

ENERGY

Turning Sunlight into Fuel

BY RENEE CHO | AUGUST 24, 2016

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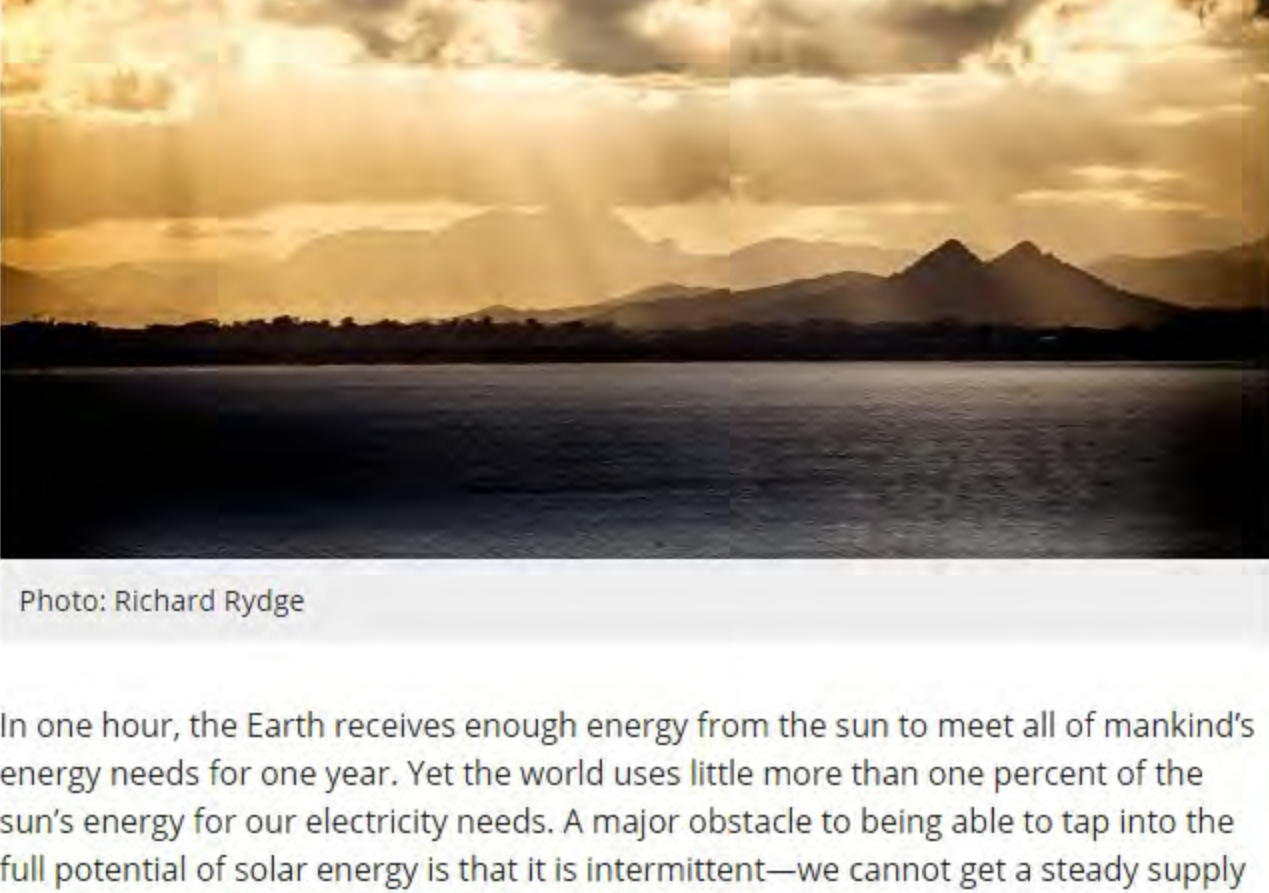
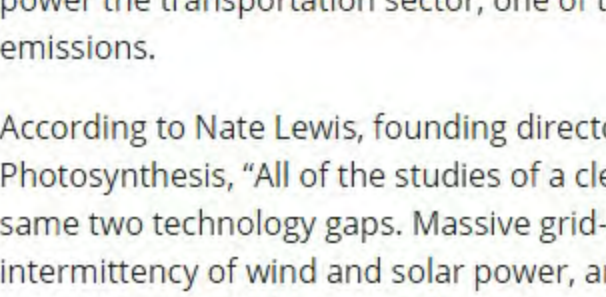


Photo: Richard Rydge

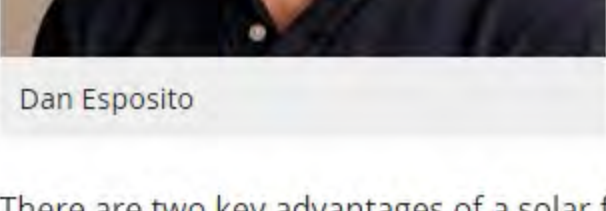
In one hour, the Earth receives enough energy from the sun to meet all of mankind's energy needs for one year. Yet the world uses little more than one percent of the sun's energy for our electricity needs. A major obstacle to being able to tap into the full potential of solar energy is that it is intermittent—we cannot get a steady supply of solar energy because the sun doesn't always shine.



power the transportation sector, one of the largest sources of greenhouse gas emissions.

According to Nate Lewis, founding director of the Joint Center for Artificial Photosynthesis, "All of the studies of a clean energy system I've ever seen identify the same two technology gaps. Massive grid-scale energy storage to compensate for the intermittency of wind and solar power, and an energy-dense, carbon-neutral liquid transportation fuel." A great deal of research is being aimed at **developing better batteries** to store energy. But it is "solar fuels" that could potentially store, transport and use solar energy to produce electricity *and* replace fossil fuels in vehicles.

Sunlight and water can be harnessed to produce hydrogen, a solar fuel, with the use of special solar cells called photoelectrochemical (PEC) cells and photovoltaic (PV) electrolysis reactors. The technology stores the sun's energy in the form of chemical bonds, then turns it into electricity through a hydrogen fuel cell. Thus far, most photoelectrochemical reactors have been based on the use of platinum and iridium, elements that are rare and expensive.

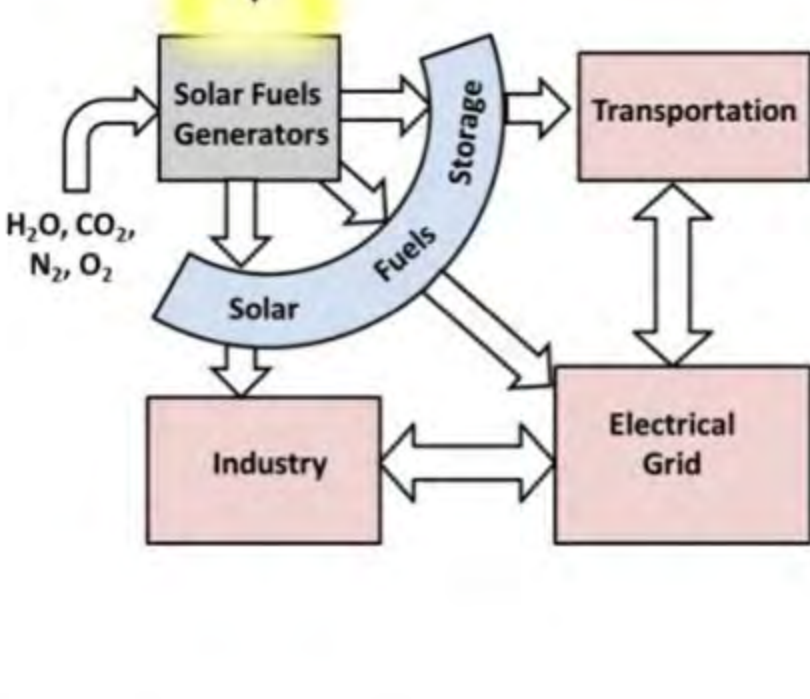


Dan Esposito

I spoke with **Dan Esposito**, assistant professor of chemical engineering at Columbia University and a core faculty member of the **Lenfest Center for Sustainable Energy**, who, with the **Esposito Research Group**, is focused on trying to find materials that are efficient, stable, and made from earth-abundant elements. The group also works to apply their findings to the design and scaling-up of "real-world" technological systems.

Why do solar fuels have so much potential?

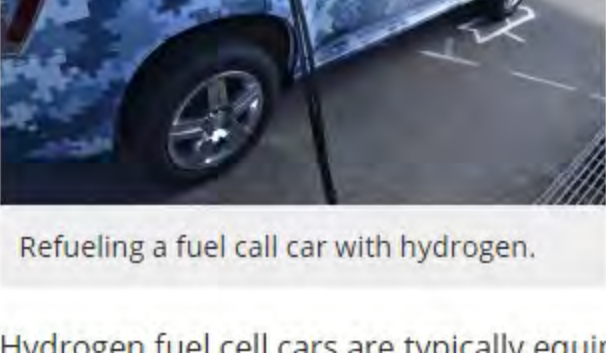
There are two key advantages of a solar fuel system. Traditional solar photovoltaic is going from solar to electricity, whereas with solar fuels technology, you're taking sunlight and using it to convert a low-energy reactant molecule such as water, then upgrading it, increasing its energy content and forming chemical energy or fuel. You're taking the energy from the sun and transferring it into energy held in the bonds of molecules.



The great thing about fuels is that they're storable, so we can keep them and put them in a tank or some other vessel and use them at a later time. Fuels are very complementary to intermittent renewable resources like solar or wind—they help to overcome the variability. Another neat thing about fuels is that they can be used in many different sectors across society— transportation, industrial energy use and residential energy use as well. It's a more versatile system.

Can you give an example of how solar fuels might be used?

Take the zero-emission hydrogen fuel cell car. The most commonly considered example of solar fuel is hydrogen, which can be produced from water (H₂O). Essentially, you're splitting water into hydrogen and oxygen. You're keeping the hydrogen as the fuel that can be used in a hydrogen fuel cell car. You're taking the hydrogen, sending it into a fuel cell and extracting electricity.



Refueling a fuel cell car with hydrogen.

You recharge it just like you would put gasoline into your gas tank in a conventional car. Usually it's compressed hydrogen, still in gas phase. Another thing about hydrogen fuel is that it can also be converted to useful work with an internal combustion engine, just like gasoline. In fact, the internal combustion energy that uses hydrogen as a fuel rather than gasoline can actually be more efficient than a gasoline engine.

Hydrogen fuel cell cars are typically equipped with hydrogen tanks that allow the car to travel around 400 miles between fill-ups, possibly thanks to the high energy density of compressed hydrogen. This long range, combined with the relatively fast refueling times of a hydrogen fuel cell vehicle, are generally considered to be the primary advantages of a hydrogen fuel cell car compared to an electric vehicle. Almost every major automobile manufacturer is developing a hydrogen fuel cell car that they're releasing by 2020. However, one of the challenges is cost and the other is infrastructure—having fueling stations.

Another example is on the electric grid, trying to overcome this issue of intermittency associated with wind and solar. There are actually places in the world where people are trying to take advantage of low-cost electricity from solar and wind, using hydrogen as a means of storing that energy, then converting it back to electricity when the sun's not shining or the wind isn't blowing. This is called "**power to gas**" and they're exploring this quite a bit in Germany. The general idea here is to take electricity when it's cheap, when it's really sunny or windy. You send it to an electrochemical device called an electrolyzer [a device that splits a solution into the atoms from which it's made by passing electricity through it] and you use it to convert your low-energy reactant, like water, into hydrogen. You then take that hydrogen and inject it into a natural gas pipeline. Later on, when the price for electricity is higher—when the sun's not shining—you convert it back into electricity with a traditional natural gas power plant.

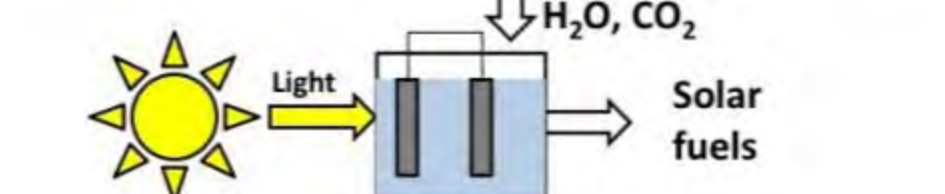
How do photovoltaic electrolyzers and photoelectrochemical cells work?

With a photovoltaic electrolyzer, think about taking a traditional solar cell—a photovoltaic panel—and connecting it directly to an electrolyzer. You have two separate devices.

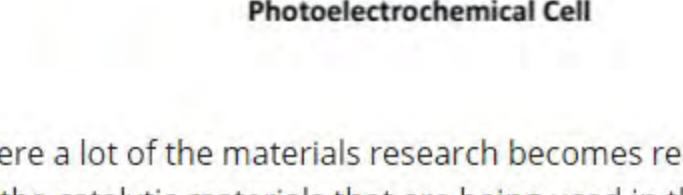
A photoelectrochemical cell combines the functionality of both of those devices into a single integrated device. You have two electrodes, your anode and your cathode, but the key distinction here is that one of these electrodes is made of a semi-conductor. In a photoelectrochemical cell, the voltage that's being generated by this photoelectrode [either the anode or cathode] is being used to drive the electrochemical reaction. Usually the photoelectrodes that we're working with are on the order of a centimeter squared or two centimeters squared. The photoelectrode can really be considered at the heart of the cell. It needs to absorb light, create a photovoltage [voltage created by the photovoltaic effect], and then use that energy to efficiently facilitate the chemical transformation of reactants [water in this case] into products [hydrogen and oxygen]. The important process by which these chemical transformations efficiently take place on the surface of the electrodes is called catalysis.

Systems for Generating Solar Fuels

1. Photovoltaic Electrolysis: Indirect use of light



2. Photoelectrolysis: Direct conversion of light to chemicals



And this is where a lot of the materials research becomes really important, because we would like the catalytic materials that are being used in these photoelectrodes to be earth-abundant, low-cost and stable. The warranty on a solar cell that you would buy and put on your roof right now is about 25 years. So if this technology is to compete, you need these things to last at least five or 10 years. That's a big challenge because you're essentially taking a solar cell and immersing it into a liquid, usually water. Corrosion can be much more of an issue in this case.

What is the state of the technology today?

Existing technology outside of what we're doing in our lab is more advanced in the case of photovoltaic electrolysis because electrolyzers and photovoltaic cells are commercial technology. You can go out and buy them and set up a system today. Electrolyzers and photovoltaic cells are called modular technologies because you can take one unit and attach it to another unit. Depending on exactly how much fuel you want, you would scale and choose the number of units appropriately. But to my knowledge, you cannot buy a photoelectrical chemical reactor today—it's all still in the research and development phase.

What are you trying to accomplish with your research?

As chemical engineers, we're interested in developing lower cost, more efficient materials for these devices, and then also designing the devices and the reactors that these materials are going to be incorporated into. In both the photoelectrochemical cell and the photovoltaic electrolyzer, you have essentially the same chemistry taking place, so if we find a more efficient catalyst material that's good for one of these reactions, we can put that in either device. We think that there's a lot of synergy and advantage in developing materials and devices concurrently. They often inform each other. We're also thinking about new sorts of architectures or arrangements for existing materials that can allow the device to operate more efficiently and be more stable over long periods of time.

What is a parameter that might optimize a material's performance?

Efficiency is very important for these devices. We have a certain amount of sunlight or electricity that's going into one of the electrochemical devices and we want to convert as much as possible of that into fuel. If you have a material on the surface of these electrodes that's not very efficient at helping to facilitate this chemical transformation, you're getting less of that energy into fuel. What it means for an electrolyzer is that you need to apply more voltage to make that reaction happen at the same rate. The extra energy that's going into the reaction with an inefficient material is being lost as heat. We want that energy to go to fuel.

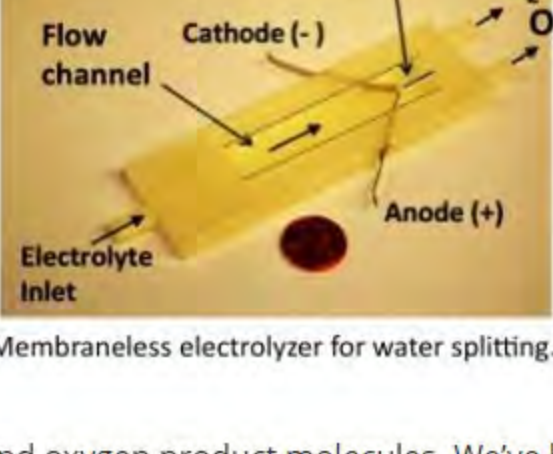
How do you go about finding better materials?

We have a couple of different types of probes that we use to study electrode materials at very small length scales while those materials are operating in a photoelectrochemical cell or electrolyzer. These include physical probes like a pen scanning around on the surface, and also optical probes, a focused light beam. We're able to use these probes to locally interrogate the properties and performance of these electrodes that we're trying to develop. There are differences in properties, typically at the micro- and nano- scale, and these tools enable us to see things in the reactive environment that you just can't see with the naked eye. By understanding what are the most efficient configurations at the micro- and nano- scales, we can then go back to the start of the design process and re-make materials and electrodes where we try to maximize or optimize those really efficient nano- or micro- structures.

We are also collaborating with the Institute for Data Sciences and Engineering at Columbia to develop new probes that will help to speed up the materials discovery process. Their expertise with big data analytics and advanced signal analysis methods will be an important part of the materials design and discovery process.

Have you found some promising new materials or designs?

We've had some nice results in terms of the materials research and also with devices. We had our **first paper** published on original research from our lab on a new type of electrolyzer...a new design.



Membraneless electrolyzer for water splitting.^[2]

And the idea here is that we're trying to simplify the design of an electrolyzer compared to the current commercial technology. Most commercial electrolyzers have a structure that involves an anode and a cathode that are positioned on opposite sides of a membrane that's important for conducting ions— charged molecules— between the anode and cathode while simultaneously separating the hydrogen

and oxygen product molecules. We've been working to develop electrolyzers that don't require a membrane. So whereas conventional electrolysis is going to have at least a dozen parts, the design that we came up with is operating with as few as three parts.

How much energy could it produce?

A pretty small amount. When you're doing research and development, it's convenient to work on a small scale for safety reasons and also because the speed of the research tends to be easier, less costly to put together. But you could scale this up. With more of these electrodes, we can make this thing tall and rectangular, and then you could take this and stack it next to other ones as well. If you want to get enough hydrogen for one hydrogen fuel cell car, you would need to have a case that's about the size of a mini-fridge.

How do you feel about the future of this technology?

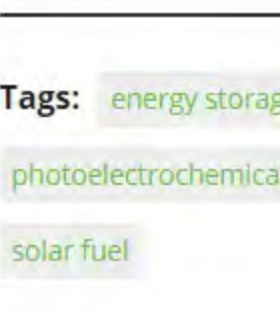
I think there are still a lot of questions to answer about what this technology is eventually going to look like. That's an exciting aspect of working in this area. Nobody really knows what the form or the scale is going to be. Will photovoltaic electrolysis make more sense than the integrated photoelectric chemical cell or vice versa? There are pros and cons to both of them.

Our hope is that by working in both the areas of materials and devices, we might help to speed up the development process and get closer to the point where some of this technology can make a difference in the world.

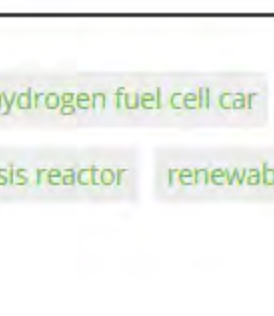
*In July, Esposito wrote a letter to U.S. Rep. Lamar Smith, chairman of the House Committee on Science, Space & Technology, advocating passage of the **Solar Fuels Innovation Act**. The legislation would require the Department of Energy to support and promote research and development of technology for the production of fuels from sunlight.*

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Lyle | August 24, 2016 at 11:56 pm

Why not the sabitier process to take hydrogen and Co2 and make methane out of it just basically an inorganic version of what algae do. This would not add to the Co2 content of the atmosphere since the Co2 is taken from the atmosphere just like plants do. essentially an inorganic version of Biomass with nothing but water and co2 on the output side.
Since there is a large infrastructure for methane, and vehicles do run on methane it seems a much cheaper solution that re-deploying a hydrogen fuel chain.



Marius | October 10, 2016 at 3:50 am

Another technology designed for the big corporations and for monopoly. I think the best technological solution in that moment is the PV , wind farms as power- generation and batteries , ultracapacitors for store and transportation. There are simple to scale up at any level from residential use to industrial and is already work on electric cars (Tesla) , public transport (buses and trains with ultracapacitors Maxwell and Skeleton), storage and grid stabilisation(Tesla Powerpack combined with ultracapacitors).

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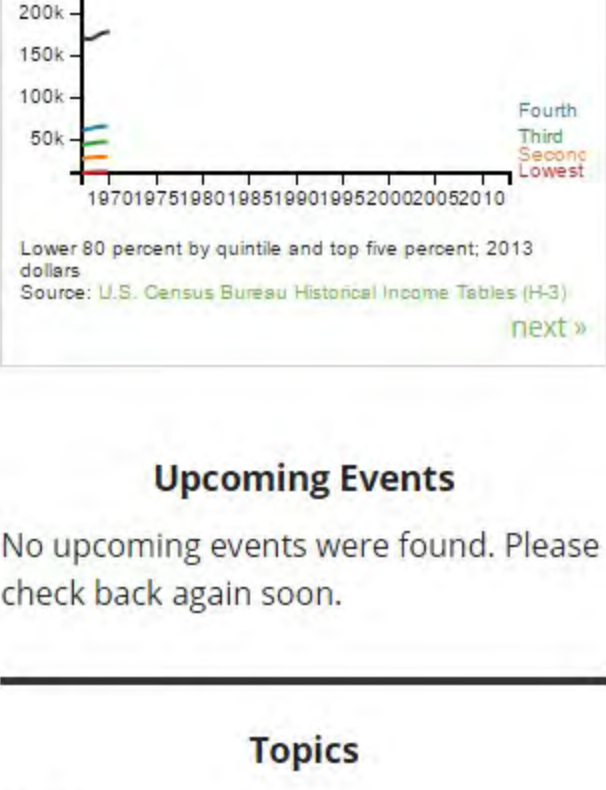
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