

Solar for Everyone

Erik Ydstie has a vision. This past summer, while on a mission through his church to teach English, the Chemical Engineering professor visited Burkina Faso, one of Africa's poorest countries. There he found isolated villagers generating electricity with solar units they had somehow obtained. "You'd see a single light bulb, inside a home, running off sunlight captured during the day," he says. "Or an entrepreneur would have a little business, with panels laid out on the ground to charge people's radio batteries and cell phones."

Ydstie is now seeking partners for a pilot project to "get this sort of thing going on a larger scale." He sees the biggest future for solar energy as being in the developing world, where wired electric grids do not reach vast areas. Leapfrogging straight to solar, instead of trying to build grid-based power systems, could serve multitudes of people faster without the environmental hazards of burning more fossil fuels.

But meanwhile, back home, there is basic research to be done.

The Attack on Cost

The main challenge in making solar energy more widely used everywhere is to bring down the cost. Here in the U.S. at present, equipping a modest-sized all-electric home with a full array of solar roof panels and related gear can cost around \$50,000. Although one then begins to save money by getting free electricity from sunlight, the payback period can run to many years and the high initial price — chiefly for the panels — is beyond the reach of many users.

On the plus side, there are also many possible ways of cutting costs. Researchers at Carnegie Mellon are investigating three major avenues of attack.

The nearest-term savings may come from Ydstie's ChemE team, which is focused on a new process for making solar-grade silicon. Most photovoltaic (PV) cells today are close cousins of microchips, in that both are semiconductor devices built from layers of doped crystalline silicon. (In a PV cell, the n-type layer — doped with trace materials to have free electrons, and thus a negative electrical potential — is

exposed to sunlight. This triggers a flow of current between the n-type and the positive p-type layer, and the current is harnessed.)

PV cells don't require silicon of the extreme purity needed for microchips. For years, the fledgling solar industry could simply buy off-spec material rejected by the IC industry, but that ride is over. Demand has now outstripped the supply of reject material and driven up prices; hence the need for a low-cost process to produce solar-grade silicon directly.

On this Ydstie is working with the firm SGS (for Solar Grade Silicon, naturally). At a facility in Moses Lake, Washington, SGS has been testing a novel silane-gas reactor process that takes place inside a thin "tower" about one foot in diameter and three stories high. Plans are under way for a production plant filled with such towers. Ydstie and Ph.D. student Christy White have had the crucial role of modeling the process and writing software for process control — a key to cost control because, as Ydstie says, "it's all about the yield."

In Burkina Faso, one of Africa's poorest countries, rural villagers generate electricity with solar units.



The Power of Plastics

On the other hand, why use silicon at all? Even cheap silicon isn't very cheap. About half of the material is later lost, as sawdust, when sawing it into ultra-thin wafers for the solar cells. Other less cost-intensive materials have photovoltaic properties, notably certain organic polymers, or plastics.

The problem with plastic cells has been efficiency. They convert about 5% of the energy from the incident sunlight to electrical energy, whereas silicon cells deliver about 18%. That alone makes polymers impractical for many uses; they need far more panel area to get the equivalent output. "However, I don't think you should count them out just yet," says Lisa Porter, professor of Materials Science and Engineering.

Porter is teaming with Chemistry professors Tomasz Kowalewski and Richard McCullough, dean of the Mellon College of Science, on new polymer-based research that could lead to breakthroughs in a field called bulk heterojunction cells. The work is very early-stage and too complex for brief explaining. What is simple, and may be reachable, is the goal: not silicon efficiency, but low cost with efficiency that's good enough for a lot of applications. Says Porter, "if we can get to ten percent, we are real players."

A Quantum Leap

Next to Porter's office in Roberts Hall sits Elias Towe, professor of Electrical and Computer Engineering and Materials Science and Engineering. And across the hall, in a clean room, stands the machine. Built by Towe, students and staff with U.S. Army funds, the machine could be a set piece for a sci-fi film: a bright metal hulk with tubes protruding, it looks as if it might teleport you if you're not careful.

It is in fact a molecular beam epitaxy (MBE) machine, used for teleporting atoms through a vacuum chamber — at controlled velocities — and "reconstituting them, one atomic layer at a time, on the other side," as Towe puts it, to make quantum dots. These tiny clumps of matter, deposited on a substrate, contain a hundred or so atoms each. The size of a quantum dot "is on the order of a wavelength of an electron," Towe says, so "it does not follow the classical rules of physics, but behaves according to quantum mechanics." He smiles. "You can get very different properties than the usual."

And this could open the door to making very high-efficiency solar cells. Currently, some high-end cells for critical uses are made with gallium arsenide, in a standard crystalline form. Quantum dots built from gallium, arsenic and other atoms could do even better. And better yet, says Towe, cells could

be made with dots of differing compositions or sizes, to capture and convert energy from different parts of the solar spectrum. (Today's uniform cells are limited by the fact that any single material interacts only with light within a limited bandgap). Quantum-dot cells could aim for efficiencies of 40%, 50% or more. They probably wouldn't be sold as cost-savers at first; more likely as specialty items for users needing high power from a small unit. But if advances in nano-fabrication can keep lowering the initial price, the efficiency factor would loom ever larger, making cells like these the cost choice for a widening range of uses.

The Future

Which solar technology will prevail in the long run? The real strength will lie in all of them coming together, says Lisa Porter: "As in other fields, it's often not just one material or application that comes to the fore, but many options for many needs." Also, just one material can itself be quite versatile. Since polymer panels would be cheap but not so efficient, Elias Towe envisions vast numbers of them spread out to make solar farms in areas where sun and space are plentiful — think of Arizona, or Burkina Faso — while Porter notes that thin, flexible sheets of polymer would be ideal for portable solar panels: you could roll them up and carry them around, to drape where needed. You could wear solar clothing.

Carnegie Mellon's role in solar energy is growing, especially through its university-wide Center for Nano-enabled Device and Energy Technologies. Starting from a few researchers, a true research community is emerging, with synergies and spinoffs. Porter and Towe have been working together; their research has common threads in nanotechnology; Erik Ydstie is mixing the worlds of computer modeling and fieldwork overseas. The future of solar depends on communities of this type, and Porter speaks for all when she says, "I think the future looks bright."

Elias Towe, the director for the Center for Nano-enabled Device and Energy Technologies, uses a molecular beam epitaxy machine to make quantum dots.

