ChillFlux, a Berkeley-born startup addressing challenges in the mobile electronics industry."
—Abbas M. Shikari *(M.S. ChemE)*

"Industry for a couple years and then hopefully pursue an M.B.A. and J.D."
—Nicholas Stephen Siegele *(B.S. ChemE)*

"Going to get an M.D. Ph.D.!"
—Mobin Skaria *(B.S. ChemBio)*

"Find a job in the U.S."
—Qiao Song *(M.S. ChemE)*

"Start a business to change alternative energies into a commonplace choice."
—Travis Stansbery *(B.S. ChemE)*

"I will work in a startup company developing cheaper material for solar cells, then I will see the need of further study based on the progress of the energy industry!"
—Dhea Suseno *(B.S. ChemE)*

"Planning to travel and start a new job!"
—Manali Tijoriwala *(B.S. ChemE)*

"I'll be a Ph.D. graduate student in physical chemistry at Princeton starting July 2015. This summer, I'll be traveling around the world (UK and Canada) to visit some friends and relatives."
—Nhu Tran *(B.S. Chem)*

"I'm taking a bit of a different route to explore the business side of things—primarily working with pharmaceutical firms in a business consulting capacity!"
—Katherine Tsen *(B.S. Chem)*

"Will be a classroom teacher in San Francisco."
—Eric Michael Uribe *(B.S. Chem)*

"Graduate school—Ph.D. program in BSMB @ UCLA or chemistry @ Penn State."
—Jing Yang Wang *(B.S. ChemBio)*

"I will be attending MIT as a Presidential Fellow in their chemical engineering Ph.D. program."
—Kira Watkins *(B.S. ChemE)*

"I plan to apply to medical school in the summer 2015 and will be taking a gap year. In that gap year I will be working as a research assistant or as a scribe."
—Shanice Renee Watts *(B.A. Chem)*

"Planning to go do research and apply to pharmacy school in upcoming academic year."
—Juwita Wijaya *(B.S. Chem)*

"Will pursue postdoctoral research with Prof. Huw Davies at Emory University."
—Sidney Malik Wilkerson-Hill *(Ph.D. Chem)*

"I'm attending the Japan America Student Conference (JASC) this summer. Past program alumni include former Secretary of State Henry Kissinger and former Japanese prime minister Kiichi Miyazawa. I'm hoping to learn lots and apply the skills from the conference to my job and leadership roles."
—Jason Yang *(B.S. ChemE)*

"I will be moving to southeastern Michigan for my first job! I will be designing and developing the battery systems for the current and next generation of electric vehicles made by GM."
—Edward Sihua Yang *(B.S. ChemE)*

"Gilbert plans to enter into the biotechnology consulting industry after graduation. He is staying in the East Bay, working at Beghou Consulting in Emeryville. He plans to go back to school to get a master's in chemical engineering in one or two years time. For now, peace out to chemical engineering."
—Gilbert Yang *(B.S. ChemE)*

"I will be pursuing a master's degree from the University of Pennsylvania while chasing my dream to be a famous musician and music producer."
—Nicholas Yiu *(B.S. ChemE)*

"Get a job after graduation for a couple years, then get my master's."
—Sasha Yogiswara *(B.S. ChemE)*

"I am planning to apply for graduate school this year."
—Junwoong Yoon *(B.S. ChemE)*

"Going to graduate school."
—Marc Zajac *(B.S. ChemE)*

"I'm going to Berkeley Optometry School in the Fall!"
—Tina Zeng *(B.S. ChemBio)*

"Sciencing further down in TSRI at La Jolla."
—Stephanie Zhou *(B.S. ChemBio)*

In Memoriam

Faculty

HERBERT L. STRAUSS

SUSAN WILSON

Emeritus chemistry professor Herbert "Herb" Leopold Strauss, an internationally recognized spectroscopist who studied the rotational and vibrational properties of molecules, died at home in Berkeley on December 2, 2014.

Strauss was born in 1936 in Germany. With the help of relatives, the family escaped Nazi Germany in 1939 for England and immigrated to the United States, where they lived in a small apartment in Queens, NY. The family placed great emphasis on education. Strauss studied chemistry at Columbia University as an undergraduate and a graduate student. He met Carolyn North Cooper in 1957, and they wed about the time Strauss finished his Ph.D. in 1960 with George Frankel, spending a year in Oxford while Strauss did postdoctoral research.

In 1961 Strauss joined the chemistry faculty at Berkeley, where he spent his entire professional career. Using Fourier transform infrared spectroscopy, he explored properties of a variety of molecules, especially n-alkanes with lengths of 5 to 40 carbon atoms. He also used Raman and neutron spectroscopy to study the rotations and vibrations of molecular hydrogen embedded in various systems, including ice and zeolites. He received the Bomem-Michelson Prize for Spectroscopy in 1994, as well as the Lippincott Award for Vibrational Spectroscopy.

Strauss's contributions to the College of Chemistry and the University were exceptional. Following retirement in 2003, Strauss continued to serve on campus, both as an Associate Dean of Undergraduate Affairs (1995-2008) and as a Professor of the Graduate School. During his tenure as associate dean, he was instrumental in increasing minority participation in the sciences, was very active in improving gateway courses in chemistry, mathematics and physics, and served as the campus coordinator for the Chevron Undergraduate Research Program for minority students. He received the Berkeley Citation in 2003 for his distinguished and extraordinary service to the University, as well as the Berkeley Academic Senate's Berkeley Faculty Service Award. He taught his last class, a graduate seminar, three weeks before his death.

He is survived by his wife, Carolyn North, and their extended family.

Friends of the college

SONYA RAPOPORT

Sonya Rapoport *(M.A. '49, Art Practice & History)*, widow of the late chemistry professor Henry "Rap" Rapoport, passed away on June 1, 2015, at her home in Berkeley. She was an innovative conceptual/digital and New Media artist who created computer-assisted interactive installations and participatory artworks. Rapoport (née Goldberg) was born in 1923 in Boston, MA. As a child, she took classes at the Boston Museum of Fine Arts and spent summers at the art colony in Ogunquit, ME. She attended MassArt and studied philosophy at Columbia University and biology at Boston University. Following marriage to Rap and moving in 1944 to New York, Sonya earned a B.A. in labor economics at NYU and attended the Art Students League of New York. In 1946 the couple moved to Washington, DC, where Sonya studied figurative art and oil painting at the Corcoran School of Art. Rap was then offered a professorship at Berkeley, and the couple moved to California. Sonya was introduced to Berkeley art historian Erle Loran through Melvin Calvin and his wife, and Loran mentored Sonya for the next 25 years. Emphasis on structure, a Berkeley influence, continued to inform her artwork. She is survived by her extended family.

ELISE C. STONE

We learned from her husband, Donald *(B.A.,'54, Med Sci)*, that Elise Stone *(B.S. '56, Public Health; Cred. '56, Public Health)* passed away on February 27, 2015, in San Mateo, CA. She was the daughter of Samuel A. Abrahams, an internationally known chemical engineer and a specialist in insulation materials, who earned a B.S. at Berkeley in 1926. Elise established the Samuel A. Abrahams Memorial Scholarship fund in 1967. The fund provides undergraduates in the College of Chemistry with support during their senior year. Elise kept in touch with the college and welcomed learning about each new Abrahams scholar, often visiting campus to have lunch with them. She was a health educator, traveler, reader, hiker, bridge enthusiast, political activist, musician and lover of the arts. Throughout her 59-year marriage, she and Don travelled to almost 50 countries; their travels increased after her retirement from the California Poison Center, where she had been the lead health educator.

Alumni

'39 Andrew A. Benson *(B.S. Chem)*, emeritus professor of biology at Scripps Institution of Oceanography, UCSD, and one of the leading plant scientists of the twentieth century, passed away on January 15, 2015. As an undergrad, he studied optics with Luis Alvarez and worked in Glenn Seaborg's lab. After earning a Ph.D. at Caltech in 1942, he returned to Berkeley as an instructor; in 1946 he was invited to join Melvin Calvin's photosynthesis group in the Old Rad Lab. Benson was the principal scientist who discovered the pathway used in photosynthesis to make sugars out of carbon dioxide, water, and sunlight. In a series of 30 publications, he and his colleagues worked out the pathway, which became known as the Calvin cycle (some scientists have called it the "Calvin-Benson cycle"). He is survived by his wife, Dee.

'40 We have learned from his daughter that William H. "Bill" Calkins *(B.S. Chem with Thomas D. Stewart)* passed away on January 24, 2015. Following WWII service in the Aleutian Islands and subsequent graduate studies at Berkeley, Calkins worked at DuPont until retiring in 1985. His DuPont projects included the development of Lucite and the development of alternative resource materials for plastics, as well as clean sources of energy. A resident of Wilmington, DE, he continued his work in fuel sciences as an adjunct professor in chemical engineering at the University of Delaware until 1999. He was predeceased by his wife, Elinor.

'43 University of Nebraska Medical Center (UNMC) emeritus professor Denham Harman *(B.S. '40, Ph.D. '43, Chem with Thomas D. Stewart)*, a scientist renowned for his 1954 proposal of the Free Radical Theory of Aging, passed away on November 25, 2014, in Omaha, NE. Harman, who was nominated six times for a Nobel, theorized that free radicals—highly reactive molecules freed in the normal chemical processes—cause aging and disease through their destructive actions in cells and tissues. At the time he developed his theory, Harman was a research fellow in the Donner Lab. The theory was initially dismissed by many in the scientific community but it gained support in the '60s. Harman, who obtained his M.D. from Stanford in 1953, served on the faculty of UNMC for 52 years. He believed that geriatrics should be a separate subsection of internal medicine. In 1973, UNMC established a section of biomedical gerontology, with Harman as section head—the first such program in the country. Harman never relented in his quest to better understand aging. "His work became his hobby," said Helen Harman *(B.A. '42, Journalism)*, his wife of 71 years. He continued to work at his office until 2010.

'45 We have learned from his son that Shee Lup Jung *(B.S. Chem)* passed away December 26, 2014, in Wilmington, DE, at the age of 92. Jung was born in Los Angeles, CA, to immigrant parents, the fifth of seven children. Arriving as a transfer student from Central James College in El Centro, he studied under William Giauque, Melvin Calvin and Wendell Latimer and was elected Phi Beta Kappa. Upon graduation, he was employed at California Ink Co.—the first Chinese-American professional to be hired at the 100-year-old company. Three years later, he entered graduate school at the University of Pennsylvania, earning his Ph.D. in 1952. He joined the DuPont Experimental Station in the Textile Fibers Division of its Pioneering Research Laboratory and worked there until 1985, when he retired to develop Jung's, an Asian antiques and art gallery, with his wife, Mary. They closed the gallery, which they had started in their basement, in 2005.

'49 Peter Haustein *(B.S. '66, Chem)* has informed us that Robert A. "Bob" Naumann *(B.S. Chem with Glenn T. Seaborg)* passed away on December 10, 2014, in Hanover, NH. Naumann was born in Germany in 1929. After graduating from Berkeley, he earned a Ph.D. from Princeton University in physical chemistry, a field that had engrossed him since early boyhood. He became a naturalized U.S. citizen and remained at Princeton for a 39-year career as the university's only joint professor of chemistry and physics. His scientific interests in nuclear chemistry/spectroscopy yielded the discovery of 21 radioactive isotopes and 12 nuclear isomers. Naumann used summer breaks and sabbaticals for research, traveling primarily to Los Alamos National Lab and Copenhagen, Geneva and Munich. In 1992 he retired with his wife, Marina, to Norwich, VT, and became an adjunct professor of chemistry, physics and astronomy at neighboring Dartmouth College.

'50 David G. Karraker *(Ph.D. Chem with David H. Templeton)*, an internationally known specialist in actinide chemistry, passed away on February 27, 2015, in Aiken, SC. Karraker was born in 1923 in Anna, Illinois. His undergraduate studies at Southern Illinois University were interrupted by service in the U.S. Army during World War II, but he returned to complete his bachelor's degree in chemistry and mathematics. After earning a Ph.D. at Berkeley and marrying his wife, Mildred, he began his research career at Argonne National Laboratory, continued at Oak Ridge National Laboratory, and ultimately settled in at Savannah River National Laboratory in 1953, where he continued to do research for 53 years. Karraker, who was an authority on actinide chemistry, also developed expertise in Mössbauer spectroscopy, focusing on the study of neptunium. In 1996, he was awarded the Glenn T. Seaborg Actinide Separations Award. He and his late wife were generous friends of the college and its programs.

'51 We have learned from his daughter that Homer C. "Charles" Carney Jr. *(B.S. ChE; M.S. '64, Nucl Engin)* of Del Mar, CA, passed away on April 5, 2012. Carney, who was raised in Bakersfield, CA, transferred to Berkeley in his sophomore year. After graduating, he worked for General Electric at the AEC's Hanford Atomic Products Operation in Richland, WA. Following 2 years of service as a nuclear officer aboard the U.S.S. *Wasp* and U.S.S. *Ticonderoga*, he joined Aerojet-General Nucleonics in San Ramon, CA, and also earned an M.S. in nuclear engineering. In 1970 he joined General Atomics in La Jolla, CA, where he developed a product line of nuclear batteries used in marine, medical and communications applications and was responsible for developing a cryogenic process for destroying Army nerve gas munitions, a robotic radiography system for aircraft inspection and long-term storage facilities for nuclear waste. His wife, Jeanne, survives him.

'55 Robert H. "Lindy" Lindquist *(Ph.D. Chem with Gerhard K. Rollefson)*, a volunteer fundraiser and generous member of our Cupola Era alumni committee, passed away on February 17, 2015. He was born in Minneapolis, MN, on February 27, 1928. He attended the University of Minnesota, obtaining a master's degree in chemistry in 1949 before coming to Berkeley. As a member of the Navy ROTC at the University, he was immediately called to service in 1949, serving for three years during the Korean conflict. Upon discharge, he pursued his plan for a Ph.D. in physical chemistry. He completed his studies at Berkeley in 1956 and that year joined Chevron Research as a research chemist, retiring in 1986. Along with his wife, June, who survives him, he was a regular attendee at College of Chemistry events, as well as a generous supporter. They made their home in Kensington, CA.

'61 A colleague has let us know that David O. Ham *(B.S. Chem)* died suddenly on October 15, 2014. Ham was a physical chemist, environmental research scientist and science educator who resided with his wife, MaryAnna, in Williamsburg, MA. He obtained his Ph.D. in chemistry from MIT in 1968. He worked for 20 years at the University of Rochester, followed by a stint at Los Alamos National Lab. Since 1980, he had been in the Boston area, employed first at Physical Sciences, Inc. in Andover, MA; then at his own company, Envirochem, conducting contract research for environmental projects; and at a Massachusetts charter public school teaching physics, chemistry and mathematics.

'68 J. Peter Clark *(Ph.D. ChE with C. Judson King)*, a generous contributor to the CBE department, passed away on June 4, 2015, in Oak Park, IL. He was born in Philadelphia, the eldest of seven siblings, and obtained a B.S. in chemical engineering from the University of Notre Dame in 1964. Following his graduate studies at Berkeley, he worked for the USDA in Albany, CA, and Washington, DC. He taught at Virginia Tech for six years, worked for ITT Continental Baking Company as director of research, and then in 1982 moved with his wife, Nancy, to Oak Park, IL, where he began a career in consulting. Clark authored eight books and served as a contributing editor and columnist for *Food Technology* magazine. In 2011 he received the Life Achievement Award from the International Association for Engineering and Food; he was a fellow of the American Institute of Chemical Engineering and the Institute of Food Technology.

'70 Donna Roudabush Sterling *(B.S.Chem)*, professor of science education at George Mason University and a strong supporter of women faculty in the College of Chemistry, passed away on June 24, 2014. When at Berkeley, Sterling trained with Melvin Calvin. After beginning a career as a research scientist, she shifted to teaching and obtained an Ed.D. from George Washington University in 1992. At Mason, Sterling served as director of the Center for Restructuring Education in Science and Technology and as principal investigator for the Virginia Initiative for Science Teaching and Achievement, a $28.5 million U.S. Department of Education grant-supported program to spearhead STEM instruction in Virginia. Sterling's research garnered major funding from numerous corporations, foundations and agencies. She collaborated with Mason's faculty to investigate evidence-based effective teaching and learning, and was the PI on more than 25 grants for STEM teacher professional development and research. She is survived by her husband, David, and their family.

'83 University of Nevada, Las Vegas (UNLV) Distinguished Professor Dennis W. Lindle *(Ph.D. Chem with David A. Shirley)* died suddenly on October 5, 2014, at the age of 57. Lindle began his career as a physicist in the Quantum Metrology Division of the National Bureau of Standards before joining the chemistry faculty at UNLV in 1991. While at UNLV, he continued to collaborate with Berkeley, doing the research that would become his life's work: studying the fundamental interactions of X-rays with atoms and small molecules. He was proud to help establish the Advanced Light Source (ALS) at the LBNL synchrotron. He is survived by his family.

'91 We have learned from her husband, Thomas Armstrong *(B.A.'88, Envir Sci)*, that Margret J. "Maggie" Geselbracht *(Ph.D. Chem with Angelica M. Stacy)* passed away on September 11, 2014, after a 30-year struggle against lymphoma. Following a postdoc at the University of Wisconsin, Madison, Geselbracht spent 21 years as a chemistry professor at Reed College. As the first woman tenured in the chemistry department, she was an inspiring teacher and mentor through her general and inorganic chemistry courses, as well as through her research. She also was one of the founding members of IONiC VIPEr, an online community of inorganic chemistry faculty to promote collaboration to develop innovative curriculum and teaching materials.

In addition to the above, we have learned of the deaths of fifty-two alumni from Class Years 1936–96.

For a list of names, please visit: **berkeley.box.com/chem-memoriam-aug2015**

Obituaries for many can be found online.

COMPILED BY KAREN ELLIOTT

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Upcoming Fall 2015 events

Homecoming (Reunion & Parents Weekend), October 2–4

October 3

10–10:30 a.m.
Complimentary coffee and pastries
Chemistry Plaza

10:30–11:30 am
Faculty lecture:
Pitzer Auditorium, 120 Latimer Hall

Speaker: CBE professor David Schaffer "Evolving New Synthetic Viruses: Sparking the Gene Therapy Revolution"

11:30 am–12:30 pm
Complimentary lunch
Chemistry Plaza

All College of Chemistry alumni, students, family and friends are invited to join us for the Homecoming weekend activities. Reservations for the above events are not required. To see a complete listing of campus events, go to **homecoming.berkeley.edu.**

The G.N. Lewis Lecture

October 20

4:00–5:00 pm
Lecture
Pitzer Auditorium, 120 Latimer Hall
Speaker: MIT professor Joanne Stubbe

5:00–6:00 pm
Reception
Chemistry Plaza

AIChE Alumni & Friends Reception (Salt Lake City, UT)

November 10

7:00–8:30 pm
Location: TBA
College of Chemistry alumni and friends are invited to attend this annual reception held in connection with the AIChE Annual Meeting. Chemical and Biomolecular Engineering Chair Jeff Reimer will host this event. Check online for more details as the date draws closer.

Alumni of the G.N. Lewis and Cupola Eras Luncheon

November 18

12:00–2:00 pm
Great Hall, Clark Kerr Campus
Once again we will celebrate the G.N. Lewis (pre-1945) and the Cupola (1946-63) alumni eras in a combined luncheon. Alumni and friends from these two eras are invited to attend. Look for a separate invitation in the fall.

For updated events information visit **chemistry.berkeley.edu/events**