Scientia: Research at the University of Tennessee

Sunlight In, Electricity Out

By JADA HUSKEY

Solar energy, long regarded as costly and impractical, is emerging as a viable alternative to fossil fuels, and UT researchers are narrowing the gap between the sun's present use and its future potential

In the global search for sustainable energy sources, photovoltaic (PV) cells are an area of keen interest because of their ability to convert absorbed sunlight to electricity through the interactions of photons (packets of light) and electrons in a semiconducting material.

In 1954 Bell Labs introduced the first modern silicon-based PV cells, but with production costs more than $1,000 per kilowatt, their use was limited. Flash forward more than 50 years, and the cost of producing PV cells now is around $4 per kilowatt, and their use, though not widespread, is more commonplace. Today PV systems power communication and navigation equipment, light homes and commercial buildings, and feed electricity back into the utility grid.

The sun radiates more energy in a single hour than the entire planet uses in a whole year, yet solar energy provides less than 1 percent of the world's electricity. Although sunlight is free, PV-generated electricity costs about 5 times more than grid electricity.

Conventional PV cells are made with highly refined silicon and manufactured in labor- and energy-intensive processes, which accounts for about 80 percent of the cost. PV cells are also plagued by low efficiency regarding the amount of absorbed sunlight converted to electricity. Silicon-based PV cells convert about 20 percent of absorbed sunlight to electricity; PV cells made with little or no silicon, such as thin films and organic semiconductors, are less expensive to manufacture, but their conversion efficiencies are much lower.

Spurred on by more than scientific curiosity, researchers are intent on developing high-efficiency PV cells that can be manufactured in automated high-throughput processes, and University of Tennessee scientists are rising to the challenge.

From the Garden

“One of the bottlenecks in PV technology is in using less silicon while maintaining efficiency,” says Barry Bruce, an associate professor in UT Knoxille’s Department of Biochemistry and Cellular and Molecular Biology.

Instead of silicon, Bruce and his colleagues at the Massachusetts Institute of Technology have developed an organic PV cell using a photosynthetic protein complex isolated from spinach leaves. They use spinach because it’s cheap, it can be grown anywhere, and it’s rich in chlorophyll, the molecule that absorbs sunlight.

Through this process, researchers liquefy spinach in a food processor, extract the protein complex, “wrap it in surfactant peptides to stabilize it, and then integrate it into a solid-state device,” says Bruce. When bathed in laser light, the protein complex produces an electrical current; not enough current to power a lamp, but enough to prove that a biological reaction center will work in an electronic circuit.

Bruce’s photosynthetic PV cell has a conversion efficiency of about 12 percent, but he thinks he can boost that by layering the protein complex, like the skin on an onion, so the cell can absorb more light. The next steps seek to improve stability and durability, and if successful, spinach-powered PV cells might one day coat window surfaces to power the lights in a building.

The notion that electricity could be harvested from the garden doesn’t surprise Bruce, who was recently named by Forbes as one of 10 revolutionary innovators who could change the world.

“I got into photosynthesis 30 years ago because I believed it was the fundamental solution to energy,” he says. “Nature has spent 2 to 3 billion years perfecting an energy conversion system that is almost 100 percent efficient, and all we have to do is take advantage of it.”

Convergence of Factors

Bruce’s colleague, Bamin Khomami—head of the Department of Chemical and Biomolecular Engineering and holder of the Armour T. Granger and Alvin and Sally Beaman Professorship—thinks that within 10 years, PV efficiencies could easily triple, which could push worldwide consumption of PV-generated electricity to 10 percent.

Semiconducting nanoparticles can be deposited on various substrates to create tailored PV films, and they can be added to organic or inorganic semiconductors to increase PV-cell efficiency. This class of PV material is attractive because nanoparticles can be tuned, making them photoactive in different ranges of light.

“Photons contain energy that corresponds to different wavelengths of light,” Khomami explains. “Only photons of the right energy can excite electrons in a given system, which then flow to create an electrical current.”

The properties of materials change as their size approaches the nanoscale, and with a model-guided experimental approach, Khomami tries to pin down the “magic” size that will deliver a desired property for a particular nanoparticle.

“By controlling particle composition, size, and distribution, we try to optimize photoactivity,” he says. With increased photoactivity, incoming photons excite more electrons, and more electrons mean more electricity and higher conversion efficiencies.

Khomami is also developing models and simulation strategies to guide development of efficient processes—for instance, a roll-to-roll process, similar to the way newspapers are printed—by which nanoparticle-based PV films can be coated onto various substrates.

“Compared with fossil-fuels technology, PV technology is in its infancy,” says Khomami, “but it is advancing at a rapid pace.” Those PV cells developed during the 1950s were for the space program, but until recently, the technology has languished because it lacked a driving force with the power of the Cold War’s space race.

But now a powerful new force created by a convergence of environmental and geopolitical factors is driving the -development in the technology, says Khomami. And the expanded interest in solar energy is underpinned by a “paradigm shift from a traditional design process that had little regard for energy or environmental costs to a new process that includes sustainability,” he says.

Net-Zero Energy

Bin Hu agrees with Khomami. “Controlling the polymer PV process is challenging,” says Hu, an assistant professor in the Department of Materials Science and Engineering who specializes in functional polymers, “but PV technology is accelerating now.” Polymer PV cells, a developing technology, may soon be a practical alternative to conventional silicon-based PV cells.

“The fundamental principles of polymer PV cells are not yet understood,” says Hu. But, organic light-emitting diodes (OLED) and polymer PV cells are like two sides of the same coin: OLEDs convert energy to light and PV cells convert light to energy.

“OLED technology is very mature and we can learn from that science,” he says. Hu recently won a CAREER Award from the National Science Foundation to support his work with OLEDs, which dovetails precisely with his work in polymer PV cells.

When light hits a polymer PV cell, a negatively charged electron breaks free from an atom, creating a positively charged hole. The electrons and holes [charge carriers] must flow in different directions to generate current, but “sometimes the charge carriers get lost,” says Hu.

To boost efficiency, Hu blends nanostructures—microscopic roadmaps—into the polymers to direct the charge carriers to the electrodes.

The efficiency of polymer PV cells currently peaks at about 6 percent, but they will be commercially competitive at 10 percent.

“Polymer PV cells have a dramatic advantage over silicon,” says Hu. Polymer PV cells are lightweight and flexible, and they can be integrated easily into building materials—a concept that is evolving, but not yet widespread.

Cheaper photovoltaic building materials will make it possible to construct homes and commercial buildings that generate most, if not all, of the energy they use, which is a major focus of the Department of Energy’s Building Technologies Program (BTP). The goal of BTP is to have in place the technology to provide cost-effective “zero energy” buildings by 2025, which will reduce the strain on the utility grid during periods of peak demand and at the same time offset the emission of harmful pollutants.

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Running on Sunshine

Duncan Earl first set foot in Oak Ridge National Laboratory in the early 1990s as an undergraduate in the Science Alliance Summer Fellowship Program. Today, this UT alumnus (engineering physics and electrical engineering) is taking ORNL-developed technology into the private sector—harnessing the sun’s power to light up working environments all over the country.

Earl is founder and chief technology officer of Sunlight Direct, which uses solar collectors and optical fibers to pump sunlight into buildings. The system works in tandem with electricity, using natural sunlight when the rays are brightest and switching to grid power when the clouds roll in. Studies have shown that natural sunlight—versus incandescent or fluorescent lights—increases worker productivity and sets off retail merchandise in a much more pleasing glow.

At present the company has 23 beta-test units across the United States. Each is remotely monitored with the data going back to ORNL, which acts as an independent evaluator. Among the current sites are an Aveda Corporation plant in Minnesota and a new unit going in at the Naval Exchange at Pearl Harbor, Hawaii.

The company anticipates a move to the commercial market by the end of 2007. The current cost for each system is $16,000, but Earl says they hope to cut that in half by 2008. The investment recoup is based on the client’s location (Hawaii, for instance, has lots of sunny days) and it's possible that some places will see payback in less than a year. On a bright day, a Sunlight Direct system can deliver the equivalent of 55 60-watt incandescent lamps, which can translate into a savings of about 6,000 kilowatt hours per year. Earl says in a couple of years the company hopes to start exploring residential possibilities for the technology.

With increasing interest from investors and a $1-million grant from the U.S. Department of Energy, Sunlight Direct is poised to find more customers and uses for solar technology. As Earl says, developing alternative energies will generate jobs, create new products to market at home and abroad, and improve the environment.

"It can be done," he says. "It's not a pipe dream."

At present the company is housed at Tech 2020, a nonprofit partnership in Oak Ridge, Tennessee, but anticipates a move soon due to limited production capacity at the current location. Earl says the company plans to keep production local. And when the company starts looking for new employees, he says, he'll be looking to the University of Tennessee.

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— C. L.