CSIRO exclusive: Solid oxide electrolysis growing on an industrial scale

By Stephen Harrison | 4 May 2020

Solid oxide electrolysis (SOE) has high potential in Power-to-X applications. Beyond that, it can integrate seamlessly into several chemical processes, rendering it a highly capable all-rounder that has been known about for many decades, but whose use at an industrial scale has so far been handicapped by some practical challenges.

Recent advances in the production of SOE equipment will, however, help to enable this technology to realise its full potential.

gasworld spoke exclusively to Dr. Ani Kulkarni of Australia's CSIRO to find out how his team's R&D programme will enable SOE to contribute to decarbonisation of the energy and chemicals sectors.

Dr. Kulkarni, let's come directly to one of the main decarbonisation challenges we face right now. How can SOE contribute to cost-effective green hydrogen production?

Solar energy has the potential to produce vast quantities of green hydrogen. In Australia this concept is as powerful as any other location. However, the conversion of solar energy to hydrogen using some technologies is comparatively inefficient. Energy losses in the PV cell and electrolyser multiply to result in overall conversion rates less than 10%.

Some people would say that in sun-drenched deserts, there is an excess of solar energy and these energy yield concerns are irrelevant. However, my team are keen to move beyond this status-quo and are working creatively to improve the energy efficiency of the sun-to-hydrogen energy conversion pathway. We *sit in* the *Low Emissions Technology Programme* of CSIRO's Energy Business Unit.

And we understand that your team have recently made some breakthroughs which will enable the commercialisation of the SOE technology?

Yes, indeed. Solid state electrolytic technologies have been a research topic since the 1960s. The focus of our work at CSIRO is to elevate this technology from the lab bench to become cost-effective at an industrial scale.

Currently, we are doing this activity as a part of a CSIRO, Australian Renewable Energy Agency (ARENA) and partners funded project. Industry and researchers from four countries (Australia, the UK, USA and Israel) are working together on the project. We share a common belief that SOE can grow up from being a precocious adolescent to become a mature and productive contributor to a decarbonised society.

That's a great analogy. In which ways has SOE been 'precocious' in the past?

SOE is a high temperature process, operating at above 500°C. It uses ceramic electrolyte and electrodes as cell components. This differs from a PEM system which might operate at less than 80°C with a flexible polymer electrolyte membrane.

In state-of-the-art SOE equipment, the cell components are constructed from a stack of flat plates. Removing heat from the outer parts of the stack is OK, but hot spots can form. This leads to thermal stresses which can damage the electrodes and cells over the long-term. So, periodic replacement of the SOE stack is required which puts a high maintenance cost into the system.

The other key technical challenges include degradation of electrodes under electrolysis conditions due to materials migration and delamination.

And how does your innovation make the SOE technology more robust?

My team at CSIRO has developed a tubular cell structure which vastly reduces the problems of thermal stress, and the electrodes will have a significantly longer life and lower maintenance costs. We have found a way to reliably construct and coat the tubular structure with the electrode material. At the heart of our development, we're leveraging materials science and manufacturing technology to improve the electrolyser production process.

In operation, our tubular cell structure also has advantages. Since the heat dissipation is better, we can ramp up the electrolyser in less than 30 minutes. This is much faster than can be achieved with a flat stack structure. That improved dynamic response means the SOE system can be used effectively in transient power management schemes to convert excess electrical production to hydrogen. This enables energy storage from the hours of peak electricity production, for example when there are high wind speeds on wind turbines or strong sunlight conditions on a PV solar farm.

What about your solid oxide electrode material, how does that compare to established SOE systems?

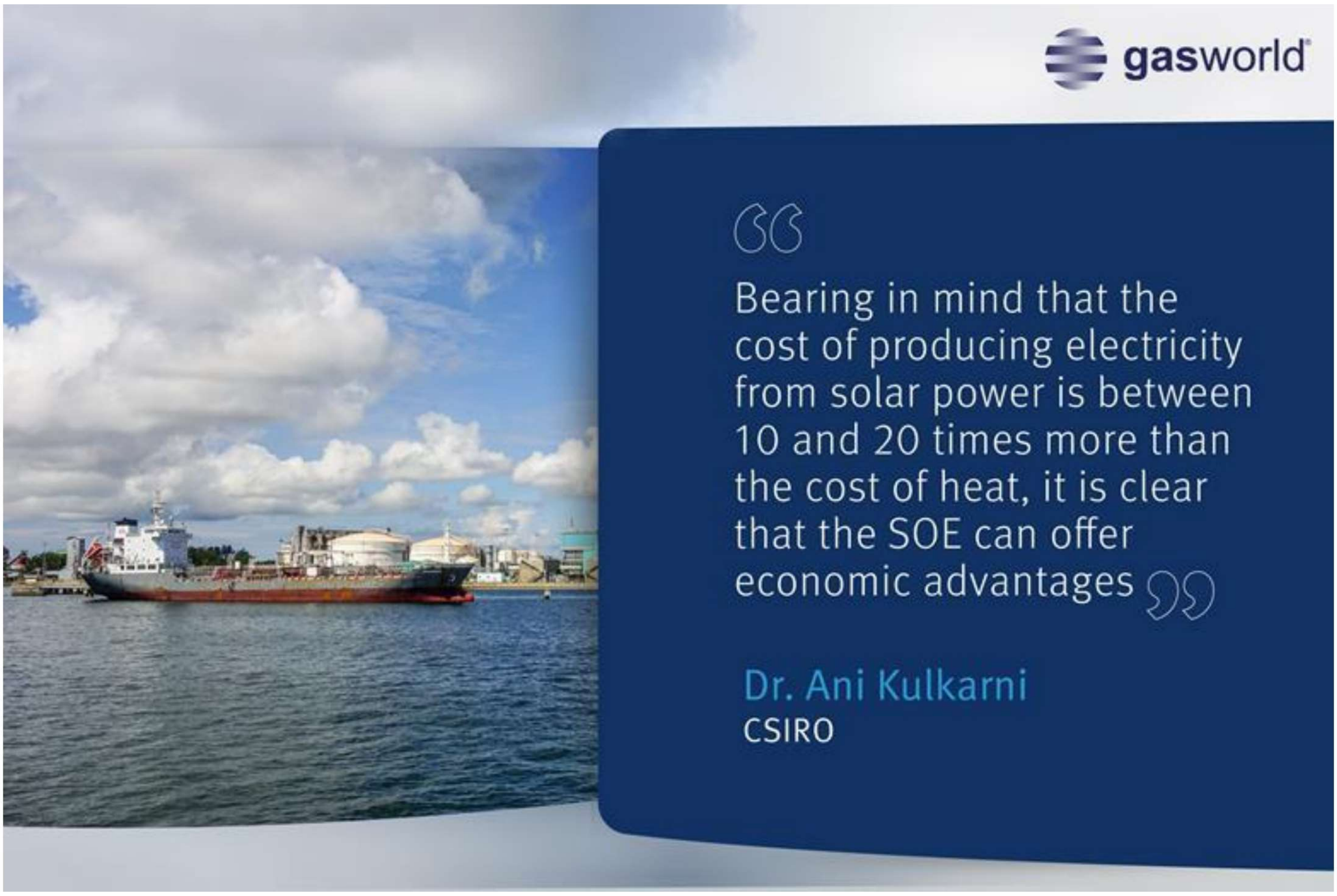
We have also made significant improvements there. The active part of our electrode is constructed from a ceramic-based mixed ion electron conductor (MIEC). We have found a material that can be coated onto the tubular electrolyte substrate in a single 'dip' and treated at 800°C.

This simplifies the manufacturing process to reduce cost. It also reduces the dip coating temperature which means better quality control and reduced electrode manufacturing energy requirements.

We are thinking about scale-up and industrialisation of the electrode manufacturing process in addition to the science of electrochemistry.

Furthermore, in our system, both the anode and cathode electrodes are made from the same material. In current SOE systems, the anode and cathode are different compositions. The benefit of using the same material on the anode and cathode is that the electrodes can be manufactured in a single step and the unit can operate both as an electrolyser to convert power to hydrogen and in reverse, as a fuel cell to produce power from hydrogen.

This is a significant breakthrough for power storage applications because the same unit can make hydrogen during periods of excess power production and then convert the hydrogen back to electricity when the grid needs a boost.



That sounds like a potent combination of enhancements. To put that into some context, perhaps we should take a step back. What is the fundamental process involved in SOE?

The electrolyser is composed of a ceramic yttrium-zirconium oxide ion conductor which supports a porous anode on one side and a porous cathode on the other. At the cathode, water is converted to hydrogen and ionic oxygen. These ions travel across the ion conductor where they are converted to oxygen gas at the anode. This is a high temperature process, so the water molecules are supplied as steam.

One of the most exciting aspects of SOE is that carbon dioxide gas can be used instead of, or in addition to, water as an oxygen source. In this mode of operation carbon monoxide is produced at the cathode instead of hydrogen. So, the SOE can be used to create syngas or pure carbon monoxide for use in chemical synthesis.

It is a highly versatile process that can readily be integrated into various chemical processing operations.

Beyond the flexibility of these chemical pathways, are there other advantages that SOE has versus other types of electrolysis?

When compared to hydrogen production using electrical power from PV cells and a PEM or alkaline electrolyte unit, the SOE technology can significantly increase the total energy conversion efficiency.

This is possible because about 35% of its total energy input is from heat and the balance from electricity.

Bearing in mind that the cost of producing electricity from solar power is between 10 and 20 times more than the cost of heat, it is clear that the SOE can offer economic advantages.

So, a combination of heat and electricity feeds the process. Where can the heat for the SOE come from?

There are many exothermic processes that produce heat as a by-product. For example, ammonia and methanol production. Integration with these industrial activities is one option. Alternatively, the combined use of solar thermal energy with solar PV power is also attractive. Our collaboration partner, Raygen will be testing CSIRO's SOE in their solar test bed soon. This unit will provide both heat and electricity.

Is there a special significance for this technology in Australia?

Some regions of the world are blessed with ideal weather conditions for wind farms and solar farms. Here in Australia, we have many locations that are ideally placed to harvest solar energy to produce green hydrogen which can be used in the domestic economy or exported to Asian markets as liquid hydrogen, methanol or ammonia. So, yes, this technology is of relevance in Australia, and we believe that it will be equally useful in other high solar density locations, such as Africa and the Middle East.

You mention ammonia and methanol as hydrogen carriers. How does that fit with SOE?

Well, one of the advantages of SOE when it is operating in the fuel cell mode is that it can be fed with ammonia, methanol or hydrogen. This means that we can use green ammonia or methanol, which can be stored and transported as liquid chemicals, to produce green power. Cryogenic liquid hydrogen transportation from Australia to export markets in Asia will soon be piloted but long-term storage of liquid hydrogen can be unattractive because of vaporisation losses. On the other hand, the long-term storage of ammonia or methanol does not result in significant boil-off losses so SOE opens up the possibility of using a wider range of hydrogen carriers in fuel cells.

What about regions of the world with a low solar energy density, is the technology also relevant there?

Yes, we believe so. Considering that SOE is a more efficient harvester of solar energy, if a region is not blessed with abundant sunlight hours, then making the most of the few that they have can be a real advantage: like the saying ‘make hay whilst the sun shines’.

Dr. Kulkarni, thanks for bringing this innovation to life with these vivid explanations.

Thank you. Having come this far with our R&D work we are keen to see this technology commercialised. The combination of heat and power to drive the SOE; the fact that it is reversible; the way it can use CO2 or steam as a feedstock and the ability to produce carbon monoxide or and hydrogen means that SOE is a highly versatile technology.

We hope that our innovations will mean that SOE can live up to its full potential to play its role in a decarbonised future in the energy and chemicals sectors.