Banking sun and wind energy

October 9 2017

Sami Tuomi and Tanja Kallio with some solar panels. Use of solar energy is increasing rapidly also on the Otaniemi campus. The 920 rooftop solar panels of the TUAS building and the Computer Science building generate enough electricity to satisfy some 6% of the annual requirement of these buildings, and up to 20% in summertime. Credit: Jaakko Kahilaniemi

The EU has a hard goal: it wants the Member States to cut greenhouse gas emissions to a fifth, or even a tenth, of the present level by 2050.

Professor Tanja Kallio and doctoral candidate Sami Tuomi consider the realisation of this goal entirely possible.

"In Denmark, for example, renewable energy already accounts for 40% of electricity generation and the target is to raise this share to 60% in a little over a decade. In theory, there is no reason why all electrical energy couldn't come from renewable sources."

A problem that needs solving before that concerns storage.

Three grams versus two tonnes

The Sun radiates 4.3 × 1020 joules of energy per hour on the Earth – about as much as the human race consumes in an entire year. Sunshine and wind can, however, be absent when there is a need for energy, and large-scale storage involves many challenges. One of these is platinum, the precious metal familiar from luxury jewellery that sells for about €30 per gram. In the storing of renewable energy, platinum acts as an electrocatalyst that enables solar- or wind-generated electrical energy to be stored as chemical energy and, in turn, the conversion of this chemical energy back to electricity.

"Catalysts account for about a fifth of the process' costs. The EU has listed platinum and many other catalysts currently in use as raw materials of critical importance. This means that they threaten to either run out globally and, prior to this, become astronomically expensive or that they are sourced from geopolitically challenging countries, where their production is not secure," Tanja Kallio explains.

Kallio and her group aim to replace platinum by developing catalysts out of cheaper and easier to find raw materials, such as iron. The price difference is enormous: a hundred euro buys about three grams of platinum, but more than two tonnes of iron. Unlike platinum, however, iron is not a good catalyst because its surface is susceptible to passivation in air.

One of the materials tailor-made by the group is a carbon nanotube with excellent electrical conductivity. Embedded in its surface is an iron particle, which is protected by a graphene layer and serves as a catalyst. It is, thanks to its manufacturing method, very active, which means that only a little electrical energy is wasted in the storage process. This makes the process economically viable.

"We've also produced nitrogen-doped carbon nanotubes. The tube itself is poor to react, but when you remove a carbon atom from the surface and replace it with nitrogen, you create discontinuity points, which are catalytically active," says Sami Tuomi.

Nitrogen doping, i.e. precipitation, is a straightforward process. First, the carbon nanotube and a solvent are combined in one vessel, while a nitrogen-containing compound and a solvent go into another. After this you stir, then merge the mixtures, and then stir again. Finally, the desired material is removed to undergo heat-treatment. Kallio says this simplicity was a conscious choice.

"We wanted a process that would be as easy as possible to scale up and commercialise."

Will it last?

When renewable energy is stored in large amounts and for a long time, it is usually done using hydrogen. The electricity generated by a solar panel or a wind turbine is transmitted to an electrolyser unit, which consists of two end plates that are surfaced with a catalytic material. In addition to electricity, one end plate is fed with water, which decomposes into oxygen and hydrogen molecules on the surface of the catalyst. The oxygen leaves the second end plate in pure gaseous form and the hydrogen is collected into storage tanks, enabling its further use or later conversion back into electricity. Storage tank volumes can range from the size of a shipping container to giant subterranean spheres the size of a small apartment building.

"Smaller containers might be suitable for storing, for example, fuel for hydrogen vehicles," Tanja Kallio reckons.

"This would also be sensible, as studies have indicated that the most economical system would be one in which hydrogen is consumed in pace with production output. In other words, renewable peak energy would yield hydrogen, which would in turn be consumed by hydrogen cars."

Tailored catalysts have some way to go before they are ready for industrial application, however. Kallio acknowledges that, even though their group has discovered several promising and interesting catalysts, it remains a mystery how and why some of them work. Another major challenge is to demonstrate that catalysts, which have been found to work excellently on a small, laboratory scale, can also serve well on a larger scale and over a sufficiently long time.

"Timescale is one of the biggest challenges. A catalyst should function for at least five years in a commercial application, but implementing a demo of such length isn't very realistic," Tuomi says.

"I myself think that we'll start with shorter times and see if any degradation occurs. This will allow us to examine how well the catalyst holds up or, if it doesn't hold up, what is the reason behind it. The commercial challenge will thus be resolved alongside the scientific problem," Kallio believes.

Three culprits out of four

A positive solution could have an enormous impact on greenhouse gas emissions, which would help combat climate change. An example from the other side of the Atlantic illuminates this huge potential.

"In the United States, electricity generation causes 29% of greenhouse gas emissions, and coal plants create 75% of these. If coal power were replaced by wind- or solar-powered electricity, the country's greenhouse gas emissions would fall 22%," says Sami Tuomi.

Such a reduction sounds utopian during the term of Paris climate accord shelver Donald Trump, but thankfully there is hope elsewhere. Asian giants India and China, for example, have already decided to reduce the number of coal plants because it is clearly cheaper to generate electricity using renewable sources. Kallio and Tuomi underline that applications can be found in other sectors as well. The activities that cause greenhouse gas emissions can be divided into four roughly equal categories: electricity generation, industry, transport and other activities like agriculture.

"We can influence the first three of these. Industry, for example, consumes enormous quantities of hydrogen, which is currently produced from natural gas. Our system would enable its manufacture from water with renewable energy."

Just one hydrogen-powered fuel cell car has been registered in Finland, and these water vapour-exhausting vehicles are still rare elsewhere in the world, too. But change is afoot: auto industry behemoth Toyota in particular is investing strongly in fuel cells and Tokyo intends to spend €350 million on the city's hydrogen infrastructure prior to the 2030 Olympic Games.

"Electric cars have proliferated rapidly because infrastructure is being built for them. If hydrogen-powered renewable energy solutions become more common, also the infrastructure would be built," Kallio says.

Hydrogen cars would be a good match with Finnish driving culture.

"Electric cars are great for urban traffic, but it is unlikely that you'll be driving long distances to the summer cottage or touring Lapland in one anytime soon."

Provided by Aalto University