TOMORROW'S ENERGY: A SYSTEMS APPROACH

How Carnegie Mellon engineers are helping NETL close the technology gaps in new energy systems

BY MIKE VARGO

"With any new energy source, you are looking at a huge systems problem," says Andy Gellman, head of Chemical Engineering at Carnegie Mellon. He explains that when people talk about energy sources like solar, fuel cells, or synthetic fuels, each one itself is often referred to as a "technology"—in the singular—whereas in fact, "each one is going to require a whole set of technologies, if you want it to have wide use and have impact on society."

In many cases, better (and cheaper) materials are needed for crucial components. Units also have to be mass-manufactured; energy and fuels have to be distributed and/or stored, often in new forms; and much more. "Each part of each system has to work well or else the whole concept crashes," Gellman says. "So we have to be aware of what the weak links are, and put research into them. That's what NETL is doing now."

NETL, the National Energy Technology Laboratory, has created a new Institute for Advanced Energy Solutions (NETL-IAES), and Carnegie Mellon is one of three universities providing research talent for the work. The others are West Virginia University and the University of Pittsburgh. Together they form what is called the CWP consortium, for the schools' initials. And within this alphabet soup is some much-needed substance, Gellman says.

Gellman is co-director of the university consortium for NETL-IAES, whose research has seven major thrust areas. Some address specific energy sources or systems, such as "Gas Hydrates" (which are promising but little-tapped natural fuels) and "Carbon Management" (technologies to capture and sequester CO_2 emissions from coal power plants). Other thrust areas deal with core or enabling technologies that could have many applications, like "Materials" and "Systems Modeling."

Carnegie Mellon is active in all areas. Twenty-four faculty from various departments of the three universities—plus graduate students and postdocs—are doing research both at the NETL main facility in Pittsburgh's South Hills and on campus. Here are glimpses of work under way.

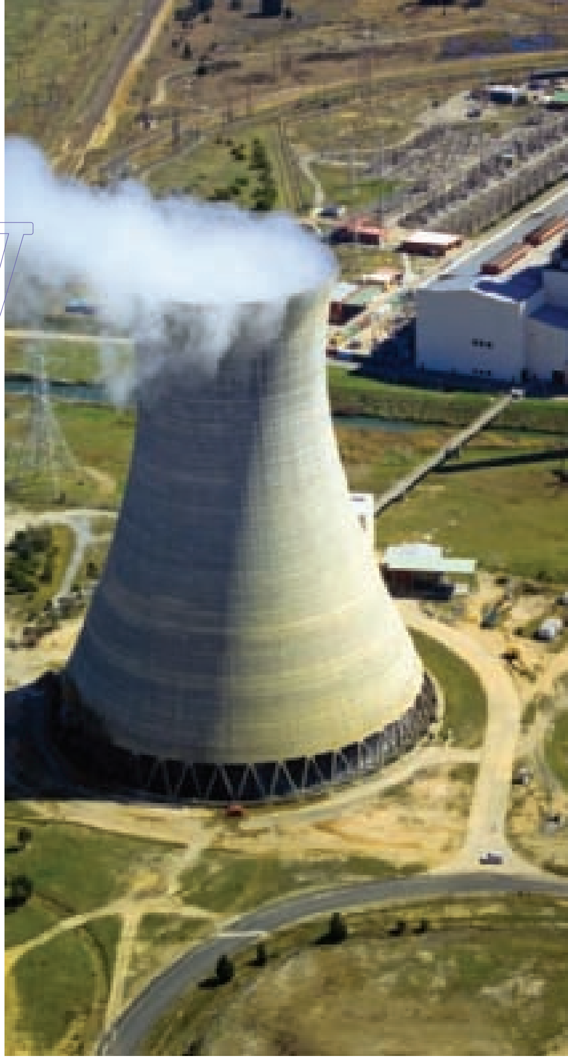
Sorting Out Many Possibilities

Some of Andy Gellman's own research has to do with deep enabling technology: he is developing new *methods* for developing materials. This is important if you want to find, for instance, a better catalyst. Catalysts are materials that can cause or speed a chemical reaction; they are used in fuel cells and in a host of processes in other energy systems.

Finding a catalyst that does a given job better than ever can be daunting, as many catalytic materials are complex ternary (three-element) or higher order alloys. It could take endless fiddling with different proportions of different elements to discover an optimum mix. Computer simulations can help—others are tackling the problem from that end—but as Gellman says, sooner or later you must experiment with physical samples, and "if you've got hundreds of thousands of possibilities, how do you try them all?"

A solution he proposes is: "Grow a thin film with compositional gradients. The make-up varies to give you, say, ten thousand possibilities. And of course,

Energy



you'd have a measuring device that makes ten thousand measurements" to see how each performs. The method is far from ready and others may be tried, but work of this type could have far-reaching benefits.

Closing in on CO_2

Elsewhere, ChemE professor John Kitchin heads a research group working on several projects of interest to NETL-IAES. In one project Robin Chao, a Ph.D. student in Materials Science and Engineering, is working with MSE professor Paul Salvador to study cathode materials for solid-oxide fuel cells.

Also, two Ph.D. students in the Kitchin group are looking at different ways of pulling CO_2 emissions from flue gases. Rich Alesi is experimenting with new sorbents to filter out this greenhouse gas, while James Landon is working on an electrochemical separation device.

Either approach, or both, could be used in the carbon-capture systems now being proposed for future coal-based power plants. Since it is likely that we must keep using coal to generate electricity for at least the next few decades, the idea is to minimize CO_2 buildup in the atmosphere by capturing it at the source and "sequestering" it—literally burying it—in underground repositories.

Carnegie Mellon faculty such as Ed Rubin of Mechanical Engineering and Granger Morgan, of Engineering and Public Policy, have done seminal work on the macro-issues and policy aspects of carbon capture. "My group's job is to focus on the technologies," John Kitchin says. "What are the physical bounds of these technologies? What ranges of performance can we deliver? What are the tradeoffs; what else can we try?"

He notes that capture-and-sequestration systems would, themselves, require a lot of energy—about 25 percent of a plant's total output, by current estimates, "and that's a best-case number," he says. "Essentially, for every three new power plants, you'd need a fourth to capture the CO_2. We're trying to get that number as low as we can."

No Free Lunch, but …

As Kitchin and Gellman both observe, there is no free lunch in energy generation. Somewhere along the line, every system that puts out energy requires energy inputs, creates emissions, and consumes scarce resources. (One obstacle to the mass use of hydrogen fuel cells, Gellman says, is that "there isn't enough platinum on the planet" for the electrodes.)

However the costs and the environmental toll can be minimized, perhaps in some cases through creative combinations. "We're not going to have just one energy source in the future but several, and we need to make them work in symbiotic and complementary fashion," says Gellman.

Kitchin gives an example: "If we can separate CO_2 from flue gas, why not from the air? Then, use the CO_2 and hydrogen to make methanol. Right now that takes a lot of energy, but if we learn to do it more efficiently—and there is work in my group that could point to a way—we'd get a liquid fuel to use in vehicles."

That fuel would then re-emit CO_2, but as Kitchin points out, "it makes a difference where the CO_2 came from in the first place." With fossil fuels, we are emitting CO_2 from vegetation that breathed it in millions of years ago, thus raising the amount in the air today. With the system outlined above, we would stabilize or reduce the amount by recycling today's gases. Some call this "closing the carbon loop." Kitchin, with a smile, calls it an example of "doing what nature does, only faster."

NETL and its Institute for Advanced Energy Solutions are funded by the U.S. Department of Energy. Initial federal funding is $26 million for two years; firms and industry consortia can participate in the research as well. One great benefit of NETL-IAES, Andy Gellman says, is that it pulls together many strands of pre-existing research: "Instead of working on these things one-by-one, now we've got binding; we've got critical mass. We can come at the problems from all levels and make a difference."

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LET'S INNOVATE — BUT HOW?

Companies can find tools and answers at CPSI, the new Center for Product Strategy and Innovation

BY MIKE VARGO

Professor Jon Cagan has been studying innovation before it became the new buzzword, or as he puts it, "the new mandate"—something that every business knows it must do well. However, firms are still wrestling with a basic problem: the toolkit hasn't caught up to the mandate.

Cagan, the George Tallman and Florence Barrett Ladd Professor in Mechanical Engineering, has led the formation of a new research center at Carnegie Mellon called the Center for Product Strategy and Innovation (CPSI), a joint center of CIT and the Tepper School of Business. Co-directed by Cagan and by Professor Peter Boatwright from Tepper, the center's goal is to help firms innovate more effectively. CPSI accepts corporate partners, who have a hand in shaping the center's research. (Early partners include International Trucks, MSA and others.) And while CPSI can help develop a specific new product, the focus is on the underlying tools for innovation—anything from formal cognitive methods to new design or decision software that companies can use to place smarter bets and make them work out.

Innovate

Research Across the Spectrum

Faculty affiliated with CPSI come from engineering, business, psychology, design and other fields. All have done previous work in innovation and some head faculty-and-grad-student research groups; the new Center thus creates a community of experts in different aspects of the topic. Research areas at CPSI include:

- The cognitive basis of creativity—How do we think and learn when we innovate? How can we do these things better?
- Emerging needs and desires in the marketplace—Every firm wants to come up with the Next Big Thing, be it the next iPod or a better industrial solvent. But if innovation consists of creating "leaps in value" for the customer, this requires sensing what customers are likely to value.
- Tools for conceptual design—By understanding how innovators think, and how customers think, researchers can build tools that make the new-product conception process both more efficient and more targeted.
- Creating products in a global context—Globalization affects innovation in many ways. It can alter the demand side (e.g., what kinds of cars or computers will customers in developing nations want?), and as CPSI researchers are finding, it also changes the creation and production side.

Moving from Intuition to Understanding

Many issues in innovation can be grasped intuitively. What CPSI is doing is studying them rigorously, with an eye to mastery, not only providing a foundation to what is intuitive but also understanding the unintuitive concepts as well. For instance, clearly a firm that offshores its manufacturing may have to design its products differently, since cost factors and capabilities are different overseas. CPSI's Erica Fuchs has studied this effect in two industries, automotive composite materials and optoelectronics. Fuchs, a professor of Engineering and Public Policy, has shown how global sourcing changes the "most competitive design" and even shifts the "technology trajectories" of firms in these industries. Now she is building on that work, developing tools and theories that all kinds of firms—as well as government policy makers—could use to make better innovative decisions in the global economy.

Meanwhile, in MechE, Jeremy Michalek is exploring a new area that he calls Design for Market Systems. As Michalek explains it, there are tools to help engineers with *design for manufacturability* (DFM), but none that also do a good job of accounting for the marketplace consequences of design decisions. For example: If you simplify the design of an auto body or a kitchen appliance, you may get an easy-to-make product that can sell at a lower price—but if you went the other way, putting in a distinctive look and features, could you sell even more at a premium price? And either way, how would your competitors respond?

Drawing on both market data and controlled experiments, Michalek is building mathematical models of customer preference and firm behavior in the face of such tradeoffs. Michalek says these models would "support the strategic design and positioning of new products that will perform well, not just in the current market, but in the future market that the introduction of the new product will create."

The whole issue of adding features to a new product is a key decision in any innovation project, says Peter Boatwright. For one thing, he notes that features cost money. Also, "non-functional" features like aesthetic design, or packaging and presentation, might plausibly affect the perceived value every bit as much as the nifty functionality that engineers like to add.

So Boatwright and Jon Cagan are doing research to quantify and model the impact of non-functional (or "lifestyle-related") product features. In one set of experiments, they manipulate features to see how this changes buyers' willingness to pay. In another project, they are developing mathematical functions that represent aesthetic preferences in a target market group. The functions, Cagan says, "can then be used by an artificial intelligence-based computer tool to generate different design concepts for different customers."

Other CPSI faculty are leaders in research on the cognitive basis of creativity. Susan Finger, of CivE, is studying how design teams create knowledge and learn from one another during the design process. Chris Schunn, a psychology professor at the University of Pittsburgh, studies patterns of analogies in innovation teams. Back at Carnegie Mellon, Ken Kotovsky of Psychology studies areas such as "mental simulation" in design and problem-solving. And cross-disciplinary work is already translating this cognitive research into practical tools. Levent Burak Kara of MechE is working with Kotovsky and others on a computational design assistant that "learns how to create 'good designs' by analyzing a few, sketched examples that you provide," according to Kara. He says the system "constructs a virtual design space subtended by the examples" and then it lets you explore and create new solutions within the space. The basic idea is similar to software programs that try to sense what you're after and offer to, say, fill in a search window for you. What is new here is a very sophisticated extension of the idea, in a tool that learns deep cognitive patterns to arrive at refined product designs.

The Door Is Open

The Center for Product Strategy and Innovation is now in growth mode. Collaborations across the campus are taking off, and so are collaborations between CPSI and industry. Decision-makers who want to pursue applied research in innovation are invited to visit the CPSI website at www.cmu.edu/cpsi. The new center, says Cagan, is a resource for any firm or organization that wants to answer two basic questions: "What's the opportunity? And how do we move toward it?"

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