The Future of Solar Energy: 2nd Post… Plastics

By John Benson

December 2022

1. Introduction

Roughly a year ago I posted the paper described and linked below:

State-of-the Art PV Panels: "One word… plastics": *Discussion of the title subject will populate sections 2 and 3 of this post. The reason is that, although the current design for photovoltaic (PV) modules (a.k.a. panels) have been widely deployed, there are still many places where they will not work, because:*

- *They are too heavy*
- *No flat surfaces on the top surfaces of the target structure (or vehicle)*
- *They are too difficult to recycle*

Several manufacturers are starting to produce modules that solve these problems, and the key to their design is (you guessed it), plastics.

https://energycentral.com/c/cp/state-art-pv-panels-%E2%80%9Cone-word%E2%80%A6-plastics%E2%80%9D

Note that the above referenced post has some details on silicon based solar modules, and well as light-weight, flexible module designs that are different from those in this post.

In my November 11 issue of Science, there was an excellent article on the perfect technology for building-integrated photovoltaic (BIPV), Organic photovoltaics (OPVs). Although these currently have some issues with efficiency, they are improving this metric over time, and they have cost advantages, are more easily recycled than existing silicon-based designs, are light and flexible.

In this post I will summarize the above mentioned Science Article plus provide information from other sources.

2. Organic photovoltaics (OPVs)

In November 2021, while the municipal utility in Marburg, Germany, was performing scheduled maintenance on a hot water storage facility, engineers glued 18 solar panels to the outside of the main 10-meter-high cylindrical tank. It's not the typical home for solar panels, most of which are flat, rigid silicon and glass rectangles arrayed on rooftops or in solar parks. The Marburg facility's panels, by contrast, are ultrathin organic films made by Heliatek, a German solar company. In the past few years, Heliatek has mounted its flexible panels on the sides of office towers, the curved roofs of bus stops, and even the cylindrical shaft of an 80-meter-tall windmill. The goal: expanding solar power's reach beyond flat land. "There is a huge market where classical photovoltaics do not work," says Jan Birnstock, Heliatek's chief technical officer.[1]

---

[1] Robert F. Service, Science, "Solar Energy Gets Flexible," Nov 11, 2022, https://www.science.org/content/article/ultrathin-organic-solar-cells-could-turn-buildings-power-generators

Organic photovoltaics (OPVs) such as Heliatek's are more than 10 times lighter than silicon panels and in some cases cost just half as much to produce. Some are even transparent, which has architects envisioning solar panels not just on rooftops, but incorporated into building facades, windows, and even indoor spaces. "We want to change every building into an electricity-generating building," Birnstock says.

Heliatek's panels are among the few OPVs in practical use, and they convert about 9% of the energy in sunlight to electricity. But in recent years, researchers around the globe have come up with new materials and designs that, in small, lab-made prototypes, have reached efficiencies of nearly 20%, approaching silicon and alternative inorganic thin-film solar cells, such as those made from a mix of copper, indium, gallium, and selenium (CIGS). Unlike silicon crystals and CIGS, where researchers are mostly limited to the few chemical options nature gives them, OPVs allow them to tweak bonds, rearrange atoms, and mix in elements from across the periodic table. Those changes represent knobs chemists can adjust to improve their materials' ability to absorb sunlight, conduct charges, and resist degradation. OPVs still fall short on those measures. But, "There is an enormous white space for exploration," says Stephen Forrest, an OPV chemist at the University of Michigan, Ann Arbor…

Conventional solar power—mostly based on silicon—is already a green energy success, supplying roughly 3% of all electricity on the planet. It's the biggest new source of power being added to the grid, with more than 200 gigawatts coming online annually, enough to power 150 million homes. Backed by decades of engineering improvements and a global supply chain, its price continues to drop…

OPV advocates don't see the technology replacing conventional silicon panels for most uses. Rather, they see it helping usher in a wave of new applications and ultimately putting solar in places silicon panels won't work. The field got its start in 1986 when plastic film experts at the Eastman Kodak Company produced the first OPV, which was only 1% efficient at converting the energy in sunlight to electricity. But by the early 2000s, fiddling with the chemical knobs had pushed OPV efficiencies up to about 5%, enough for several companies to try to commercialize them. Their hope was that printing panels on roll-to-roll machines such as newspaper presses would make devices cheap enough to be useful despite their shortcomings. But poor efficiency and degradation under relentless sunlight doomed the early models…

Part of the difficulty in raising OPV efficiencies—then as now—is that they work differently from cells made from inorganic materials, such as silicon. All solar cells are sandwich-like devices, with semiconductors in the middle that absorb photons and convert that energy to electrical charges, which then migrate to metallic electrodes layered above and below. When sunlight strikes silicon cells, the added energy kicks electrons out of their orbits around individual silicon atoms, freeing them to flow through the material. Each excited electron leaves behind an electron vacancy, also known as a "hole," which carries a positive charge. The positive charges flow to a negatively charged electrode (the cathode), whereas the electrons flow to a positively charged electrode (the anode), creating an electric current.

By contrast, the molecules in organic semiconductors tend to hold onto their charges more tightly. When OPVs absorb sunlight, there's enough energy to kick an electron out of its atomic orbit, but not enough for the positive and negative charges to split up and move their separate ways. Rather, these opposite charges stick to each other, creating *what is known as an exciton. To generate electricity, the excitons must be separated into positive and negative charges that can travel to their respective electrodes.*

The moment of separation comes when excitons move and encounter an interface between two semiconducting components, called donor and acceptor materials. The acceptor attracts electrons, and the donor attracts the positive holes, pulling the exciton apart. It needs to happen quickly: If the excited electron and hole happen to combine with each other before they can reach that interface, they often release their original jolt of excitation as heat, wasting it…

Work through the mid-2000s pushed the efficiency above 5%, mainly by incorporating soccer ball–shaped carbon compounds called fullerenes into the materials. The fullerenes' hunger for electrons makes them powerful acceptors. For the next decade, the action shifted to the donors. By 2012, a series of novel semiconducting polymers used as donors propelled efficiencies to 12%.

Then the field suffered a double blow. First, progress plateaued as researchers struggled to find the next breakthrough material. Then a rival thin-film solar technology, called perovskites, burst on the scene. Perovskites are blends of organic and inorganic compounds that are cheap to make, easy to process, and great at capturing sunlight and turning it into electricity. While OPV progress stalled, the efficiency of perovskites skyrocketed from about 6.5% in 2012 to about 24% in 2020…

Today, perovskites remain hot. But challenges with long-term stability and their reliance on toxic elements have sapped some enthusiasm. Meanwhile, OPVs soon got a burst of innovation of their own.

Author's comment: I have been monitoring perovskites for about five years. I keep looking for one these designs that have solved the above mentioned "…*long-term stability…*" problem. I haven't found one yet. On the other hand it appears OPVs may have solved this issue – keep reading below.

In 2015, researchers led by Xiaowei Zhan, a materials scientist at Peking University, reported the first of a new class of nonfullerene acceptors (NFAs). Although fullerenes were good at grabbing and transporting electrons, they were lousy at absorbing sunlight. On a molecular level, Zhan's new compound, dubbed ITIC, looked like an extended Olympic symbol with extra rings, and it did both jobs well, first absorbing red and infrared light and then transporting electrons once excitons split.

Author's comment: I really hate undefined acronyms, so I looked extensively for a phrase to clarify ITIC without success. Since ITIC is an extremely complex compound with many variations, my only conclusion is it is a description of its structure, possibly in Mandarin (the Chinese Dialect used in Beijing (Peking)).

Zhan's first NFA device was only about 7% efficient. But chemists around the globe quickly began to tweak ITIC's structure, producing improved versions. By 2016, new NFAs pushed OPV efficiency to 11.5%. By 2018, they hit 16%... In August, Zhan Lingling at Hangzhou Normal University and her colleagues reported in Advanced Energy Materials that an OPV based on a similar multicomponent strategy achieved 19.3% efficiency…

What remains to be seen, however, is whether such cells will retain the internal structure needed for high efficiency over decades. "In some of the record-breaking cells, the *morphology changes over time and the performance doesn't hold up," Armistead*[2] *says. NFAs are especially susceptible, because the best ones consist of small molecules that can easily shift through the material.*

Replacing the NFAs with acceptors woven into long polymers to help keep them in place could help. "They have the chance to be very robust," Armistead says. Progress is on the march here as well. In the 18 August issue of Advanced Materials, researchers led by Alex Jen, a materials scientist at the University of Hong Kong, reported all-polymer solar cells that had an efficiency of 17% and retained 90% of their efficiency under accelerated aging tests. "That is quite notable," says Bao, whose team also works on all-polymer cells.

Author's comment: Another name for polymers – plastics!

Yet, stability and high efficiency still won't be enough. To make it in the market, solar cells also need to prove reliable for decades. "It's a three-legged stool and you have to have all three legs," Forrest says. Under intense exposure to the ultraviolet (UV) in sunlight, the organics in solar cells can degrade, much as our skin burns during a day at the beach. In the 14 September 2021 issue of Nature Communications, Forrest and his colleagues reported adding a thin layer of UV-absorbing zinc oxide—the same material in some sunscreens—to their OPV, which extended its life up to 30 years in accelerated aging tests. "It's sunscreen for solar cells," Forrest says. Larson, who was not part of Forrest's team, calls it "a huge result." On one score, OPVs already have a clear advantage over just about every other energy generating technology: a strikingly low carbon footprint. In evaluating Heliatek's panels, the German testing institute TÜV Rheinland certified that for every kWh of electricity the company's panels produce, at most 15 kilograms (kg) of carbon dioxide (CO_2) would be emitted in making, operating, and eventually disposing of them. That's compared with 49 kg of CO_2/kWh for silicon panels, and a whopping 1008 kg of CO_2/kWh for mining and burning coal. Even with their low efficiencies, Heliatek's panels will generate more than 100 times the energy it takes to make and deal with them over their life span.

OPVs' carbon footprint is sure to lighten further as their efficiency continues to set new records, lifetimes climb, and production methods advance. Those trends are buoying hopes of a world where solar power spreads not only across rooftops and desert scrubland, but also along the curved facades of skyscrapers, the windows of the world, and just about anywhere else people are looking for a bit of juice. That could make prospects for addressing climate change just a little bit brighter.

3. OPV Manufacturers

The main manufacturer mentioned above is Heliatek. Although this is a German Manufacturer, they have a very good English-language website.[3]

Swedish company called Epishine sells OPVs that work indoors and can replace disposable batteries in everything from temperature sensors to automated lighting controls. Like Heliatek, they have a very good English-language website.[4]

---

[2] Paul Armistead, who oversees OPV funding at the U.S. Office of Naval Research.

[3] Heliatek, https://www.heliatek.com/en/

[4] Epishine, https://www.epishine.com/

Ubiquitous Energy is developing energy-generating OPV windows that primarily capture infrared and ultraviolet photons while allowing visible light to pass through, something CIGS and other opaque thin films can't do. Ubiquitous Energy is in Redwood City in the San Francisco Bay Area.[5]

4. Multimode Renewables

OPVs could morph into a multimode renewables. For instance, the main image of this post (Wind turbine with OPVs on the monopole) could be designed with battery energy storage in the bottom of the monopole. Thus the main energy source (wind turbine) could be supplemented by the OPV and storage when the peak demand period coincides with low wind speeds. This may ultimately require a larger diameter monopole to still allow a climb-through tunnel (with batteries placed around the circumference of the monopole).

---

[5] Ubiquitous Energy, https://ubiquitous.energy/