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NEWS FROM THE UNIVERSITY OF CALIFORNIA ENERGY INSTITUTE

From Lab to Market

PLASTIC SEMICONDUCTORS MAY LIGHT UP THE FUTURE

Ben Schwartz

Yang Yang

Next time you go camping with your family, imagine spreading a plastic tarp of solar cells over the top of your tent. The cells would collect solar energy during the day and power electric appliances around the campsite at night. Sound far-fetched? It's not.

Two UCLA researchers are involved in pioneering research to increase the energy-conversion efficiency of plastic semiconductors that can be engineered to collect energy through solar cells or emit it through light-emitting diodes (LEDs). The technology already is revolutionizing products and processes around the world.

Benjamin J. Schwartz, a professor in the Dept. of Chemistry and Biochemistry, and Yang Yang, a professor of Materials Science and Engineering, approach the study from different but complementary directions. Schwartz, a physical chemist, studies the fundamental properties of the materials – to determine what makes them click. Yang, an engineer, takes advantage of the materials' physical and electrical properties to create useful devices – to build a better mousetrap. Both are among the first in this new field, which has grown rapidly over the last decade.

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Global Energy International Prize

A symposium and presentation commemorating the establishment of a new international prize for energy research just finished its inaugural tour through the United States, with the last stop at UC Berkeley on November 19.

The Global Energy International Prize, initiated in Russia, will award at least $750,000 annually for scientific achievements in the fields of energy and power engineering. Russian President Vladimir Putin presented the first award of $900,000 in St. Petersburg in June to Nick Holonyak of the University of Illinois, Ian Douglas Smith of Titan Corporation in San Leandro, Calif., and Gennady Mesyats, director of the Russian Academy of Science's Institute of Electrophysics. President George W. Bush sent a congratulatory letter.

The driving force behind this new prize for innovative energy research is Zhores Alferov, 2000 Nobel Laureate in physics, director of St. Petersburg's famed Ioffe Institute, and member of the Russian Academy of Sciences. In a statement on the Global Energy International Prize Web site, Alferov explains his motivation for creating this new research prize:

"It was decided to present this new scientific award in the United States to emphasize that your country and Russia both have immense scientific and energy resources. We are ideally situated to undertake important cooperation in basic and applied science in the field of energy, and we believe that these events will be an important step to further development of this cooperation in the interests of mankind."

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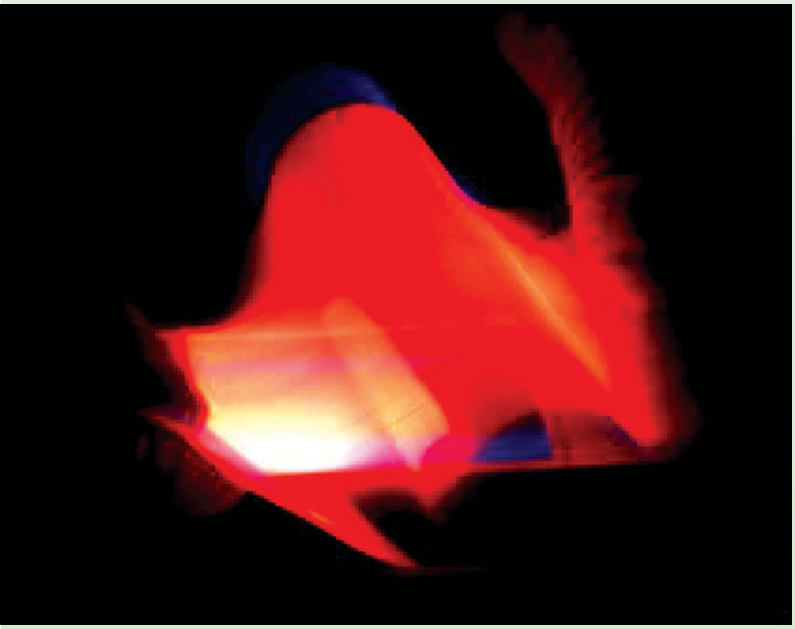
Plastic semiconductors are organic compounds with unique properties. When the individual polymer chains are designed so that their electrons can be mobile, they have electrical properties similar to inorganic semiconductors, such as the silicon in computer chips. Still, they have physical properties similar to polyethylene or polystyrene. Such plastics are easily processed; they can be rolled into thin film like food wrap, dipped like a coating, or blown into an injection mold. If these processes were extended to semiconducting polymers then they, too, could be easy to make. Unlike silicon semiconductors, plastic semiconductors are more environmentally benign to manufacture; they don't involve clean rooms, heavy metals and expensive, energy-intensive production lines. With volume production, they could be much less expensive, as well.

Despite their likely production benefits, organic plastic semiconductors may never compete with inorganic semiconductors in certain uses, such as computer CPU or CD player diode lasers. But in some solar cell and LED applications, Schwartz says, they will have a place. "Even if efficiency is lower by a factor of five or 10, if they can be 100 times cheaper then they come out ahead for many, but not all applications."

Schwartz's interest in the fundamental properties of the materials has led him to study the relationship between the morphology of how the polymer chains are packed and their semiconducting properties. "Controlling the way the chains are packed together—how electrons are excited or relaxed, and how they move within the chain—is, in my opinion, the most important determinant in how the materials behave," he says.



A large area of conjugated polymer thin film coated by a continuous coating process; this thin film could be used in flexible polymer solar cells.

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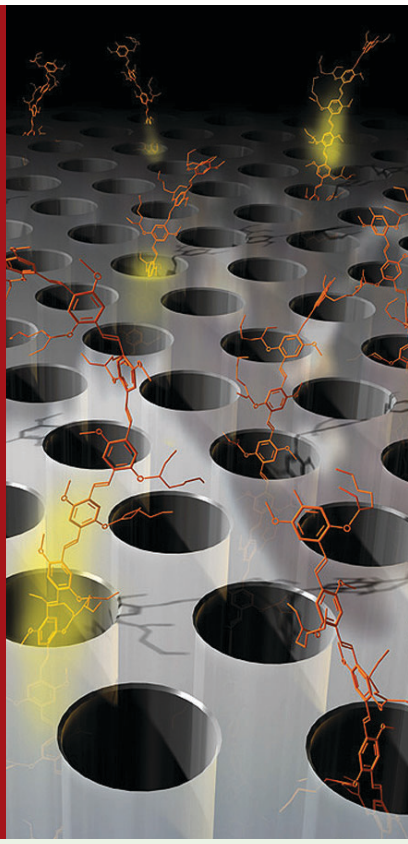
—BEN SCHWARTZ



Artist's rendition showing that encapsulating conjugated polymer chains in nanoporous silica enables researchers to control energy flow along the chains. Design Credit: Dan Schwartz, D.I.S.C.

If the chains are packed one way, they can be optimized for collecting solar energy to convert to electricity. If they're packed another way, they can emit light energy in an LED. In work funded in part by UCEI, Schwartz continues to explore new methods for obtaining control over the chains. One of his research papers has been cited more than 140 times and is listed as one of the 10 most-cited papers in chemistry for the last six months by *Science Citation Index.*

In Yang's quest to develop useful devices, he has already had success. His research group holds two patents for a unique way of printing a color LED display using inkjet printing technology. The polymer is dissolved in an organic solution and loaded into a printer's inkwells. The printer prints the solution onto a conducting substrate. When a current is passed through the substrate, the printed area lights up in a colored display.

Similar technology is being used to produce color displays for cell phones, personal digital assistants and other small electronic displays. It also is being used to print radio-frequency identification (RFID) tags on shipping containers. RFID is a new technology that is fast replacing barcode scanners for tracking product movement in warehouse and shipping operations. It may soon be used for tracking checked luggage on commercial airliners.

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"Practically, once the efficiency of the plastic solar cell reaches 10% or higher, it has a chance to compete with the silicon solar cell."

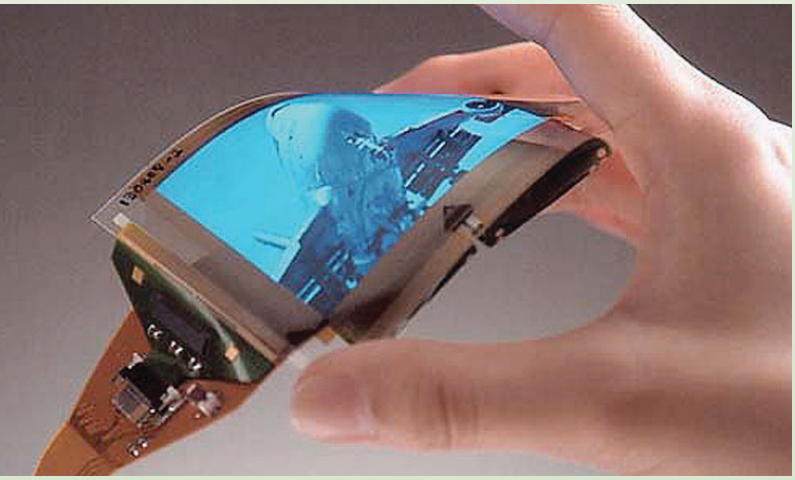
—YANG YANG

A 15-inch organic display manufactured by Kodak and Sanyo in a Japanese joint venture.

"The application of the technology has been widespread, much beyond what we anticipated in the beginning," Yang says. "It's very exciting."

In his light-harvesting work with photovoltaic cells, Yang's approach to increasing the conductivity of plastic differs from Schwartz's chain-packing concept. Yang is mixing the polymer with an ionic conductor so that the materials can collect the charge more easily. Yang's approach has led to improvements in the overall photovoltaic efficiency, but his highest achieved efficiency of 3-4% still falls short of the 10-14% efficiency of silicon solar cells. Even so, the military and NASA are interested in this work, and that is rewarding, he says.

Continuing to improve the efficiency of both light-harvesting and light-emitting plastic semiconductors remains the biggest challenge to their widespread use. Commercialization appears closer for plastic LEDs than for plastic solar cells, especially for LEDs used in displays that do not need very bright light. In addition to color cell phone displays, potential applications include greeting cards that light up, indoor exit signs, and luminescent panels that could someday replace fluorescent lighting. One problem yet to be solved is that the colors in a polymer LED color display decay differently, resulting in a green tinge after a period of operation, Yang says.



Flexible organic semiconductor display made by Pioneer.

While plastic LEDs may work well in low-light displays, both Yang and Schwartz question whether they will ever meet the bright light and long life demands of applications such as traffic signals, which now commonly use silicon LEDs. Still, Schwartz notes that researchers in large corporations are hard at work on solid-state lighting applications, so he counters his own skepticism by raising the possibility that there could be a breakthrough in five to ten years.

Yang and Schwartz agree that plastic solar cells will have a place in certain niche applications. Their views differ, however, on the materials' widespread use.

"At this point, I'm skeptical that plastic solar cells will ever play a role for major electricity production, unless there's a real breakthrough in efficiency in the next couple of years," Schwartz says.

Yang, on the other hand, believes that the technical challenges can be overcome, perhaps within five to seven years. Right now, he says, the biggest barriers are the stability of the polymer and the encapsulation technology. Additionally, more research is needed on the structure of the device and on flexible substrate materials. "Practically, once the efficiency of the plastic solar cell reaches 10% or higher, it has a chance to compete with the silicon solar cell," Yang says.

Profile:

Natalia Fabra, **Visiting Researcher**

Deregulation of the electricity industry is not typical dinner table conversation in most households. But for Natalia Fabra, such conversations provided insights that led to a career.

Fabra came of age in Spain in the 1980s, where her father helped shape reforms of the electric power industry. "When I first started to study economics in college, I realized I already had some industry knowledge. That I could discuss these issues with my father was very enriching," she reflects.

Now working on her own research—she earned her Ph.D. from the European University Institute, in Florence, Italy, in 2001—she and her father still debate policy, but at a different level. "We share common views, but also learn from each other's perspectives," she notes. "We sometimes force disagreement to explore new ideas and the other side's arguments."

Fabra, an assistant professor at Universidad Carlos III de Madrid, is a visiting researcher at UCEI through February 2004. Her work analyzing competition and market power in electricity markets has recently focused on market design issues. "We ought to understand how competition takes place in order to devise market rules that contribute to mitigating market power," she explains. Motivated by recent debates over discriminatory versus uniform-price auctions, she has analyzed how these different auction formats affect generators' dynamic bidding incentives, the degree of competition, and overall welfare in decentralized electricity markets. Recent deregulation experiences in England, Wales, and Spain have provided real-world data for her work.

In a broader discussion about electricity restructuring, Fabra advocates for caution, as there is no agreement on the best policy choices. Between a pure market solution and a return to the old system of regulated monopolies is a continuum of many regulatory alternatives worth investigating, she says. The first-best solution may not be feasible when the full complexity of electricity markets is taken into account, including political, social and implementation issues.

"One thing we've learned is, failure is very costly in the court of public opinion. And it's hard to win that back. We know reforms take a long time, and we can assess and learn a lot by watching the transition process," she notes.

Currently, Fabra is working on a new project that examines the interaction between retail and wholesale competition under differing degrees of vertical integration. Initial findings show that a generator may profit from vertical integration since it would bid more aggressively and would gain market share. Furthermore, a firm may integrate in order to preempt a rival company's integration. A second integration round would not be profitable, since it would lead to fierce competition and low profit margins. Fabra's research suggests that, as a result, some companies may be vertically integrated and others not, leading to a scenario in which consumers end up paying high prices.

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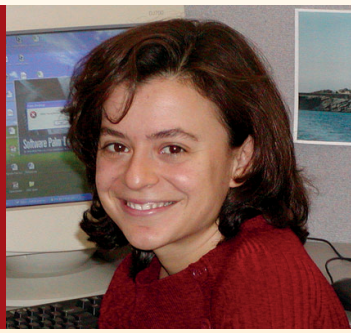

Fabra embarked on this new research direction after interacting with two other UCEI visiting researchers, Catherine Waddams and Frank Wolak, who led seminars on retail competition and vertical integration at Camp UCEI last August. She gladly accepted the invitation to be a visiting researcher this fall, and says she will return to Madrid in February with an expanded repertoire thanks to many productive discussions with colleagues here.

Further Reading:

Fabra, N., 2003, "Tacit Collusion in Repeated Auctions: Uniform versus Discriminatory," *Journal of Industrial Economics,* Vol. L1, No. 3 (September), pp. 271-293.

Fabra, N., von der Fehr, N.-H., and D. Harbord, 2002, "Modeling Electricity Auctions," *Electricity Journal,* Vol. 15, No. 7, pp. 72-81.

Fabra's work is available at http://www.eco.uc3m.es/~nfabra/.

CSEM Fall Policy Conference

QUESTIONS AND ANSWERS PROVOKE SPIRITED DISCOURSE

Although California hasn't experienced any blackouts lately, there is still a lot of interest in energy issues, judging by attendance at the Fall Policy Conference of UCEI's Center for the Study of Energy Markets.

This year's seminar focused on what UCEI Director Severin Borenstein described as three "front-burner" topics: realtime pricing and resource adequacy, procurement and retail competition, and transmission access and investment. More than 150 energy analysts and policy makers attended to hear and question proposals for future changes that will create conditions for a more efficient and reliable electricity market.

Borenstein presented new results from research on the long-run impact of realtime pricing. Although RTP was discussed during the electricity crisis as a defense against sellers exercising market power, the new research shows that even in a completely competitive market, RTP could reduce the need for peaker capacity, increase capacity utilization, and lower the average cost of production. The modeling results demonstrate that even with very little demand response to high prices, the benefits from RTP for large industrial customers would far exceed the costs.

UCEI's James Bushnell discussed the current policy debate over the future of retail competition and its implications for resource adequacy. He pointed out that excess capacity comes at a cost, such as the relatively high average rates paid by California consumers during the 1990s. Bushnell advocated that direct access customers should have the flexibility to choose their appropriate level of planning reserves, rather than have the state regulatory agencies determine reserve levels for everyone. However, he also argued that those who are allowed to choose a level of reserves outside of the utility planning process must bear responsibility for their choice. This means that, in the event of resource scarcity, customers of the supplier with inadequate reserves would bear the consequences of any shortfall, rather than all customers. Not everyone in the audience seemed quite ready for that level of choice.

Frank Wolak, a UCEI visiting researcher and professor at Stanford, addressed how transmission upgrades in a wholesale market regime should be determined and how the costs of such upgrades should be allocated. He described how transmission lines perform an important role in promoting competition in a deregulated electricity market, in addition to the traditional function of enhancing reliability. Wolak enthusiastically advocated that more transmission lines should be built as a means to acquire lower-cost energy and to mitigate the exercise of market power.

The overall theme of the three presentations was that one must address all angles of the incentives a firm or firms face when deciding regulatory policies. The state regulatory agencies need to align the incentives with the public policy goals of the agencies.

The policy conference, made possible by a grant from the California Energy Commission, is one of CSEM's ongoing outreach programs. Together with the annual POWER Conference in March, bi-weekly seminars, and a two-day executive education course in January, the Policy Conference helps CSEM achieve its mission of fostering top research on energy policy to promote better understanding of how energy markets function and deregulation affects the energy industry.

What's Wrong With Regulating Gasoline **Prices?**

By Severin Borenstein

Editor's note: Rising and falling gasoline prices are a fact of life in California. Supply disruptions, ethanol blending, demand, and a variety of other factors affect the prices that consumers pay at the pump. Toward the end of last summer, high gas prices were again in the news. This article was originally published in *The Sacramento Bee,* September 12, 2003.

Gas prices are up, and politicians don't want to appear complacent. But proposed responses could be much worse than doing nothing.

Attorney General Bill Lockyer decries price gouging, while Lt. Gov. Cruz Bustamante advocates regulating gas prices and draws parallels to the electricity crisis. As someone who supported price controls in electricity, but opposes them in gasoline, I think it's important to understand the difference between these situations.

In any market, prices can fluctuate, even if sellers can't control them. California's house prices have skyrocketed, even though no one is withholding housing supply from the market or creating an artificial shortage.

Price increases that reflect real shortages send valuable signals to the market, rationing the limited supply that exists today and encouraging entrepreneurs to bring more of the product to market in the future.

But not all shortages are real, and not all high prices are caused by a simple principle of supply and demand. In some markets, a few sellers can make greater profits if they reduce their supply and drive up prices. When that happens, the high prices are not reflecting a real shortage, and the signals they send to buyers and investors are misleading.

Whether the shortage is real or artificial, the sellers make money from the high prices and some customers are hurt in the short run. This invariably leads to calls for price regulation. The problem is that if the shortage is real, price regulation is more likely to harm consumers than to help them.

If there is a real shortage in the gasoline market, pushing prices down with regulation will cause demand to exceed supply, which means lines of people waiting to buy gas. In the gasoline market of the 1970s, and with many other price controls, the time spent in line and the inconvenience of some people not being able to buy the product at all outweighed the consumer savings from price controls. Also, if the shortage is real, price controls discourage investment in the market, leading to more shortages.

If, however, the shortage is created by sellers who are withholding supply, price controls can benefit consumers. A company's incentive to restrict supply diminishes if the company knows prices won't be allowed to rise beyond a certain point. In this case, price controls can decrease prices and increase supply.

So, the key is to know when high prices reflect real shortages and when they are artificially caused by sellers with market power.

With careful analysis, I and others studying the California electricity market concluded that prices were well above competitive levels, reflecting an artificial shortage created by sellers withholding supply. These studies of electricity production and prices have since been supported by internal documents of electricity producers.

No studies, however, have shown that California gasoline prices are significantly above competitive levels. Yes, prices are high, but there have been refinery disruptions as they've adopted a new formulation that includes federally mandated ethanol. Also, a pipeline break in Arizona caused some California gasoline to flow toward higher Arizona prices.

Do those real supply problems explain California's high prices? It is extremely difficult to know.

Remember the questions during the electricity crisis about whether a plant was legitimately down for maintenance or why it was producing less than capacity? Those questions are much more difficult to answer with gasoline because refining is a much more complex production process than electricity generation.

In addition, gasoline can be stored, so the price today also depends on how much gas is in storage, and how much will be produced and consumed in the near future. Regulators would be very hard-pressed to determine the competitive price of gas on any day.

California does have a real gasoline problem. Demand has outstripped the capacity to produce the state's low-polluting blend, causing real shortages. But the tight market also puts the largest sellers in the market—with market shares up to 24%—in a position to boost prices by withholding supplies.

Unfortunately, price controls are a dangerous response to this very real problem. Unless regulators can determine how much of the high price is due to real shortages, they are likely to make those shortages worse.

Instead, the state should push to increase supplies, either by permitting more refineries to be built in California or by helping smaller companies find out-of-state sources that can meet our strict pollution standards. More supply sources and more competitors are much more likely to benefit consumers than are price controls.

Short Takes

UCEI Has Moved to Its Permanent Home

Effective December 8, UCEI can be found at 2547 Channing Way in Berkeley. UCEI staff, graduate students, and visitors have offices on each of the three floors of this historic, brown-shingle house on the northwest corner of Bowditch and Channing. All UCEI phone numbers and e-mail addresses remain the same; the only difference is we have now ended our nomadic existence and are settling in for the long term.

CSEM Executive Education Course in January

The annual "Economic Fundamentals of Electricity Regulation and Markets" executive education course is taking registrations for its two-day course on January 8-9, 2004. The course will be taught by Severin Borenstein and Jim Bushnell at the California Independent System Operator's Board Room in Folsom, Calif. For more information, please visit our web site at www.ucei.org.

Ninth Annual POWER Conference Scheduled for March 19, 2004

UC Energy Institute will host its Ninth Annual POWER Conference on March 19 at the Joseph Wood Krutch Theatre on the Clark Kerr campus, UC Berkeley. Organized by UCEI's Center for the Study of Energy Markets, this conference presents the work of leading researchers on electricity industry restructuring. As the conference draws nearer, please watch for more details on the UCEI Web site.

Global Energy International Prize

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"Globalnaya Energia." Left to right: Richard Newton, Ian Smith, Gennady Mesyats, Zhores Alferov, Severin Borenstein.

The event at the Joseph Wood Krutch Theater on Berkeley's Clark Kerr Campus drew U.C. energy researchers from the Berkeley, Davis, and Irvine campuses and the Lawrence Berkeley and Lawrence Livermore national laboratories, visiting members and staff of the prize committee, the laureates, and private industry.

College of Engineering Dean Richard Newton, UCEI Director Severin Borenstein, and Energy and Resources Group, Public Policy and Nuclear Engineering Professor Dan Kammen welcomed the audience. The program included a short video and presentation about the prize by Alferov, and talks about pulse power by winners Smith and Mesyats. Holonyak, whose research included the development of white light-emitting diodes, was not present. The program concluded with a talk on energy efficiency by Art Rosenfeld, California Energy Commissioner and Berkeley Professor Emeritus of Physics. A dinner followed the symposium.

The UC Berkeley College of Engineering, Department of Nuclear Engineering, Energy and Resources Group, and UCEI hosted the event, which UCEI's Mike Lederer organized. In addition to publicizing the prize, the event and dinner provided an opportunity for energy researchers from California and Russia to exchange ideas about important directions in energy research.

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