Aspen Global Change Institute Energy Project

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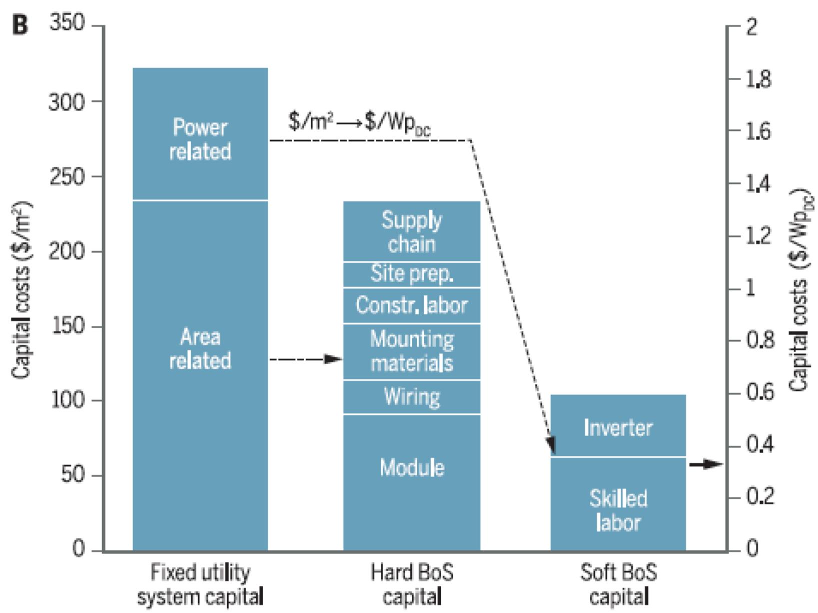
ADVANCES IN SOLAR ENERGY

Nate Lewis from the California Institute of Technology is at the forefront of technological advances in solar energy technology. He has provided a review of these state-of-the-art advances in a recent issue of Science (2016). The story of how photovoltaic solar energy panels (PVs) have had an amazing ride down the manufacturing learning curve is disruptive to the conventional wisdom that solar electric is too expensive. Panel prices have plummeted over the last 20 years – achieving approximately a 20% reduction in price for each doubling in global panel production. Over the same period of time, however, the balance of system costs (BOS) remain stubbornly resistant to the same economies of scale. Savings in installation labor, power condition equipment, permitting, and inspections, while improving, are not dropping in cost at the same rate as the cells themselves. The BOS cost issue is partially compensated for by having panels with higher efficiency thereby reducing the installed area for the same peak power.



The above figure of a utility-scale PV system from the Lewis (2016) paper shows how some components of the system scale with the required array area – such as installation labor (middle column), while some do not – such as those tied to the power produced (in right column).

Less obvious is what is happening on the solar energy research front beyond just solar electric conversion. In this review paper, Lewis explores three distinct advanced technologies: solar thermal, solar fuels technologies, and solar electricity. Here we discuss the latter two.

Regardless of the conversion technology, solar has two fundamental hurdles compared to electricity sources with very high power density, such as nuclear or a fossil fuel power plants: 1) the solar average power density available at the surface of the Earth of about 250 W/m^2, and 2) the intermittence of supply due to clouds and the day-night cycle.

Solar Electricity

On the solar electricity front, Lewis discusses commercially available PVs, advanced cells that are currently in a demonstration mode, and cells types that are still in the laboratory research stage of development. Materials used in these technologies range from mono-silicon and multi-silicon cell types with conversion efficiencies of about 18-23%, to thin film and more exotic types utilizing dye-sensitized materials, organics, perovskites, and quantum dot approaches. Techniques are being explored to exceed the single band-gap theoretical limit of 32% conversion efficiencies in direct sunlight without concentration to cells reaching over 40% efficiencies in concentrated sunlight.

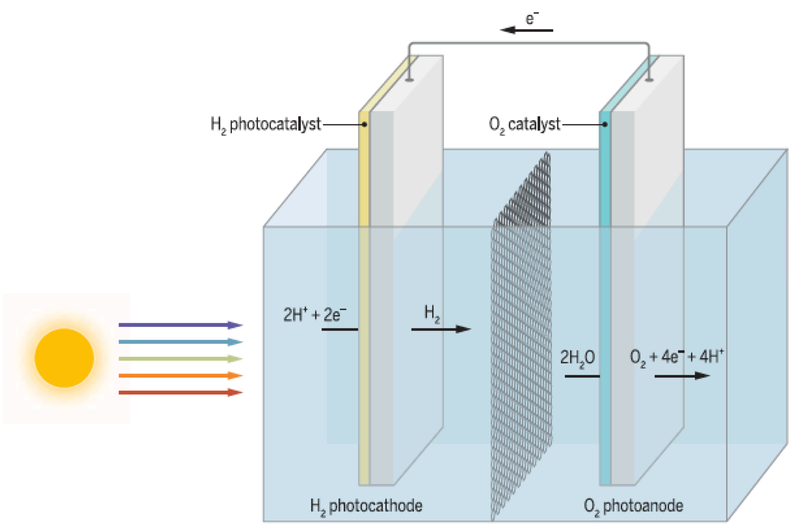
Cell types can take years of development in the lab to move up in conversion efficiency, but also must solve manufacturing hurdles to move from the lab to the market. In the field, consideration must also be given to degradation in performance over time and other practical issues such as panel weight. Overall achievements have been impressive in a relatively short period of time and are continuing. Lewis provides present day installed cost of about $1.80 per peak watt and a levelized cost of electricity (LCOS) at $0.10-$0.15/kWh for utility-scale systems with the range in cost depending on sunlight potential and other factors.

Solar Fuels

Solar fuel technologies offer an exciting complement to direct solar for electric conversion. By using sunlight to generate fuels, solar can be attached to the difficult problem of decarbonizing energy sources for the transportation sector serving modes other than light-duty vehicles. The impact could be significant, given that ships, heavy duty trucks, and aircraft make up about 40% of global transportation fuel requirements (Lewis 2016).

The paper outlines four types of systems. Here we will discuss the approach used in artificial photosynthetic systems that attempt to mimic biological photosynthesis but with non-biological architectures. In a sense these systems use an approach that integrates PV technology with an electrolyzer to produce H_2 and O_2 in a type of photoelectrochemical (PEC) cell that uses sunlight to split water. The H_2 produced can be stored, combusted, used in a fuel cell, or combined with carbon dioxide or carbon molecules derived from biomass to, for example, produce carbon-based fuels.

In order to play a major role commercially, this emerging technology will need to outcompete existing technologies such as conventional electrolysis of water driven by conventional PVs at $7-$20/kg of H_2 produced, or the fossil fuel approach of producing H_2 from natural gas steam reforming (~$2/kg). This figure from Lewis (2016) shows an idealized schematic of a PEC configuration where water on the cathode side (left in figure) is reduced to a fuel in the form of H_2, or alternatively CO_2 and H_2O are reduced to a carbon-based fuel. At the anode (right side) O_2 is liberated from water. The central membrane preventing unwanted chemical combinations between sides supports H_2 collection.



Overall Lewis finds great progress in solar technologies in pursuit of "…higher efficiencies, lower costs, improved scalability, and new functionality…".

Lewis, N. S. (2016). "Research opportunities to advance solar energy utilization." *Science* 351(6271).