14 Aug · Written By Stephen B. Harrison

CRT announce hybrid hydrogen electrolyser breakthrough

Affordable green hydrogen is coming a step closer to reality. Australian startup Cavendish Renewable Technology (CRT) has made unparalleled progress to develop an electrolyser which integrates aspects of solid oxide electrolysis and alkaline water electrolysis.

This new electrolyser, the 'C-Cell', represents a paradigm shift in technology through its affordable construction, minimised balance of plant (BoP), durable cell design and, its ultra-high efficiency. On top of those key attributes, it has a configuration which is scalable, will enable precise load following of variable renewable power and slashes the cost of direct connection to photovoltaic solar electricity.

Through rigorous laboratory testing, CRT is confident their C-Cell can achieve an efficiency of 41.5 kWh per kg of hydrogen, based on DC power input at stack level. The ultra-high efficiency also results in a reduced BoP power consumption and capex savings, because heat removal costs are slashed.

CRT Team and laboratory ©CRT

"Our test results have shown that we have a winning technology. We are eager to break out of the lab and set up pilots with interested partners to demonstrate our C-Cell in the real world," declares Anirudha Kulkarni, CEO of CRT.

The C-Cell will boost the prospects for green hydrogen to support global net-zero ambitions. There is, indeed, light at the end of the tunnel.

Better business cases

Green hydrogen business cases have been failing due to high costs of production. Only a small percentage of announced projects have come through final investment decision (FID). Major actors have withdrawn support for projects they previously championed. Many projects have failed to mature due to high costs of hydrogen production resulting from unacceptably high capex, opex, and installation. Furthermore, complexities with balance of plant systems have layered on costs. These issues will not always be the case. Transformational innovation has re-injected hope into green hydrogen. With a shift in electrolyser capex costs, efficiency, and a simplified balance of plant, green hydrogen business cases will become more attractive.

The main costs of green hydrogen production are green electrons and the capital cost of the electrolyser. The electrolyser cost includes its associated power management equipment, other BoP items and project related costs, such as installation. On top of these main costs come lifetime operating costs, such as labour and maintenance costs for stack replacement maintenance, due to degradation.

Conventional electrolyser innovation has been incremental, forcing compromises between capex and efficiency or between durability and operational flexibility. “There is no longer a need to trade-off capex, opex, flexibility and stack life. Our C-Cell, has broken the paradigm: we have improved all four attributes in harmony,” explains Kulkarni.

Hybridisation: the best of both worlds

The principle of the C-Cell is based on a similar concept to an anode supported solid oxide fuel cell (SOFC) or solid oxide electrolyser cell (SOEC) technology. The foundation is novel ceramic membrane supported on a metal substrate. The thickness of the membrane coating is less than 100 microns.

The membrane-electrode has a very high surface area to catalyse the oxygen evolution reaction. This is generally the rate limiting step of classical alkaline electrolyser designs. Overcoming this hurdle has been a breakthrough that sets the C-Cell in a class of its own.

The C-Cell membrane-electrode is thinner than state of the art alkaline diaphragms, resulting in lower ohmic resistance. Furthermore, the electrodes are highly effective, meaning they have a low kinetic resistance. These attributes contribute to the ultra-high efficiency of the C-Cell by enabling operation above 100°C.

CRT C-Cell ©CRT

The operating temperature of the C-Cell is achieved without the need for waste heat integration from an external source. All the heat required for efficient operation is generated in situ and in operando, with no external heat needed to achieve an efficiency of 41.5 kWh/g H2. Moreover, cheaper membrane fabrication methods compared to traditional membrane casting processes, as well as a the C-Cell having a design which enables manufacturability and ease of assembly, will reduce capex substantially.

Unlike SOEC and PEM technology, the C-Cell uses an alkaline electrolyte, or lye. The alkalinity used in the C-Cell lye is somewhere between conventional alkaline water electrolysis and the emerging anion exchange membrane (AEM) technology. The use of conductive lye also contributes to the ultra-high efficiency of the C-Cell.

Hotter, better, cheaper

Another reason to be using lye, rather than pure water, as the electrolyte is that the electrolyser can operate between 120 and 150 °C. The elevated temperature results in higher electrical conductivity of the lye and improved reaction kinetics. Both aspects contribute to the ultra-high efficiency of the C-Cell.

PEM electrolysers use pure water and therefore have a severe limitation on the maximum operating temperature. Classical alkaline systems and emerging AEM systems use membranes and diaphragms that would become unstable at high operating temperatures. The rugged construction of the C-Cell membrane-electrode sets it apart from these competing technologies because it allows higher temperature operation.

High temperature operation also improves the 'current density'. This means that a smaller electrolyser is required to yield the same amount of hydrogen. The C-Cell has been proven to operate with a current density of 0.6 A/cm2 at 1.9 volts. Kulkarni says that "with high current density and small stacks, users win twice: with compact size and reduced materials requirements. These lead to capital cost savings."

Taking the best and leaving the rest

The SOEC can be a highly efficient electrolyser, due to the high temperature operation. Efficiency can further be improved if waste heat at 120 °C is available to vaporise the feed water to steam. Waste heat at this temperature is common in industrial and power generation processes. This thermal advantage is incorporated in the C-Cell.

However, to achieve the maximum possible efficiency, an SOEC also needs heat input at 600 to 700 °C. This is high grade heat, not 'waste heat' and must be generated within the stack using electrical trim heaters, reducing the efficiency of the SOEC system by around 5% from its theoretical potential. The C-Cell avoids this efficiency loss.

To recover energy from hot gases leaving the stack and transfer that to heat the incoming gases, expensive BoP items are required around the solid oxide stack. This boosts the system manufacturing cost and complexity. The C-Cell has a high efficiency and generates its own heat for operation, so minimal BoP is required, saving costs of equipment supply and installation.

Furthermore, solid oxide electrolyser seals are generally made of glass, so it operates at close to atmospheric pressure. Unfortunately, the need for capex and opex intensive hydrogen compression is therefore inevitable. With operation at 5 barg proven, and the potential to go higher, the C-Cell can reduce or eliminated the hydrogen compression requirement.

Additionally, in the SOEC system the need for air sweep on the anode side combined with low operating pressure means that beneficial oxygen utilisation is not possible. The C-Cell yields oxygen at more than 99% purity at pressure, meaning that it can potentially be used to feed adjacent processes that benefit from oxygen enrichment.

"In essence, we have taken the best attributes of solid oxide electrochemistry and developed a new class of electrolyser based on a hybrid alkaline / SOEC solution which moves beyond the issues that have held back the progress of SOEC systems", emphasises Kulkarni.

Leveraging component supply chains

At the core of the C-Cell membrane-electrode is a mesh of porous stainless steel. Unlike a pipe, which is intentionally non-porous, this type of component is created by sintering together stainless steel powder. Such powders are also used in additive manufacturing applications to create elaborate 3-D shapes.

The C-Cell it is not the only application of this porous metallic mesh type material. Filters, battery components and porous transport layers for PEM electrolysers also rely on similar materials. The consequence is that the component supply chain is established and has achieved economies of scale that help to reduce the cost of the C-Cell.

The design of the C-Cell can be scaled up in a similar way to filters ©CRT

To create an electrolyser stack, multiple C-Cells are bound together. Each C-Cell will be about 1.5m in length and 15mm in diameter. A bundle of 1,200 cells will provide sufficient electrolyser capacity to convert 1MW of input power to hydrogen. The tubes and manifolds to create this stack configuration leverage equipment that has been in use for decades on reverse osmosis and ultra-filtration units in water purification applications.

Solar integration

The majority of PEM, AEM and classical alkaline electrolyser stacks are built with multiple cells in series. The voltage drops from one end of the stack to the other, limiting the maximum stack size. Another limitation is that the entire cell must be ramped up and down as a single unit. This limits the operational flexibility of the electrolyser.

In contrast, the C-Cell stack will be configured with a modular design where each module is built of several hundred C-Cells and is connected in parallel. Turndown can therefore be achieved through turning off modules within the stack, in addition to turning down the current.

“In the laboratory, we have demonstrated that each cell can turn down to only 7% of nominal load and maintain better than 99% oxygen purity”, claims Kulkarni. “Our CFD modelling indicates that at a cell level, turndown to 20% of nominal capacity, will be achievable at scale. However, implementation of our modular design will result in an unprecedented degree of operational flexibility.”

The benefits of this operational flexibility mean that the C-Cell will be perfect to align with variable and intermittent renewable energy such as solar. Furthermore, it will be able to run intermittently and exploit short periods of negatively priced power. This mode of operation crushes the cost of green hydrogen generation.

Another up-side of the modular design is that it simplifies direct connection to solar electricity. Solar power is produced as DC, not AC. And electrolysers want DC power, not AC. However, conventional solar powered electrolyser schemes must use a DC to DC converter to provide DC power at the required voltage for the electrolyser.

The modular design of the C-Cell stack and its preference to operate with higher voltages than conventional electrolysers enables a significant reduction in the cost of the DC to DC conversion equipment. This improves the business case for solar powered hydrogen generation.

Credible ambition

CRT is no newcomer to electrolyser development. The team has designed and scaled pressurised alkaline and AEM electrolysers to industrial-sized cells and stacks, with AEM cells reaching up to 5,000 cm^2 active area—among the largest AEM electrolysers by cell format. The team has also played a key role in taking technologies from the lab to market. The C-Cell is their third successful moon-shot.

We are very cautious about our public announcements”, states Kulkarni. “I stipulate that our products must endure thousands of hours of tests before we go public with our claims. We want to be creating credible solutions, not simply making noise”.

One area that CRT invested heavily in during testing was gas purity analysis. Excessive hydrogen cross-over into the oxygen is an issue that has plagued other electrolyser innovations. Hydrogen purity is also important to ensure high value applications can be served. “We must be certain of the results we claim, so we bit the bullet and spent about $50,000 on a highly accurate gas analyser”, declares Kulkarni.

Forging ahead

At present, the C-Cell is operated at 5 barg in CRT’s development environment. This pressure can potentially be increased to the industry standard pressurised alkaline electrolyser operating pressure of 15 barg. Kulkarni confirms that “there is no electrochemical limitation on the operating pressure. The limit is governed by structural integrity of the stack and the required pressure testing to achieve safety certification.”

The temperature of operation can also be increased. With an appropriate lye concentration and pressure, operation at up to 200 °C may be possible. CRT has plans to validate this hypothesis through their R&D programme. The benefit would be that with waste heat input to sustain the higher temperature, the efficiency would be further improved, resulting in reduced power consumption and operating costs.

CRT is committed to focus on what is unique about their work. Kulkarni puts it like this: “corporations with a depth of cash and resources can support us with component production and scale up. What we have do best, and will continue to focus on, is pursuing innovations that will transform green hydrogen’s prospects for the better.”

CRT’s C-Cell IP protection strategy focuses on the unique key to the success of their C-Cell: how the membrane-electrode is manufactured to achieve the necessary performance transformation through low cost and ultra-high efficiency.

Their ‘secret sauce’ can be leveraged to produce highly durable AEM and PEM membranes. This is more than a hypothetical wish, CRT has already proven that the base structure can be used to support Nafion, a popular PEM electrolyser membrane polymer. Furthermore, the C-Cell can be adapted for use in PEM fuel cells with a novel tubular geometry.

Due to its unique membrane structure, use-cases for the C-Cell technology extend beyond hydrogen electrolysers and fuel cells. It also has potential to be used in RedOx flow batteries and carbon dioxide recycling through carbonate electrolysis which can convert carbon dioxide into e-fuels and renewable chemicals.

For more information, visit **www.cavendishrenewable.com.au**.

Author credit – Stephen B. Harrison, sbh4 consulting