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ENERGYnotes

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NEWS FROM THE UNIVERSITY OF CALIFORNIA ENERGY INSTITUTE

Some Like It Hot

Geothermal energy is seeing a rebirth as industry looks for new ways to replace fossil fuels. That's why, from Calistoga to Iceland, UC scientists are puzzling over the energy beneath our feet. With its wide swath of harvestable underground heat, California is poised to lead that search.

A drilling site in the southwest of Iceland run by energy provider, Hitaveita Suðurnesja. Although they have not started drilling, this site will eventually host one of the three IDDP supercritical geothermal holes.

When you get right down to it, there are only two sources of power on the planet Earth.

The first is sunlight. Sunlight is the energy source for plants, which in turn feed the animals; all of which die and can eventually be transformed into coal, oil or natural gas. The sun also heats the landscape and creates wind.

In fact, the sun so dominates our planet's energy cycles that many people don't even think about the second source, the Earth itself. Under the thin shell of the earth's crust, the natural heat flow of our planet contains more than enough energy to power our entire civilization. The problem is finding and accessing that heat economically. For solutions, one UC researcher is poking around California hotspots while another is traveling to Iceland for one of the boldest experiments in renewable energy.

Mack Kennedy of UC Berkeley's Lawrence Berkeley Laboratory (LBL) is one in a growing field of researchers who believe in the potential of California's underground heat resources. He says geothermal power is one of the most underutilized sources of renewable energy in the world. A recent, highly-anticipated MIT-led review of geothermal energy in the United States estimated that 13 million exajoules (one exajoule is about 278 billion kilowatt hours of energy) of energy lie beneath our feet – over 1,000 times the energy of the world's oil reserves – mostly in the western states.* Only a small percentage of that energy, about 200,000 exajoules, is realistically extractable, but this is still 2,000 times the annual consumption of primary energy in the U.S.

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* *See http://www1.eere.energy.gov/geothermal/pdfs/future_geo_energy.pdf*

In this issue

OIL:
The Next Big Energy Resource?

As the world frets about this quickly-disappearing fossil fuel, two researchers worry that those reserves may never end.

"Is the world's oil running out fast?"

That was a headline that ran on BBC News in 2004 after an oil conference on a concept called "peak oil." It was followed by the sub head, "If you think oil prices are high at $40 a barrel then wait till they are four times that much."

This may have seemed like hyperbole in 2004 but with oil prices now more than three times as high, some experts are saying a turning point is coming soon. The theory goes that as oil production someday declines (some say it already has), higher oil prices will make renewable energy more cost-effective and the market will naturally shift toward carbon neutral fuels.

However, researchers at the University of California Berkeley say rising oil prices may not force a shift to expensive, cleaner power, but rather to expensive, "dirty" power. Because of entrenched infrastructure, the thinking goes, it will be more cost effective to stay with carbon-intense fossil fuels and simply expend more energy in getting them.

Adam Brandt and Alex Farrell say that most supply and demand models of petroleum limit oil to what comes out of traditional wells. The classic idea that decreasing oil production and rising prices will invite renewables to step in as a competitor makes several dangerous assumptions. First, it assumes oil is running out.

"We are not running out of energy," says Farrell. "We have lots of energy under the ground. It's just really dirty."

By "dirty" Farrell means that it produces a lot of carbon dioxide or greenhouse gases. This energy includes non-traditional sources like remnant oil from depleted reservoirs, oil pulled out from tar sands, liquid fuels synthesized from natural gas or coal, and oil extracted from solid rocks called oil shale. Taken together these sources could increase the world's current oil supply (often estimated at two trillion barrels) by nearly a factor of ten. That is as much as 18 times more oil than has been produced to date. But it would not be cheap or clean energy.

Consider tar sands, currently the most widely used non-traditional source of oil. Tar sands are naturally occurring clays that run under 54,000 square miles of Canada and contain as much as 25 percent bitumen, a thick sludge that can be converted to oil. According to Brandt and Farrell, tar sands may hold as much as 1.5 trillion barrels of liquid fuel – enough to meet current U.S. oil needs for two centuries. However, accessing them requires more energy and more fossil fuels than does conventional oil, adding roughly $15 per barrel to the cost of extracting oil.

Traditional thinking holds that as oil becomes more expensive, market forces will cause a switch to more environmentally friendly options, like electric cars. However, the high price of oil also makes the production of oil from non-traditional sources more cost-effective, so the shift could be to a fuel that is even more carbon intensive than oil. Furthermore, the infrastructure for refining oil derived from tar sands already exists. Cars would not have to change. Brandt says that even if the fuel were more expensive, the industry is likely to augment traditional oil with tar sands before making a risky new investment in an environmentally preferred technology.

Farrell says oil from tar sands might be more politically secure than foreign oil, but it comes at an environmental cost that some economists and politicians ignore. Relative to the carbon dioxide the petroleum industry releases producing a barrel of conventional liquid fuel, the tar sands industry releases two to three times as much to produce the same barrel. When added to the carbon emitted from consumers actually burning that fuel, the production and use of tar sands could increase the total carbon emissions by as much as 40 percent. (See graph on page 3). Other non-traditional sources, like synthetic fuel from coal, are even more expensive and carbon intensive; extracting and processing coal releases four to five times more carbon.

The most carbon-intensive and expensive source of non-traditional oil is oil shale. Not actually shale, these are sedimentary rocks found mostly in the United States and Russia, which contain a mixture of solid hydrocarbons called kerogen. In a process called pyrolysis these hydrocarbons are heated, either in a refinery or in situ, to create crude oil. Currently the amount of energy necessary to create oil from shale dwarfs any other method and costs as much as $80 more per barrel (adjusted to 2000 dollars). Oil shale is a commercial fuel in a few countries,

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Oil: The Next Big Energy Resource?

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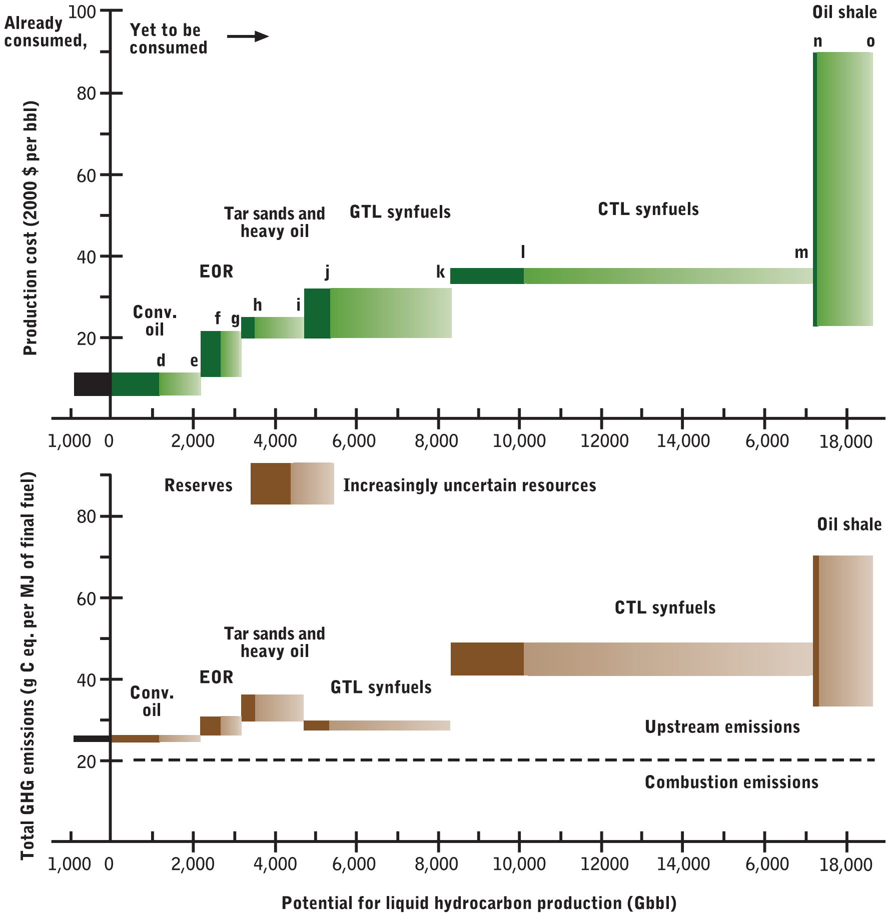

A Much Deeper Well of Liquid Fuels

These figures show the increasing costs of non-traditional sources of oil (enhanced oil recovery, tar sands, gas-to-liquid, coal-to-liquid, and oil shales). In the first graph, the green bars represent the economic cost of extracting fuels (not the actual price of the fuel themselves). The black bar to the left of the vertical axis represents all the oil that has been used until now (about a trillion barrels). The height of the bars represents the degree of uncertainty for the production costs, indicating, for example, that there is less uncertainty about the costs to produce coal-to-liquid synthetic fuel than there is about the cost of producing fuel from oil shale, which ranges from $20-$90 a barrel. The width of the bars represents how plentiful the resource is; although no one knows for certain, coal could provide at least two trillion barrels of synthetic fuel, but perhaps as much as eight.

The second graph is similar, this time charting greenhouse gas emissions. The dotted line represents the amount of emissions all fuels create when consumed. Above the dotted line indicates the amount of emissions released in the production of each fuel. The height of the bars indicates the range of estimates of emissions for each fuel.

notably in Estonia, which uses it to produce electricity and accounts for about 70% of the world's oil shale production.

Getting oil from non-traditional sources may be expensive now, but Farrell's and Brandt's work shows that as the price of oil goes up, it becomes more feasible. This is especially true if the transition happens incrementally – say 2% per year – allowing industry to adjust, rather than a sudden jump that would shock the system. Already the oil industry is mining 1.25 million barrels of oil a day from tar sands in Canada. The Navy and the Air Force are considering large investments in coal-derived synthetic fuel. Worldwide non-traditional sources provide about 3% of the total oil—about 2.5 million barrels a day. By 2010, this output could be increasing so fast that each year it may add half a million more barrels per day.

In the end, Brandt says, it may not even matter if switching to renewable energy becomes less expensive, especially if policy is simultaneously encouraging non-traditional fossil fuels.

"There is this sort of inertial issue here. The worry is that we will look back and realize that a little push in 2008 – through subsidies of coal-to-liquids for example – ended up pushing us in a direction we did not plan," he says.

Industry inertia underlies much of the Berkeley research. There is a strong incentive to stay with a fuel that is familiar, even if it is environmentally, economically, or politically less than optimal. As a comparison, Brandt points to the modern keyboard. Some have argued that the layout of the keys is highly inefficient and was designed to slow down typists, rather than hasten them. Yet every attempt to change to a new keyboard has failed.

"It's a different sort of context, but it's the same sort of inertia. Once you invest in something like coal-to-liquid you get a lot of technical, scientific people who know about it and know how to do it," Brandt says. "It's taking the easy way out. And once that's done in the short term there's a chance it will snowball."

Alex Farrell died before this article went to press. See page 7. He was an esteemed colleague and a good friend.

SOMETHING IN THE AIR

Wind turbines have come a long way from the charming but inefficient machines installed in California in the 70s and 80s. A new generation of wind energy is growing in the United States and will soon give birth to a powerful source of energy.

It's a crystal clear, blustery spring day. UC Davis professor Case van Dam wheels his BMW convertible along a small country back road and cranes his neck to look up through the windshield to the hills outside.

"Those are Vestas V80s in front of us. To the left, these are GE 1.5s – these are 1.5 Megawatt machines," he says, excited, looking at a cluster of wind turbines. "It's a good day today."

Indeed, it is a good day for wind. A steady 15-mile-per-hour breeze is coming out from the bay, and all of the wind turbines in sight are busily spinning away. Between the gentle hills, the little farmhouses, and van Dam's Dutch accent, this could be somewhere in Holland.

As it happens, we are in the San Francisco Delta, near the town of Rio Vista. The area is just one of many relatively untapped wind resources in California getting noticed by energy companies. After a period of hibernation in the 80s and 90s, wind energy has been reemerging as a mature, money-making industry, thanks partly to California's requirement to have 20 percent of its electricity come from renewable resources by 2010.

UC Davis professor Case van Dam looks for winds of change near Rio Vista, California. Behind him are several larger, 1.5 megawatts turbines.

Currently wind provides around two percent of the state's electricity needs, but experts say that may rise as high as 10 percent in the coming decade. Van Dam says California easily has room to quadruple its production in places like the Tehachapi Mountains, Altamont Pass, and here at Rio Vista.

Van Dam has been working in wind research for over 20 years and is a leading researcher in the field. He says the basic rule in wind turbines is that longer blades (usually measured by the diameter of the circle they sweep) generate more energy. With this in mind, he points up a hill to several smaller towers spinning furiously and says that most people's idea of a turbine is 20 years out-of-date. The device is about 50-feet tall, looks like a tripod, and generates about a tenth of a megawatt. Beyond it is a series of turbines atop thick, single towers with sweeps that measure more than 200 feet in diameter. These more modern devices generate up to 15 times more power each, depending on their location. (See sidebar on page 5.) That's enough to provide electricity to 700 average homes. However, you still need 950 of these turbines to replace a coal plant, and up to 1,900 to replace a nuclear reactor.

Therefore, much of van Dam's work focuses on ways to push blades ever bigger. However, the heavier the blade, the more expensive they are to build and transport. Plus, they take more energy to spin. So the newest blades are as big and light as possible. But this leads to problems.

"They do 20 rotations per minute, 60 minutes an hour, 24 hours a day, 365 days a year for over 20 years," van Dam says. "There are few pieces of machinery that we have that incur more fatigue cycles than wind turbines."

Of course no site has enough wind blowing to run all its turbines all the time. In fact, the average amount of time that a wind turbine actually produces electricity (called the capacity factor) is usually about 36 percent for modern turbines. Nevertheless, "fatigue" is a real problem due to the intense punishment of the wind. Larger turbines are the most vulnerable to this fatigue, and struggle in erratic wind patterns. Installing smaller turbines, however, means missing out on potential power.

But what if wind turbines could adjust themselves to the wind conditions? Then the turbine could take full advantage of the calmer days, but not get destroyed by heavier gusts. Van Dam is one of many scientists designing so-called "smart blades" with various movable parts. The idea is to use subtle changes in the aerodynamics of the blade to adjust for weather conditions and increase efficiency. This allows for 10-15 foot longer blades, and thus more energy collection.

Smart blades might contain retractable ridges along the turbine blades or perhaps movable tabs reminiscent of airplane flaps. One design actually extends and

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Something in the Air

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retracts the length of the blades as they are spinning. Van Dam focuses on devices called micro-tabs that rise like a tiny wall across the width of the blade, near the tip. When extended, the tab creates a wind eddy that decreases lift and takes some pressure off the blade.

The tabs automatically adjust in a fraction of a second, which means each wind turbine must have a set of sensors and actuators to monitor the wind and release the tabs. Van Dam says current wind turbine rotors have only one, maybe two sensors and just make basic adjustments from the hub.

Van Dam believes that advanced blade designs can be simple enough to be economical. But he admits they can only do so much to move the technology forward. At best, bigger smart blades will only squeeze out about 20% more energy than today's turbines. He estimates that the land-based wind turbines, which are limited by the difficulty of transporting the blades, will likely not go much above three megawatts. The biggest breakthroughs in wind power, he says, will come from a new generation of wind farms offshore, where turbines of five to seven megawatt are currently under consideration. The ocean offers stronger, steadier winds, and large turbines are easier to transport by sea than by land.

However, the major challenges for offshore wind are not in the blades, but in the foundations. Jason DeJong, also of UC Davis, is a geotechnical engineer and expert in wind-turbine foundations. Current offshore wind turbines are similar to their terrestrial cousins only taller, since they may go as deep as 100 feet underwater.

At that depth, much of the Eastern Seaboard becomes eligible for wind farms. The trick, DeJong says, is to find soil strong enough to support the forces of not only wind, but waves and currents. On land, the foundation of a turbine is between 50% and 100% of the height of the turbine. Offshore foundation depth varies with the site, but with loose sandy floors ocean turbines may go considerably deeper.

"If the cost of an onshore turbine is two million dollars, then the cost offshore would be about five to six. The foundation system alone could cost as much as the whole turbine onshore," he says.

However, the richest waters for wind energy are not off the East Coast; they are here in the West. California alone holds 20-30 % of the nation's offshore wind potential. But in California waters, turbines may have to spin as much as 100 to 500 feet above their base on the seafloor, depending on the water depth.

No such turbines exist yet, and the only working offshore farms are in Europe. But DeJong says it may someday be feasible to go down to 160 feet using heavy cables to connect the seafloor to the sides of the towers, like tensioned flying buttresses. To find out how this would work, wind experts must take cues from the oil industry, which has a long history of drilling offshore wells in deep water.

Another design gleaned from oil rigs is a floating turbine. In this case, either a single turbine or a fleet of turbines would be anchored to the seafloor with cables. DeJong say we are not ready for offshore California wind farms yet, but his work shows that it's not far away.

"It's really early in the process. But it's something that is inevitably going to happen, there's no way around it. It's a matter of putting the resources behind it to make it viable."

Location, location, location

One of the primary criticisms of wind energy has been that wind is too irregular and therefore not a reliable source of power. Wind speeds vary by season, time of day, and weather. The trick, then, to setting up a profitable wind farm is finding a good site and matching it to the proper turbines.

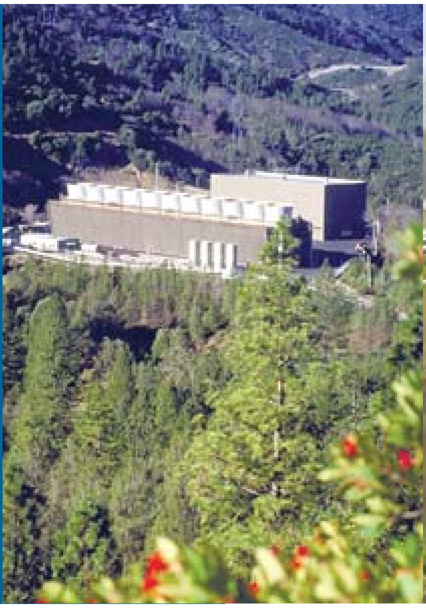
The turbines only generate power when the wind reaches a minimum operating strength known as the "cut-in speed," and stop if it goes beyond the "cut-out speed." A large turbine in a gentle wind won't spin. Furthermore, even if its rated capacity is 1.5 megawatts, it will not reach that output until the wind blows above about 25 miles per hour.

Engineers use "capacity factor" to represent the ratio of average power produced by a turbine over a given period to the rated capacity of that turbine. Capacity factors depend on the characteristics of the turbine as well as the quality of the wind site. Smaller turbines installed in Altamont Pass in the 1980s typically have capacity factors around 25 percent or less, meaning they average only about a quarter of their potential power. Around Rio Vista, the better wind conditions give a capacity factor of nearly 50 percent during the summer months.

It's not just the supply of power that ebbs and flows, but also the demand. In California, thanks to air conditioning, energy needs are highest in the summer, making power more valuable. California wind sites generally benefit from higher summer winds that contribute to meeting this peak demand. However, at some sites the winds tend to pick up late in the day and continue into the night, after the afternoon peak in electricity demand.

Some Like It Hot *Continued from page 1*

> **"We are aiming to drill a well to a depth of four and a half kilometers, where we will be looking for temperatures in the 500 and 600 degree range. We are anticipating that we will be drilling the hottest and deepest geothermal well that has ever been drilled."**
>
> **UC Riverside Professor Emeritus Wilfred Elders**



However, geothermal energy currently provides only 0.3% of the nation's energy. In California, which boasts one of the world's few natural dry-steam geothermal systems, about 5% of the installed electrical generating capacity is geothermal. Kennedy says this is because traditional geothermal wells are hard to find.

"The explorations arm of geoscience – looking for systems – is really about minimizing the risk of the first well," Kennedy says. "Making sure that first hole is in the right place so you can hit something."

First, temperatures in a geothermal well must exceed about 200° Celsius. To operate turbines at an electric generating plant those wells need to be capable of producing huge amounts of steam. Therefore, most geothermal prospectors look for the few most obvious sites near active volcanoes or geysers.

But Kennedy says there are untold other pockets of hot water hidden under the surface throughout the western states. Moreover, there is plenty of "hot dry rock" – geothermal heat with no water, and thus no steam to run a generator. This doesn't mean energy can't be extracted though. According to Kennedy, the Holy Grail of modern geothermal work is a model that allows investors to pick sites for Enhanced Geothermal Systems (EGS). In EGS projects engineers drill two adjacent holes into dry rock. Then they pump water into one, which goes through fracture networks to the other, and comes back as steam. To do this, scientists need an intimate knowledge of things like the permeability, porosity, and hardness of rock layers three or more kilometers below the surface before they drill a hole.

Once you pick the right spot and access the heat, there is still the problem of how to keep water flowing through the holes as fractures shift or water clogs them with mineral deposits. To keep the fractures open, engineers create tiny earthquakes with water pressure in a process called hydrofracking. Therefore, in addition to geological modeling, much of LBL's geothermal work looks at fluid dynamics to understand how this can work and how it can go wrong. To date, a number of experimental EGS projects exist, but none turns enough profit to inspire commercial investment yet.

Wilfred Elders, an emeritus professor at UC Riverside, says there is another way to enhance the economics of geothermal electric plants. He is the co-chief scientist for a pathbreaking program called the Iceland Deep Drilling Project (IDDP) in Northern Iceland.

"The hottest producing wells that I know of in the world are in Larderello, Italy, where they have temperatures as high as 400° Celsius," he says. "[In Iceland] we are aiming to drill a well to a depth of four and a half kilometers, where we will be looking for temperatures in the 500° and 600° range. We are anticipating that we will be drilling the hottest and deepest geothermal well that has ever been drilled."

At these deeper, hotter parts of the crust, fluids reach a state known as supercritical, in which the difference between steam and liquid water disappears and a single aqueous fluid emerges with very low viscosity and extremely high energy density. Supercritical fluids have been studied in the laboratory, but no one has attempted

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to directly observe them in nature. If it works, supercritical fluid should enhance flow rates and potentially produce as much as ten times more power than a conventional geothermal well.

Iceland's government and three of its largest geothermal companies are chipping in to drill an expected three holes, each costing more than $20 million. The first hole is scheduled to begin this summer and finish in 2009. Elder's team, including scientists from UC Davis as well as six other countries, is charged with studying the scientific implications of the project. They will take measurements directly from the drill hole and retrieve regular core samples for laboratory analysis.

He is especially interested in issues like water/rock relationships at such high temperatures. Through close examination of some metamorphic rocks, we know supercritical fluids under pressure can dissolve solids around them. How much dissolution depends on the chemistry of the fluids and their temperature and pressure, but again, this is poorly understood in natural environments. This is the kind of basic science research that can help scientists understand a wide array of topics like rock metamorphism and the ability of a substance to transmit heat energy.

Elders says with ten times as much energy as conventional geothermal wells, the wells could be very profitable, since the hotter the well, the more valuable it is. This could be important for EGS work. One of the primary criticisms of EGS is that it is too expensive compared to coal or natural gas. It requires twice as many holes as an oil production well, and there is a higher risk that a well will have complications with the connecting fracture systems.

"If you can increase the output of a geothermal well by a factor of ten," Elders says, "that would be a very attractive prospect for investment."

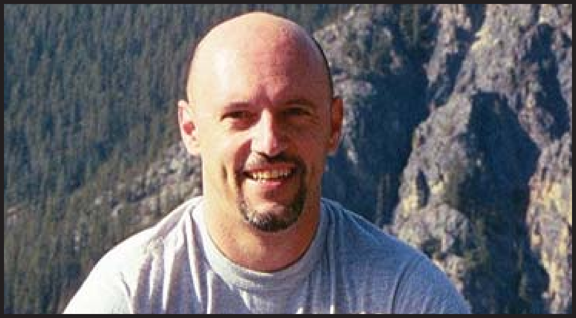
As an added benefit, Elders says the project may reveal something about the chemical and physical nature of so-called black smokers, a phenomenon found at mid ocean ridges. These mysterious vents emit plumes of sulfide-rich minerals that look like underwater black smoke. However, they are hard to access and therefore little studied. The IDDP project is located in one of the few places where a spreading mid-ocean ridge is accessible out of the ocean.

The driving force behind supercritical geothermal research is still energy production. That said, it's not clear what role this type of mining will play in the future of geothermal energy. Iceland's unique geography makes it the perfect testing ground but no one knows if it will find applications in other parts of the world. Kennedy says the prospects for drilling to 600° Celsius in the US are slim and that we need to focus future research on EGS.

Elders is more optimistic about other applications but is careful not to get too far ahead of the task at hand.

"This is the first time I think that anyone will be able to directly drill into supercritical conditions. If we are successful, that would be a first and a huge technical achievement," he says.

In Memory of Alex Farrell



Professor Alex Farrell

It is with tremendous sadness that we share the news that Alex Farrell died on April 13.

Alex brought passion and an intellectual curiosity to some of the most pressing environmental and energy issues. He was a tremendous resource, a first-rate researcher, and a very caring person.

The world of energy research and policy is much poorer for losing him.

Alex was a visiting researcher at UCEI last fall and a frequent attendee at the UCEI lunch since then. We enjoyed our lunchtime conversations with him and will deeply miss our friend and colleague.

2008-2009 UCEI GRANT RECIPIENTS

The UC Energy Institute will award $490,862 during the next fiscal year to fund the outstanding UC research projects listed below. Graduate students on UC campuses are the largest recipients of these funds. Nearly two-thirds of the grant awards will go directly to support graduate students. UCEI is proud to contribute to expanding the knowledge and technical innovations aimed at solving California's and the world's critical energy issues.

CALIFORNIA ENERGY STUDIES PROGRAM

Michael Anderson, *UC Berkeley*, "The Hidden Benefits of Fuel Economy Standards"
Yihsu Chen, *UC Merced*, "Examining Short-Run Economic and Emissions Implications of Different Emissions Trading Programs Under California AB32"
Nael El-Farra, *UC Davis*, "Control of Distributed Energy Resources Over Communication Networks"
Paul Erickson, *UC Davis*, "The Use of Thermal Storage Refrigeration to Lower Peak Demand and Optimize Renewable Energy Resources"
Qinghua Guo, *UC Merced*, "Mapping California Solar Irradiance and its Implications for the Power Sector"
John Quigley, *UC Berkeley*, "Doing Well by Doing Good? The Economics of Green Office Buildings"
Diego Rosso, *UC Irvine*, "The Energy-Footprint of Energy-Efficiency Upgrades in California's Wastewater Treatment Plants"

ENERGY SCIENCE AND TECHNOLOGY PROGRAM

Mark Goorsky, *UC Los Angeles*, "Engineered Layer Transfer Substrates for Solar Cell Applications"
David Kisailus, *UC Riverside*, "Biologically Inspired Synthesis of Nanostructured Sensitized Solar Cells"
Suneel Kodambaka, *UC Los Angeles*, "Synthesis of Si, Ge and SiGe Nanowires with Tunable Surface Morphologies"
Delmar Larsen, *UC Davis*, "Probing the Relationship Between Morphology and Kinetics in Bulk Heterojunction Photovoltaics"
Yat Li, *UC Santa Cruz*, "Development of InGaN Nanowire Heterostructure Arrays for High Efficiency Photovoltaic Cells"
Laurent Pilon, *UC Los Angeles*, "Waste Heat Harvesting from Power Generation and Transportation Systems"
Yayoi Takamura, *UC Davis*, "Superlattices of Perovskite Structured Materials for Solid Oxide Fuel Cells"
Jean VanderGheynst, *UC Davis*, "Characterizing Microalgea Cell Walls and Starch Reserves for Biofuel Production"