SURF 2009

Annual Report
Summer Undergraduate Research Fellowships
California Institute of Technology

Dear Friends of SURF,

I am very pleased to report that this past summer a total of 401 students, including nearly 50 more Caltech students than last year, participated in hands-on research with our world-class faculty as part of the SURF program. The fact that we could accommodate this increase in numbers is particularly noteworthy, given the economic downturn the country experienced over the past year. Last fall, as we began to evaluate how our income would be affected by these economic changes, the campus leadership worked hard to ensure that the core of our academic and research endeavors would remain strong. As a key component of undergraduate education, SURF was certainly a priority. In December 2008, when the SURF application period opened, we took a series of measures to quickly respond to potential funding problems.

- **The SURF director provided weekly updates to the provost regarding the number of available research opportunities.**
- **The division chairs and the provost urged faculty not to shy away from making summer commitments to undergraduates. And, with the support of JPL Director Charles Elachi, additional research opportunities were made available at JPL.**
- **Guided by our Business and Finance team, we did our best to protect programs that provided undergraduate aid and support.**

The interest and enthusiasm of the student body in SURF certainly did not lessen, as we received a record number of applications. Thanks to the ongoing financial support from our donors, alumni, and faculty, and to the strength of the SURF endowment, 401 students were awarded summer undergraduate research fellowships in 2009 (329 were Caltech students and 72 were from other colleges and universities around the world). This is up from 2008 when of the 354 SURFers, 282 were Caltech students and 72 were from other colleges and universities.

The efforts to continue making these unparalleled research opportunities available to all our interested undergraduates are what make Caltech such a special place. It is one of the many reasons why the Institute is able to face difficult times and not only survive them, but continue to thrive. Congratulations to all of you who were involved in the success of SURF 2009! We are most grateful for your hard work, commitment, and generosity to undergraduate education at Caltech. Thank you!

Jean-Lou Chameau
President, California Institute of Technology





THE SURF EXPERIENCE

A WONDERFUL VARIETY

Kirk Dawson, SURF Board Chair

As the thirty-first year of SURF comes to a conclusion it seems useful to consider the many benefits that the program offers to the students. Clearly, the major academic thrust of SURF is the opportunity to experience research under the guidance of a world-class faculty. The quality of this experience is enhanced by the small size of Caltech and the close relations that can be established between faculty mentors and students. As we have been told by many SURF participants, the program opens up the real possibility of pursuing careers in research and university teaching. The excitement and challenges of unlocking the mysteries of nature can truly influence a student's career plans. There are, of course, exceptions where research, once experienced, is not their expected career path. But this too has real value by guiding the student away from a career path that they would likely not enjoy.

Although the research experience is the cornerstone of SURF, in this report I would like to highlight another aspect of the program that sometimes gets overlooked. I've called this part of SURF the "enrichment" activities. With the aid of the SURF Board and Administrative Committee, the Student-Faculty Programs Office, and many members of the Caltech community, a wide set of non-research activities are offered to the students on a weekly basis throughout the summer. These have evolved over the years and have both educational and social enhancement characteristics. Participation is optional for the students but a surprisingly large number decide to take advantage of the offerings. Together these offerings bring both balance and a richness to the already stellar experience happening in the labs and research groups.

I want to thank all those involved in bringing these activities to the students for doing a fine job.

Here is a partial list of these "enrichment" activities:

Caltech and JPL Seminar Series
These weekly presentations by Caltech faculty members and JPL scientists and engineers allow students an opportunity to explore the vast array of research happening in our community and to explore research across the disciplines.

William Whitney Professional Development Workshop Series
This series of interactive workshops helps students make short-term career decisions in the context of long-term life and career goals. Topics have included career planning, networking, leadership style, effective public speaking, and applying to graduate school. Eighty to one hundred students attend these sessions every week.

Opportunities to Present Research Results
In addition to the October SURF Seminar Day, a number of students apply and are selected to present their research results at local and national conferences such as the Southern California Conference on Undergraduate Research (SCCUR) and the National Conference on Undergraduate Research (NCUR). For many this is a great opportunity to further refine their communication skills.

Prizes
Several supporters of SURF have long recognized the need to encourage students' development of effective communication skills.

The Doris S. Perpall Speaking Award was endowed by Robert Perpall in memory of his late wife, Doris. This award recognizes students that have prepared and presented excellent papers at SURF Seminar Day.

The late Marcella Bonsall, who had been a long-time member of the SURF Board and the Caltech Associates, established the Marcella and Joel Bonsall Prize for Technical Writing in 1998 as an incentive for students to write excellent technical papers.

The SURF Student Advisory Committee (SURFSAC) Events

SURFSAC organized a wide set of almost weekly activities including: visit to Huntington Gardens, explore LA on Metro trip, ice skating, pool parties, beach trips, July 4th BBQ, hiking, weekly sports nights and movie nights, and weekly small group dinners with faculty and students.

Dedication

SURF 2009 is dedicated to Carl and Shirley Larson. Dedicatees are chosen because they have made a significant contribution to and impact on the SURF program. The Larsons certainly embody the perfect dedicatees! Carl is a Caltech alumnus, ME '52, and member of Ricketts House. He has served on the SURF Board and was Chair of the SURF Board Development Committee. In that role, he led SURF into a $10 million endowment drive that has been a great success!

Together, Carl and Shirley have supported dozens of Larson SURF Fellows. In 2007, they wrote this to future Larson Fellows: "We are supportive of the SURF program because it is an extraordinarily efficient and effective way for a young person to learn how to do research and to help determine if this is a career path that they wish to follow. It is our way of investing in both your future and our future." Thank you Carl and Shirley!

SURF Dedicatees

1985	Dr. Ernest Swift
1986	Dr. Lee A. DuBridge
1987	Dr. Robert P. Sharp
1988	Dr. Ray D. Owen
1989	Dr. Hans W. Liepmann
1990	Dr. Fredrick H. Shair
1991	Dr. Lew Allen, Jr.
1992	Dr. John D. Roberts
1993	Dr. Robert E. Bacher
1994	Dr. Edward C. Posner
1995	Mr. Samuel P. Krown
1996	Dr. Edward B. Lewis
1997	Dr. Harold Brown
1998	Dr. Thomas E. Everhart
1999	Dr. Ward Whaling
2000	Dr. Terry Cole
2001	Dr. William M. Whitney
2002	Dr. Edward C. Stone
2003	Dr. Thomas A. Tombrello, Jr.
2004	Dr. Harry B. Gray
2005	Paul K. Richter and Evalyn E. Cook Richter Memorial Funds
2006	Lew and Edie Wasserman
2007	Carolyn A. Ash
2008	Dr. David L. Goodstein
2009	Carl and Shirley Larson

SURF AdComm
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Harry Gray
SURF Administrative Committee (AdComm), Chair

The underlying theme of this annual report is ***energy*** — and that's a great way to describe the activities of the SURF Administrative Committee (AdComm) this year!

This fall Fred Shair, the indefatigable founder of SURF, stepped down as AdComm Chair and I am pleased to have been asked to carry the torch forward. Several other long-time AdComm members were also "paroled for good behavior." I'd like to thank Paul Bellan, George Djorgovski, Joe Kirschvink, Nate Lewis, Carl Parker, Dave Rutledge, Tom Tombrello, and Jerry Houser for their years of service. Collectively they provided strong leadership and guidance and helped grow SURF into the program it is today.

I'd also like to welcome several new members to the SURF AdComm Team:
> John Dabiri, SURF '00, Associate Professor of Aeronautics and Bioengineering
> Kevin Gilmartin, Professor of English
> David Chan, Associate Professor of Biology; Investigator, Howard Hughes Medical Institute
> Jennifer Jackson, Assistant Professor of Mineral Physics
> Glenn Orton, Senior Research Scientist, Jet Propulsion Laboratory

Together with continuing members Steve Frautschi, Geoff Blake, William Whitney, and Rick Wilson, the AdComm is ready to tackle any SURF issue that might come its way.

Every ten years or so, Caltech undergoes an accreditation review through the Western Association of Schools and Colleges (WASC). This process, currently underway, offers the campus a chance to review and evaluate our educational programs. Caltech chose three themes to focus on: the Core Curriculum, the Honor Code, and Undergraduate Research. SURF, being the primary undergraduate research program on campus, is a core part of the review.

The first step of the process was to complete a self-study focused on "Caltech's capacity for providing adequate and meaningful opportunities for students to engage in undergraduate research and our ability to successfully assess the educational impact of such experiences." Anyone who has been involved with SURF over the past 31 years knows of its success! And, the numbers confirm it:
> Nearly 80% of all graduating seniors have completed at least one SURF project;
> Of the 2008 graduating class, 25% of students single- or co-authored a manuscript in a peer-reviewed journal; and 15% presented a talk (another 13% a poster) at a professional conference;
> Alumni who participated in undergraduate research are significantly more likely to attend graduate school than are their peers who did not participate in undergraduate research.

Also, as part of the self-study the faculty worked to identify and establish student learning outcomes. The development of student learning outcomes will enable direct assessment measures of the impact of undergraduate research on student learning. These outcomes emerged out of a series of student focus groups and conversations with faculty, including the Faculty Board and AdComm. The student learning outcomes include that through their participation in an undergraduate research project, students will be able to:
> Develop a research question, problem, or design;
> Apply basic principles and knowledge found in the literature related to the research question;
> Develop a research proposal to address or resolve a specific research question or problem;
> Apply and evaluate methodology throughout project;
> Collect, interpret, and critique data in order to resolve a research question or evaluate a design;
> Communicate research findings;
> Appreciate what the process of scientific research entails.

The next step in the accreditation will be to further develop mechanisms for assessing these educational outcomes. The final WASC visit will be in April 2010. Such mechanisms can not only help us understand the full impact of SURF on the undergraduate experience but also help us find ways in which we can improve the SURF experience.

PROJECT ENERGY

Introduction by Carol Carmichael, Faculty Associate in Engineering and Applied Science

I was in a meeting in downtown Pasadena recently, where I chair the Environmental Advisory Commission, and an older gentleman noted that most of us involved in long-term planning for the city—the size of the population, the nature of our landscape, our mobility and transportation options, electricity sources, and water supply—were bringing to the table experiences rooted in our upbringing decades ago. But when the city matured, the gentleman continued, our decisions would be inherited by college-age students today. He wondered: what kind of city would they want? Good question. What kind of lifestyle, what kind of society, will they want?

Caltech is investing a precious commodity, the minds of the best scientists and engineers in the world, in finding ways to meet the challenges we face as a society. As we seek fundamental understanding of the world around us, we're also finding ways to use these insights to address pressing needs related to clean water, global environmental instability, renewable energy, and health. We're depending on the ingenuity and passion of our students to help us live more sustainably; providing insights and developing technologies that enhance our lives today while allowing future generations to define and experience a quality of life they desire.

The joy of fundamental discovery and understanding is matched when these insights yield unanticipated solutions to the problems we face. By participating in this process, SURF students contribute as citizens and scientists. The research portfolio at Caltech includes numerous studies with direct application to problems in society. For example, several of the SURF studies described in this report provide hope for our nation's energy future: developing microporous materials for storing hydrogen, taking inspiration from insects to design wind turbines, or working in multidisciplinary teams to find catalysts to make fuels from sunlight. Our hope is that, whenever possible, the research mentors in our SURF program help the students recognize the broader implications of their work for society at-large.

But how do we connect what we're doing in the Caltech laboratories with the broader context of city planning I mentioned earlier? How do we connect the longer term research developments with our near term challenges? We turn the campus into a living laboratory for sustainability. Several SURF studies focused on our campus energy systems, helping us understand energy usage and identifying options for conservation or incorporation of renewable sources into our local supply. We talk about their insights often, and they can see how their work is supporting improvements to our infrastructure on campus. Our hope is that students will be inspired by the research challenges and informed by our campus practices. Our hope is that while they're here and when they leave the campus, they'll have ideas about the kind of community they want, understand how science and engineering can contribute, and have the motivation to make a difference.

HARVESTING THE WIND AS WELL AS THE GRAIN

Scott Christian-Dold has lived many years in rural Kansas, where wind turbines are part of the landscape, mining the skies for energy above the amber waves of grain, driven by the moving air. Years later, after arriving at Wichita State University, he decided to pursue a degree in Aerospace Engineering. His area of interest: renewable energy.

A family friend introduced him to Mory Gharib, Caltech's Hans W. Liepmann Professor of Aeronautics and Professor of Bioinspired Engineering. Before long, Scott successfully applied to become a Summer Undergraduate Research Fellow. He spent this past summer working with Dr. Gharib developing a wind turbine that incorporates attributes of insect flight. The work was inherently interdisciplinary, a marriage of aeronautics with bioengineering.

If you've ever chased a fly buzzing through the kitchen or a butterfly flitting across a field, you know how quickly insects can change direction in midflight. They seem to propel themselves every which way, regardless of wind direction. Despite their unsteady flight pattern, they get around quite nicely.

Scientists, and inventors, have long sought to emulate insect flight. It's a complicated endeavor. Different insects have different ways of flying, depending on how their wings and bodies are put together. One technique, used by fruit flies and some butterflies, is called "fling and clap." The fly claps its wings together, compressing the air between them. The opposing force of the compressed air propels its body upward and flings its wings open again.

The wind turbine Scott helped to develop has a similar design. Unlike most wind turbines, it spins about a vertical axis, similar to a merry-go-round. The majority of wind turbines in use today are similar to pinwheels. Their blades revolve around a horizontal axis that is parallel to the ground.

In the model Scott tested, the wind flows between two wing-like panels that "fly" sideways rather than up. As the wind pushes against the flaps, it flings them open like a parachute. The force propels them around the central axis, attached to a horizontal arm that makes a circular sweep like the handlebars of the merry-go-round. Eventually, the arms rotate far enough that the back of the flaps face the wind. The wind pushes against them from the opposite side and the two flaps clap together again. Meanwhile, another pair of flaps on the other end of the handlebar, like a child getting ready to give the merry-go-round another push, begins the process anew, driven by the force of the wind.

Like all wind turbines, vertical-axis wind turbines convert the mechanical energy of moving parts into electricity. Vertical-axis wind turbines have some advantages over their more conventional, horizontal-axis cousins. For one thing, most of their components are near the ground and easier to reach. They are less affected by skewed winds that rise up from the ground or draft downward from the sky. They perform the same regardless of wind direction, eliminating the need for yaw control systems. They work well in arrays because they are less likely to generate turbulent flows that can interfere with the operation of other turbines nearby.

The primary disadvantages of vertical-access wind turbines are that the technology is less well-developed, they cost more, and they produce less power. That could change with continued research and development and with the power of an eager SURFer at work!

Working in the Gharib Lab, guided by his co-mentor, aerospace engineering graduate student Julia Cossé, Scott tested different designs in Caltech's Lucas Adaptive Wall Wind Tunnel. He found that three pairs of "wings" separated from each other by 120 degrees performed better than only two. He found that adding a servo mechanism to help clap the flaps together at just the right moment also improved power output. Like an insect's flight muscles, the servo exerted a minimum amount of energy for a maximum amount of gain. "The servo gives it a partial rise in efficiency," notes Scott, "but it is still nothing compared to horizontal axis wind turbines."

Scott also achieved a mild increase in power output by adding plates to the top and bottom edges of the flaps to prevent wind from escaping vertically around the edges.

Thanks to the SURF program, he has the satisfaction of knowing that, as a rising senior in college, he has already made a tangible contribution to the global quest for renewable energy. "Caltech has filed a patent for the wind turbine design and has plans to conduct full-scale tests in the future."

Far from his home on the Great Plains, Scott enjoyed surfing the ocean waves as well as SURFing in the lab. Like scholars throughout the ages, he discovered that the more he learns, the more there is to know. As he puts it, "There is so much more research to be done in this area, but the importance of the research we've done can't be overlooked."

— *by Linda Doran*

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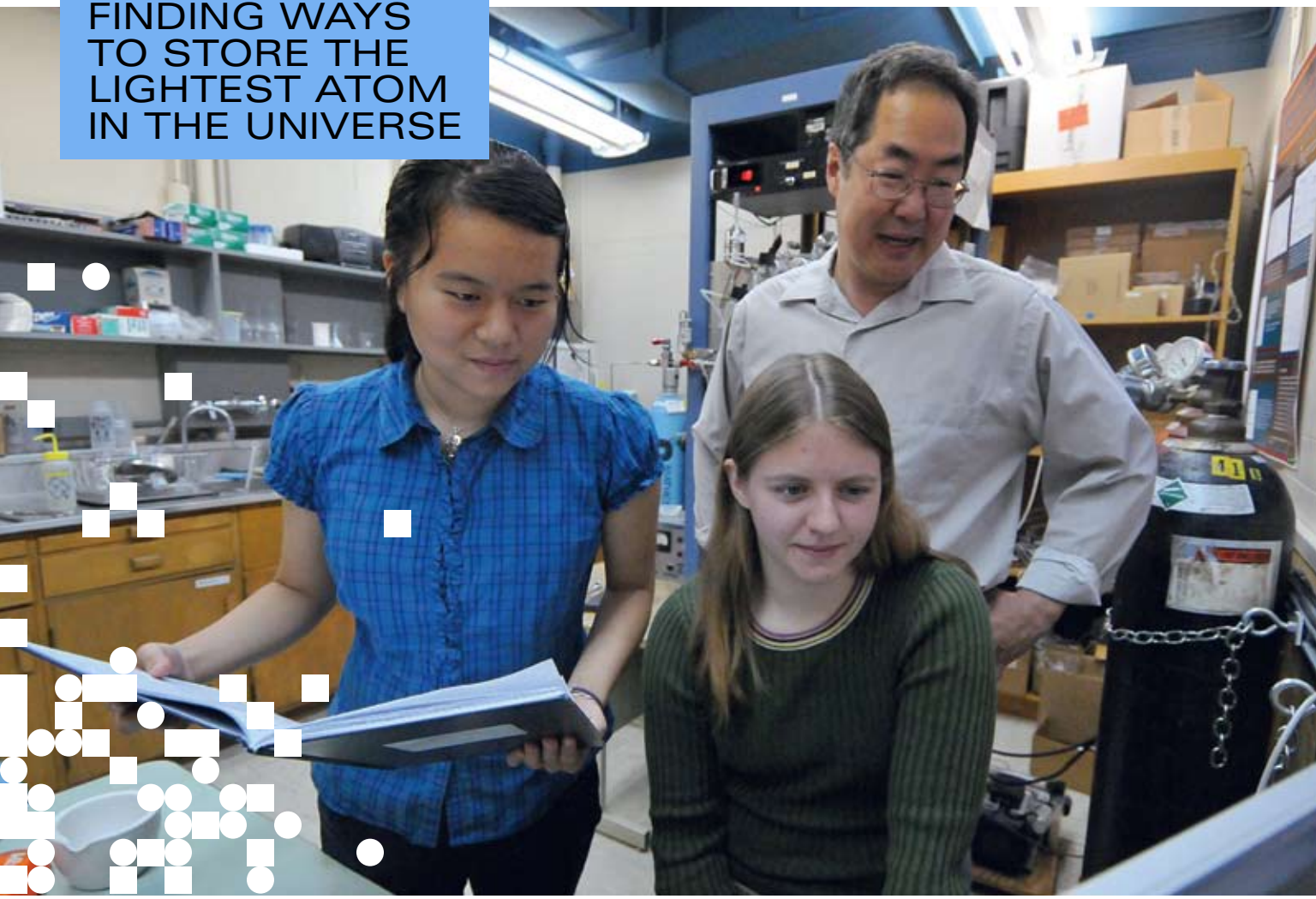
FINDING WAYS TO STORE THE LIGHTEST ATOM IN THE UNIVERSE



Supercritical Drying of Hydrogen Storage Materials

Like her father back home in Massachusetts, Caltech freshman **Jenny Wang** enjoys solving problems. Her dad works on thermoelectrics in a Boston College lab. Jenny is interested in materials research. She spent her first summer break at Caltech as a SURFer, working on developing materials for storing clean-burning hydrogen fuel.

"Energy research is a field in which materials research has a lot of potential to be useful for solving problems," she says. Renewable energy sources, such as sunlight, are only effective if excess energy can be stored for use when the energy source is not available.

Hydrogen is the lightest element in the periodic table. Because of its low density, hydrogen gas has a much greater volume than hydrocarbons such as gasoline and requires a larger, heavier fuel tank. At room temperature, most hydrogen storage systems contain only about 6 to 7 percent hydrogen by weight, notes Jenny. If the storage system is a fuel tank on a motor vehicle, an awful lot of energy is burned just driving the fuel tank around.

Working with Caltech mentor Brent Fultz, Professor of Materials Science and Applied Physics, and co-mentor Channing Ahn, Jenny synthesized and tested lightweight, microporous materials for storing hydrogen and removing it easily when needed. How "micro" are the pores? They're atomic in scale, several angstroms wide, completely invisible to the human eye but bigger than a molecule of hydrogen gas, which consists of two atoms of hydrogen bonded together.

"Essentially, we're sticking hydrogen in a bunch of little holes that don't form chemical bonds with the hydrogen," says Jenny. "The hydrogen sticks to the interior of the material with help from intermolecular forces. It's also easily removed when needed."

Jenny's goal was to improve the hydrogen-carrying capacity of the materials by increasing the surface area of the pores. In practice, microporous materials often do not store as much hydrogen as predicted. One possible explanation is that some of the individual pores collapse as they are dried.

The drying process is similar to that for making aerogels, high-strength materials that have the lowest known density of any solid. They are made with solvents and then dried. Jenny made hydrogen-storage materials by combining powders and solvents to form a porous, metal-organic framework. If the material is not dried, liquid blocks the pores. If it is dried by heating, the liquid turns to gas and escapes but also tugs on the interior pore walls, potentially damaging some of them.

To prevent the pores from collapsing, Jenny used a technique known as supercritical drying. Biology labs use it to prepare samples for scanning electron microscopes. She soaked the material in pure ethanol (a liquid solvent that is the intoxicating agent in liquor, beer, or wine). She then bathed the ethanol-treated material in a dryer full of liquid carbon dioxide to allow the carbon dioxide to replace the ethanol inside the

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pores. Like a pressure cooker, the dryer processed the contents at supercritical pressure and temperature, where there is no transition from carbon dioxide liquid to carbon dioxide gas and no distinction between the two. For carbon dioxide, the supercritical temperature is like a warm summer day, about 31 degrees C (88 degrees F). The supercritical pressure is about 1,070 pounds per square inch. Above that point, carbon dioxide has no surface tension and does not exert pressure on the pores.

To be sure all the carbon dioxide went supercritical, Jenny heated the dryer to 40 degrees C, which simultaneouly increased the pressure to about 2,000 psi. She then slowly released the supercritical fluid to leave the empty pores behind, ready to be filled with hydrogen. She is now in the process of testing all the samples. She's also looking ahead to more research as a Caltech undergraduate. "We're already thinking of potential projects that I can work on during the year as part of my work-study assignment," she says. "I consider it a great opportunity and am very thankful that my mentors and the graduate students are willing to let me into their lab."

Metal Alloys for Storing Hydrogen

Working in the same lab as Jenny, 2009 Larson SURF Scholar **Sarah Howell** also spent the summer developing different storage materials for hydrogen. Also under the guidance of Brent Fultz and Channing Ahn, she experimented with metal alloys that absorb and hold large amounts of hydrogen.

At room temperature and pressures, a gram of hydrogen gas occupies about 11 liters (2.9 gallons), notes Sarah. To decrease the amount of space needed, it must be stored in vessels at great pressures. Or, it can be stored in liquid form stored at extremely low temperatures, far below zero. "Neither approach is practical for everyday use," she adds. "A possible solution is to store hydrogen in hydride form."

Certain metal alloys bond with hydrogen to form metal hydrides. In particular, iron titanium hydrides have shown promise because they can absorb and release large amounts of hydrogen repetitively without deteriorating. Sarah's goal was to further improve their performance by replacing some of the iron and titanium with varying amounts of palladium, nickel, and chromium.

Sarah also compared two different methods of fabrication: arc melting and mechanical alloying. In arc melting, metal is melted by placing it in direct contact with an electric arc, a bolt of electricity that travels through the metal between two oppositely charged electrodes. In mechanical alloying, also known as cold welding, metal powders are mixed with steel balls in a vial known as a ball mill and smashed together repeatedly until they weld into the desired nanocrystalline particles.

Her research paid off. When Sarah compared the results, she found that some of the modifications did indeed improve the stability of the alloys, increase their hydrogen storage capacity, and enhance their ability to absorb and release hydrogen by adjusting temperature and pressure.

Like Jenny, Sarah found that her SURF experience gave her an opportunity to apply what she's learned in school to solving practical problems. "I enjoyed my research experience this summer and I am looking forward to working on energy projects in the future," she said. "I'd like to thank my mentors for their guidance and Caltech for the Institute's efforts to organize and fund the SURF program."

— *by Linda Doran*

POWERING THE PLANET: ONE SURFer AT A TIME

If scientists are correct, then college students of today will inherit a world with a set of challenges unseen by generations before. Global temperatures are rising, the ocean surface is warming, and sea ice, glaciers, and permafrost are melting. At the same time, carbon dioxide levels are rising.

Permafrost by itself contains enough buried carbon dioxide and methane, another greenhouse gas, to increase greenhouse gases by a factor of ten, notes Nate Lewis, Caltech's Argyros Professor of Chemistry. The last time anything like that happened, carbon dioxide in the Earth's atmosphere increased tenfold and 90 percent of all species went extinct. That event was the Permian extinction some 250 million years ago. "We do not know if this will happen again," says Lewis. "We do know there is only one way to find out." That way is to continue relying primarily on the burning of fossil fuels to meet the world's energy needs.

If preventing global warming sounds like an ideal challenge for the expertise of Caltech professors combined with the energy and determination of SURF students, it is. And, they're already on it—working together on a project called "Powering the Planet."

More solar energy hits the Earth in one hour than the energy the entire world consumes in one year. However, the drawback to using solar power is the unmet need for affordable and efficient ways to store the energy. Guided by Professors Harry Gray, the Arnold O. Beckman Professor of Chemistry, and Nate Lewis, Caltech is collaborating with researchers around the

world to create a three-part system for harnessing sunlight and using it to split water into oxygen and hydrogen. Two of the three components of the system are catalysts for splitting water. One catalyst provides two electrons for reducing water to hydrogen gas; the other strips four electrons from water to produce oxygen gas. The third component is a central membrane that separates the positive and negative charges, provides a platform for attaching the catalysts into a solar cell assembly, and is permeable to hydrogen atoms, allowing H_2 to be collected and stored for future use. Both Gray and Lewis have been mentoring SURF students for nearly three decades. In fact, they are currently embattled in a friendly rivalry for the second and third spot over who has mentored the most students. It is no wonder they turned to SURF in order to get students involved in creating this novel system. Says Gray, "Undergrads bring new ideas to our solar energy research program. They are energetic and enthusiastic, often willing to tackle high risk projects that grad students and postdocs won't touch!" This past summer ten fortunate students had the opportunity to work with Gray, Lewis, and their MIT colleague, Jonas Peters.

Building the SURF Team: Across All Boundaries

Solar energy research is inherently interdisciplinary. So although Gray, Lewis, and Peters are all chemists, they recruited undergraduates from a variety of disciplines. **Jessie Ku**, for example, is a Caltech sophomore in applied physics. This summer, as a Richter Scholar, she used metals such as nickel and cobalt to generate hydrogen gas from water. Along with **Tina Ding**, the 2009 John and Maria Laffin Trust SURF Fellow and a sophomore in chemical engineering, they demonstrated techniques for depositing nanoparticles of the metals onto flat silicon surfaces. The results will help create structured, "aspen forest" solar arrays consisting of microrods grown in the lab or pillars etched into the surface.

The 2009 Edward W. Hughes SURF Fellow, **Jeanne Peng**, is a junior studying electrical engineering. She spent the summer depositing thin films of zinc sulfide onto slides and characterizing their ability to serve as buffers between oxidation and reduction reactions in zinc phosphide solar cells. She used various chemicals to try to create soluble molecules with metal ions that would not react with other ions or elements.

And **Sijia Dong**, from Hong Kong University, did computational studies of molecules containing iridium, a metallic element associated with the extinction of the dinosaurs. Her work focused on iridium-bearing, carbon-ring molecules that have an even larger number of potential electron holes for stripping electrons from water than demonstrated in previous studies.

Powering the Planet also relies on combining together the expertise of students familiar with the lab and the project with students who are experiencing research for the first time. Freshman **Eric Chang**, a 2009 Richter Scholar, is already off and running, working with mentors Gray and Jay Winkler to study the transfer of electrons across proteins found in the membranes of living cells and bacteria. He used two amino acids, cysteine and tryptophan, to try to achieve electron transfer in nanoseconds, a time scale similar to that in photosynthesis. "Having the opportunity to participate in research, especially after only my freshman year, speaks to the emphasis that Caltech places on undergraduate research and the trust they place in their students. I had a wonderful summer in the Gray Lab, where I gained valuable experience in research and the scientific process."

Chang worked side-by-side with veteran SURFers **Carolyn Valdez**, the 2009 Doris Everhart SURF Fellow, and **Xueliang (Leon) Liu**, the 2009 Rossum Family SURF Fellow. Carolyn, who has done three SURFs in the Gray Lab exclaims: "Working with this project as a SURF student is so rewarding! If I have a bad week or am confused about my research, I only have to listen to someone in the lab talk about the scope and promise of the proposed water-splitting solar cell to feel reenergized and work to tackle my problems. When I am successful, I have a large group of intelligent scientists congratulating me on my hard work." This summer Carolyn synthesized and tested organic molecules that brought two cobalt catalysts together. Her goal was to rapidly reduce two hydrogen ions at a time to produce hydrogen gas from water.

Leon, a junior in applied physics at Caltech, just completed his third SURF project with Nate Lewis. He experimented with different thicknesses and light absorption properties of electrically conductive polymers on silicon surfaces. His work will help optimize the performance of silicon-polymer solar cells.

Finally, the real strength behind Powering the Planet is the project's focus on bringing together scholars and students from many different schools. Two students from California State University, Los Angeles,

joined the summer team. **Miguel Ortiz**, a junior in biochemistry, created porous films of tungsten oxide for splitting water into oxygen. He used an electrolyte solution to deposit tungsten oxide on an anode, with the goal of achieving a thickness of 6 microns, about one-tenth the thickness of the finest human hair. The thicker the oxide layer, the more likely it is to resist degradation during the oxidation of water. Chemist **Jacquie Malette** investigated cobalt as a catalyst for producing hydrogen gas from water. Cobalt is much less expensive and more readily available than platinum, a precious metal that works as a catalyst but is far too rare and expensive to meet the world's energy needs. "This project helped me gain valuable knowledge as well as a rewarding lab experience. I am grateful to have had the opportunity."

On the other side of the country, **Chantal Mustoe**, a Caltech sophomore, went to MIT to work with Jonas Peters, where she also worked on the design and synthesis of cobalt-based organic catalysts.

For over thirty years SURF mentors and students together have made significant contributions to science. It is impossible to believe that the Powering the Planet team won't make a significant contribution—both to science and to our grandchildren.

— *by Linda Doran and Candace Rypisi*

SPOTLIGHT ON TIM RAUB

SURF Alum, Co-Mentor, and Friend

As an undergraduate, there were many things about Tim Raub that would have made him stand out as a superstar. He came to Caltech as an AP National Scholar and a National Merit Scholar. He received a Caltech Merit Award and got involved with research the summer before his freshman year. He was a member of the intercollegiate cross country and track and field teams and a feature writer in the student newspaper, *The California Tech*. However, if you ask the SURF staff what they remember most about Tim from those days, they would tell you it was the titles of his SURF projects! After all, with titles such as "Baja-British Columbia: Long Distance Tectonic Transport of the Insular Superterrane—or—Give Vancouver Back to Mexico!" and "Is Utah's Belly-Button an Innie or an Outie?" how could it not be!

As an undergraduate Tim conducted four SURF projects, all with Joe Kirschvink, Nico and Marilyn Van Wingen Professor of Geobiology. After completing both a B.S. and M.S. at Caltech, he finished his Ph.D. at Yale University, where he studied the timing and geographic patterns of ancient glaciation, global warming, and environmental oxidation during a period of time some 650-500 million years ago. In July 2007 Tim returned to Caltech as a Postdoctoral Scholar in Geology. Since then he has served as a co-mentor to eight SURF and MURF students. He has also been involved in SURF Seminar Day as both a judge and session chair.

We caught up with Dr. Raub recently and here is what he had to say about SURF, mentoring, and becoming a dad!

Q: How much of what you studied in grad school was influenced by your SURF experience?

A. All of it. My Prefrosh SURF with Joe Kirschvink (B.S./M.S. '75) is when I fell in love with magnetism. Magnetism and its interrelation with electricity underlies most instrumentalism, and plenty of theory, across all fields of science. Paleomagnetism, as a geologic tool, lets you query almost any geologic question. Age, pace, and location of events; degree and style of crustal deformation; degree of alteration and thermal reactivity of different minerals—these overarching characteristics inform almost any specific, interesting question you might ask about the rock record. They are all partly addressed by various paleomagnetic techniques. Four years of SURF also taught me to be comfortable with multiple working hypotheses, data that challenge prior assumptions, and a healthy dose of "nuttiness." I remember feeling frustrated by all three as a prefrosh. I'm still working to fully embrace—while keeping appropriately leashed—my inner Nut.

Q: What made you come back to Caltech as a postdoc?

A. In my opinion, it's the best place in the world to do collaborative science—certainly geology—hands down. For so many Techers, science is fun. Spending enough time here, it's easy to take that attitude for granted, but I believe in the wider world it's both fundamental and easily neglected.

Q. What are your post-postdoc plans?

A. I get a kick out of teaching as well as research. Geology is a wonderful story-telling science, which people relate to easily. I'd like to teach Earth history and field geology, and build a paleomagnetics lab as a university professor.

Q. What's it like being a co-mentor now?

A. Great! Science is most fun when you're working with other people on a common goal—collaborating on a project, coauthoring a manuscript, building and testing an instrument.

Q. What lessons did you learn from your SURF mentors that impact the way you mentor?

A. Students are colleagues. Enthusiasm and hard work are as important to successful research as experience and inspiration. Although I researched with Joe Kirschvink from the day I entered campus as a prefrosh to the day I graduated, David Evans, Lee Silver, George Rossman, and Dianne Newman also strongly influenced my ideas of how to try to be an adviser.

Q. Have you ever found yourself saying to students: "When I was a SURFer..."?

A. Sure. When I was a SURFer, I never finished a project in only ten weeks, so don't worry. Sometimes it took much longer...

Q. Do you have a favorite SURF project or interesting SURF story?

A. My 1999 SURF asked the question, is Upheaval Dome, a beautiful circular chasm in Canyonlands National Park, Utah, the result of an eroded salt diapir, or a meteorite impact? (Planar shock defects in constituent quartz and feldspar crystals indicated it is an impact crater.) On our way back from sampling shock-liquefied sandstones surrounding Upheaval Dome, we camped overnight on the rim of Meteor Crater in Arizona. A pack of coyotes surrounded our tentless sleeping bag circle in the early morning dark and kept me wide awake, whimpering, until dawn, when they learned we were filthy, scrawny, and unappetizing. That felt like grand adventure in wild country!

Q. Why do you participate in SURF as a judge and session chair?

A. I really appreciated when SURF judges asked questions about my seminar day presentations. Feeling that other people think your research is as interesting as you do stokes the motivational fire, which you need to get through the rest of the school year. Research was a huge part of my happiness as an undergraduate.

Q. I understand you've married another SURF alum and have a little SURF baby—can you tell me something about them?

A. I married Theresa Daniels, who SURFed with geomicrobiologist Dianne Newman in 2001, synthesizing different iron oxide minerals as analytical standards. SURF motivated Theresa to enter grad school as a hard-core field geologist, working in the Arctic and Australian Outback to help piece together a map of the continents, two billion years ago. Theresa also returned to Caltech for a postdoc, imaging trout brain cells containing iron oxide crystals, which torque in response to changing magnetic fields. Now we've begun raising a seven month-old daughter, Rachel, who seems to enjoy traveling into the field with us. Unfortunately, Rachel apparently inherited her Techer parents' aptitude for getting by on too little sleep!

Highlights of Summer 2009

Allied Programs

This summer the undergraduate research community at Caltech consisted of 649 students from schools and universities across the nation and world—our biggest summer class yet! While many of these were SURF students, others were participants in one of the allied programs affiliated with the Student-Faculty Programs Office.

MURF
Laser Interferometer Gravitational-Wave Observatory (LIGO) SURF
Caltech Amgen Scholars Program
NASA Undergraduate Student Research Program
NASA Space Grant
NASA Planetary Geology and Geophysics Undergraduate Research Program
Caltech-IIT Kanpur Exchange
Caltech-National University of Singapore Exchange
Caltech-Hong Kong Universities Exchange
Caltech-Cambridge Exchange
Caltech-University of Iceland Exchange
Howard Hughes Medical Institute EXROP

SURF Summer Program

Wednesday Seminar Series

Providing students an opportunity to learn about research across campus

Bil Clemons
Assistant Professor of Biochemistry
Protein Translocation Pathways

Julia Greer
Assistant Professor of Materials Science
Size Matters: Mechanical Properties of Materials at Nano-Scale

Mark Stalzer
Executive Director, Center for Advanced Computing Research
Engineering Computational Science and Engineering

Athanassios G. Siapas
Associate Professor of Computation and Neural Systems
Network Mechanisms of Memory Formation

Matthew Golombek
Senior Research Scientist, Jet Propulsion Laboratory
Mars Exploration Rover Science Results: Climate Change From Wet to Dry

Rana Adhikari
Assistant Professor of Physics
Gravitational Wave Detection

Bill Deverell
Professor of History, University of Southern California
Environmental Planning and the Growth of Los Angeles: Lessons From the Past

Beverly McKeon
Assistant Professor of Aeronautics
"Tickling" Fluid Flows Using Morphing Surfaces

David Anderson
Roger W. Sperry Professor of Biology
Molecular Genetic Analysis of Neural Circuits Underlying Emotional Behaviors

Jet Propulsion Lab Seminar Series

Providing students an opportunity to learn about the variety of research at JPL

John Callas
Project Manager, Mars Exploration Rovers
The Second Copernican Revolution: Our Changing View of Our Place in the Universe

Randii Wessen
Project Formulation Office Deputy Manager
The Future of U.S. Robotic Planetary Exploration

Patricia Beauchamp
Strategic Missions and Advanced Concepts Office in the Solar System Exploration Directorate
Missions to Titan, the Enigmatic Moon of Saturn

Thomas Valdez
Research Engineer for the Development of Fuel Cells and Electrolyzers
Hybrid Fuel Cell/High-Power Battery Power Source for the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) Robot

Pamela Conrad
Co-Investigator and Payload Investigation Scientist for the SAM Suite
21st Century Exploration: Preparing for Environmental Assessment on Other Planets

Randall Friedl
Chief Scientist for JPL's Earth Science and Technology Directorate
A Cold Look at a Warming Earth

Richard Terrile
Director of the Center for Evolutionary Computation and Automated Design
Rise of the Machines: Exploring Space With Intelligent Robots

Anita Sengupta
Senior Systems Engineer, EDL and Advanced Technologies Group
Enabling Technologies for Mars, Venus, and Beyond

The William Whitney Workshops on Professional Development

Helping students make short-term career decisions in the context of long-term life and career goals.

Inventing Your Future: What Are Your Options?
Dr. William Whitney, Deputy Manager, Education Office, JPL; Carolyn Ash, Quondam Director, Student-Faculty Programs

Understanding Your Leadership and Work Style
April White-Castaneda, Senior Director of Employee and Organizational Development; Lori Valdivia, Employee Relations Consultant

Networking: How to Make It Work for You
Dr. John Davis, SURF '91, The Aerospace Corporation; Angela Wood, Assistant Director, Career Development Center; Candace Rypisi, Director, Student-Faculty Programs

Graduate School: The Nuts and Bolts of the Application Process
Dr. Joe Shepherd, Dean of Graduate Studies; Edgardo Garcia, MURF '03, '04, Graduate Student, Chemistry; Alex Hudson, SURF '07, Amgen Scholar '08; Ann Marie Cody, Graduate Student, Astronomy; Amit Lakhanpal, M.D./Ph.D. Student, Biology

SURFers 2009

Class Level	*Percent*
Freshman	25%
Sophomore	37%
Junior	35%
Senior	3%
Women	38%
Minorities	9%
Average GPA*	3.50

** Caltech students only, excluding freshmen*

SURFSAC Events

Helping to provide balance to all of the research activities, the Student Advisory Council, or SURFSAC for short, provided social and cultural events for students throughout the summer. This year SURFSAC led trips to the Huntington Gardens, held a pool party, sponsored a broomball and ice skating excursion, and sponsored "Explore LA" Metro trips. Of course, events with food, such as the annual 4th of July BBQ and laid-back "Chillin' on the Olive Walk" events, remained most popular with the SURFers!

SURFSAC Suppers
Again this year, SURFSAC coordinated weekly suppers for Caltech faculty and small groups of students at local restaurants to encourage informal conversation between students and mentors. We thank Catherine Jurca, outgoing Master of Student Houses, and Geoff Blake, incoming Master of Student Houses, for generously subsidizing the cost of these popular suppers. Over 100 students had the opportunity to attend. A special thanks to the faculty who participated:

MIKE BROWN, *Richard and Barbara Rosenberg Professor of Planetary Astronomy*
JEHOSHUA (SHUKI) BRUCK, *Gordon and Betty Moore Professor of Computation and Neural Systems and Electrical Engineering*
OSCAR BRUNO, *Professor of Applied and Computational Mathematics*
CAROL CARMICHAEL, *Faculty Associate in Engineering and Applied Science*
PRESIDENT JEAN-LOU CHAMEAU
KANIANTHRA (MANI) CHANDY, *Simon Ramo Professor and Professor of Computer Science*
JOHN DABIRI, *Associate Professor of Aeronautics and Bioengineering*
CHIARA DARAIO, *Assistant Professor of Aeronautics and Applied Physics*
MARK DAVIS, *Warren and Katharine Schlinger Professor of Chemical Engineering*
RAYMOND J. (RAY) DESHAIES, *Professor of Biology*
GEORGE DJORGOVSKI, *Professor of Astronomy*
BRADLEY FILIPPONE, *Professor of Physics*
STEVEN C. FRAUTSCHI, *Professor of Theoretical Physics, Emeritus*
HARRY GRAY, *Arnold O. Beckman Professor of Chemistry*
ANDREW INGERSOLL, *Earle C. Anthony Professor of Planetary Science*
JENNIFER M. JACKSON, *Assistant Professor of Mineral Physics*
STEVEN LOW, *Professor of Computer Science and Electrical Engineering*
JERROLD E. MARSDEN, *Carl F Braun Professor of Engineering, Control and Dynamical Systems, and Applied and Computational Mathematics*
ELLIOT M. MEYEROWITZ, *George W. Beadle Professor of Biology*
MITCHIO OKUMURA, *Professor of Chemical Physics*
PAUL PATTERSON, *Anne P. and Benjamin F. Biaggini Professor of Biological Sciences*
DOUGLAS C. (DOUG) REES, *Roscoe Gilkey Dickinson Professor of Chemistry*
GIL REFAEL, *Associate Professor of Theoretical Physics*
GEORGE ROSSMAN, *Eleanor and John R. McMillan Professor of Mineralogy*
ANGELIKE STATHOPOULOS, *Assistant Professor of Biology*
ZHEN-GANG WANG, *Professor of Chemical Engineering*
ALAN WEINSTEIN, *Professor of Physics*
KAI ZINN, *Professor of Biology*

COMAC

Co-mentors—the graduate students, postdoctoral scholars, and staff scientists who help mentor summer students—play a critical role in the success of SURF. This year the Co-Mentor Advisory Committee (COMAC) has continued to help think about ways to best support co-mentors throughout the summer. This year the COMAC helped design and implement two trainings for first time co-mentors. Additionally, they helped organize three student/co-mentor coffee hours. These coffee hours provided students and their co-mentors the opportunity to meet outside of lab to discuss research progress and academic goals.

Awards and Prizes

The Doris S. Perpall Speaking Competition was endowed by Robert C. Perpall (BS '52, MS '56) in memory of his late wife, Doris Perpall. The prize encourages students to prepare excellent SURF presentations. The competition is a three-round event. The best SURF Seminar Day presenters, as evaluated by the session chair and a judge from the discipline, advance to a semifinal round held in November. Six to eight finalists advance to a final round held in January. The 2008 winners were Evan Gawlik, Mitchell Wang, and Kimberly Scott.

Conferences

The National Conference on Undergraduate Research (NCUR) in April drew over 2,600 undergraduates, faculty, and administrators to the University of Wisconsin-La Crosse. Students presented their research, scholarly, and creative activities in oral and poster sessions. This year six SURFers presented at NCUR:

EVAN GAWLIK, *2008 Aerospace SURF Fellow*
THOMAS GWINN, *2008 William Hassenzahl Family SURF Fellow*
LEON LIU, *2008 Carol Carmichael SURF Fellow*
KASRA RAHBAR
ILA VARMA, *2008 Samuel P. and Frances Krown SURF Fellow*
MITCHELL WANG

This year eleven students represented SURF at the Southern California Conference on Undergraduate Research (SCCUR). SCCUR 2008 was held at the California State Polytechnic University, Pomona on November 22. It brought over 600 students from regional colleges and universities to present their research in oral and poster sessions. SCCUR is multidisciplinary including the sciences, the humanities, social sciences, art, and performance. SCCUR was started at Caltech in 1993.

EDWARD CHEN, *2008 Rose Hills Foundation SURF Fellow*
OMER DURAK, *2008 Howard Hughes Medical Institute EXROP Fellow*
ALI EBRAHIM, *2008 Reed and Ruth Brantley SURF Fellow*
ANSON LAM
GONGJIE LI, *2008 Alain Porter Memorial SURF Fellow*
YINGKUN LI, *2008 John and Maria Laffin Trust SURF Fellow*
GABRIEL MENDOZA, *2008 Hannah Bradley SURF Fellow*
ERIC MINTUN, *LIGO SURF Fellow*
KASRA RAHBAR
DAN (LINDA) SONG, *2008 Richter Scholar*
ANDY YEN, *2008 Rose Hills Foundation SURF Fellow*

SURFers 2009

Division	*Total # of Students*	*CIT Students*	*Non-CIT Students*	*Mentors*
Biology	59	48	11	22
Chemistry and Chemical Engineering	77	66	11	28
Engineering and Applied Science	104	78	26	44
Geological and Planetary Sciences	21	18	3	14
Humanities and Social Sciences	23	16	7	14
Physics, Mathematics, and Astronomy	81	50	31	52
Jet Propulsion Laboratory	42	20	22	29
Off Campus	37	28	9	33
International	11	11	0	11
Total	455*	335	120	247

**this includes LIGO and exchange SURF students*

Statistics From the 2009 Graduating Class

Total number of BS graduates	231	
Of these, the number graduating with Honors	131	57%
Total number of BS graduates who have done a SURF	177	
Of these, the number graduating with honors	108	61%
Percentage of BS graduates who have done a SURF		77%
Number of prizes awarded to BS graduates	133	
Of these, the number of prizes awarded to SURFers:	120	90%

funding SURF

SURF students receive an award of $6,000 for the ten-week summer period (resulting in a total 2009 program budget of over $2 million). Generally, mentors pay half the award, and funds raised from external sources are used as matching funds to pay the other half. The Student-Faculty Programs Office, in partnership with the Development Office, raises funds to support Caltech SURF students from a variety of sources including gifts from individuals, foundations, and corporations.

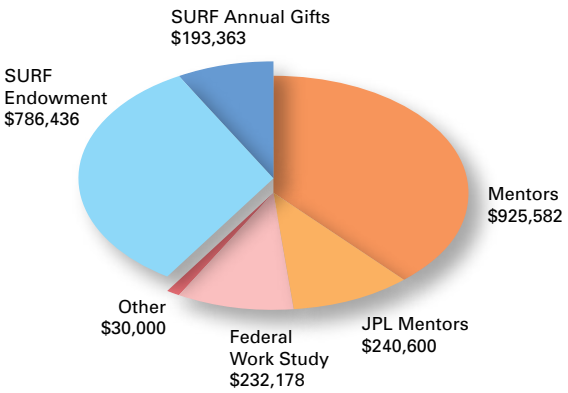
SURF depends upon the generosity of its many friends for annual gifts or for contributions to the SURF endowment to build a robust financial base. We thank the many donors who have supported SURF 2009 and beyond!

New Endowments

Named endowments help to ensure the future of the SURF program and provide Caltech students with unparalleled research opportunities. We are delighted to announce the establishment of several new endowments:

The Saul and Joan Cogen Memorial
SURF Endowment
The Professor Homer J. Stewart SURF Endowment
(which will support two students)
Cassatt Family SURF Endowment

2009 SURF Award Funding



New Prizes

This year two new prizes were established to encourage and recognize excellent communication skills among our SURF students.

John and Barbara Gee created the Gee Family Poster Competition for SURF Seminar Day. This competition is designed to encourage and support excellence in effective scientific communication. Posters will be judged on content, visual organization, and verbal presentation.

With guidance and support from Priscilla McClure, the Gordon McClure Memorial Prize for Communication Skills has been established to recognize a rising sophomore, junior, and senior who have demonstrated strong written and/or oral communication skills.

Thank you to the families who have created these new endowments and prizes! Their vision and commitment to undergraduate research will provide opportunities to students for years to come!

Matching Opportunities Still Available for New Endowments

Individuals or groups may establish an endowment for $125,000 to support one student annually in perpetuity, and it may be named as the donor designates. There are several ways to establish endowments—they may be paid in full at creation, given in installments over a period of three to five years, or specified in the donor's estate plan.

Endowment contributors can be proud of the investment they have made in the future of Caltech's bright and talented students, and the donors gain the personal satisfaction from playing an important part in the formation of young people, many of whom will make significant contributions to the nation and the world.

Several years ago a very supportive alumnus and his wife offered $2 million as a matching challenge to other SURF donors. They will match up to $50,000 for those who contribute endowment gifts or pledges of $75,000! Matches are still available!

Established Endowments

Thanks to the generosity of many committed donors, gifts to the SURF endowment will ensure students the opportunity to conduct research for generations to come. Scholar endowments provide support for five students annually in perpetuity. Fellow endowments provide support for one student annually in perpetuity.

SURF Scholar Endowments
Larson Scholars
Kiyo and Eiko Tomiyasu Scholars

SURF Fellow Endowments
Arthur R. Adams SURF Endowment
Stephen Adelman Memorial SURF Endowment
Brenda and Louis J. Alpinieri SURF Endowment
Carolyn Ash SURF Endowment
The Associates SURF Endowment
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Class of '36 SURF Endowment
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Edward W. Hughes SURF Endowment (2005)
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Frank W. Wood SURF Endowment
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SURF Prize Endowments
Marcella and Joel Bonsall SURF Prize for Technical Writing
Gee Family Poster Competition Award
Gordon McClure Memorial Prize for Communication Skills
Doris S. Perpall SURF Speaking Award

Endowments Through Planned Gifts
Dr. and Mrs. George Boone
Dr. Paraskeva N. Danailov Endowed SURF Fellowship in Biology

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