Hydrogen electrolyser technology advancements

Affordable electrolytic green hydrogen for processing refined products will make the business case to invest in refinery decarbonisation technology more robust

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Hydrogen is the blood flowing through the arteries of modern refineries. Whether the refined product feedstock is traditional crude, vegetable oils, or synthetic crude, hydrogen is mission-critical for hydrocarbon processing.

Hydrogenation to convert plant oils to bio-diesel; hydrotreating of syncrude to remove oxygenates; isomerisation to achieve the pour point specification for Jet; hydrocracking to upgrade heavier molecules to marketable products; and desulphurisation to enable the use of abundantly available, lower cost sour crudes, are all reliant on hydrogen.

Hydrogen is essential for a variety of processes.

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- Hydrotreating of syncrude to remove oxygenates.
- Isomerisation to achieve pour point specification for Jet.
- Hydrocracking to upgrade heavier molecules to marketable products.
- Desulphurisation to produce on-spec products from a range of lower-cost 'sour' crudes.

Refinery hydrogen production has traditionally led to carbon dioxide (CO_2) emissions from the reforming of natural gas or light hydrocarbons. Green hydrogen from electrolysis is a potential decarbonisation route to reduce the environmental impact of hydrogen production. However, its deployment has been hampered by high Capex and Opex costs.

Breaking through to better business cases

Australian start-up Cavendish Renewable Technology (CRT) has developed its C-Cell electrolyser (see **Figure 1**), which integrates aspects of solid oxide electrolysis and alkaline water electrolysis.

Figure 1 CRT C-Cell – hybrid electrolyser for efficient hydrogen production

Chiral Energy, a peer hydrogen tech start-up, has achieved a technological breakthrough that improves the performance of hydrogen electrolyser electrodes. These electrodes convert electrons and water into hydrogen and oxygen. This advancement is grounded in biochemistry and life sciences, exploiting what nature has been doing for millennia. Plants convert water, soil nutrients, CO_2 from the air, and energy from the sun into starches and sugars. Sucrose, glucose, and fructose are all chiral molecules. Amino acids are also chiral molecules, and human DNA is a chiral helix.

Chiral Energy has extensively researched how nature uses chirality to its advantage and has exploited this to improve the energy efficiency and process intensity of hydrogen electrolysers, resulting in more hydrogen per dollar of Capex, and less power consumption per kg of hydrogen produced.

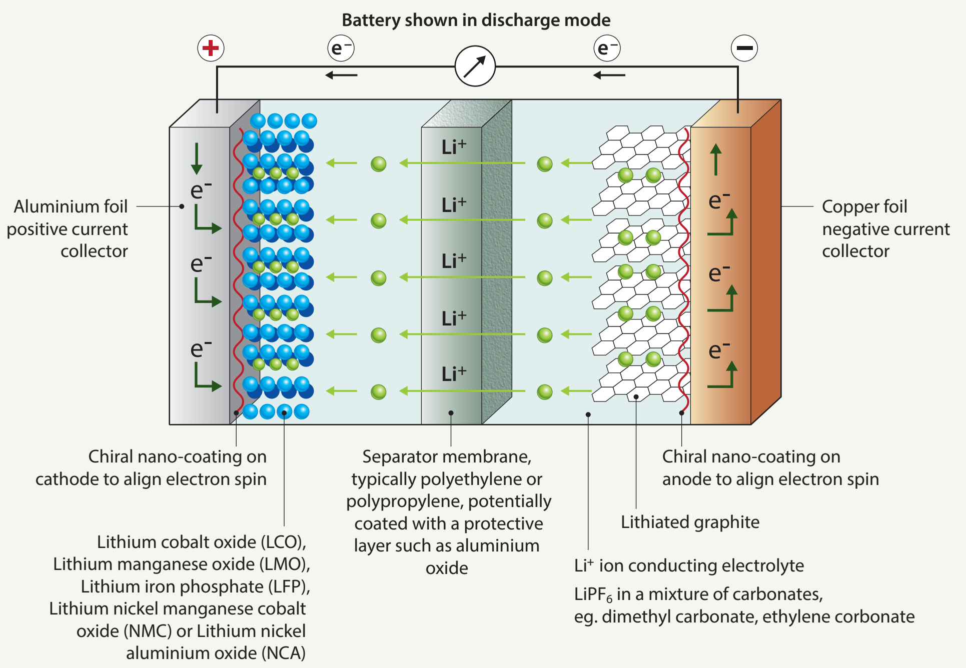

Figure 2 Lithium-ion battery with chiral-coated electrodes to control spin and increase efficiency

incremental, forcing compromises between Capex and efficiency or between durability and operational flexibility. The CRT C-Cell has broken the paradigm: improving all four attributes in harmony. There is no longer a need to trade off Capex, Opex, flexibility, and stack life.

Through rigorous laboratory testing, CRT is confident that its C-Cell can achieve an efficiency of 41.55 kWh per kg of hydrogen, based on DC power input at stack level. This high efficiency also results in reduced BoP power consumption and Capex savings, because heat removal costs are decreased significantly. The combination of Capex and Opex reduction leads to the lowest possible total cost of ownership.

These two technologies will boost the prospects for electrolytic green hydrogen in refineries. Additionally, both can go beyond electrolysis to enhance other electrochemical processes, such as lithium-ion batteries and proton exchange membrane (PEM) fuel cells (see **Figure 2**).

Enabling green hydrogen deployment

Green hydrogen business cases have been failing due to unacceptably high Capex, Opex, and installation costs. 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 the high costs of hydrogen production. Furthermore, complexities with balance of plant (BoP) systems have layered on engineering, procurement and contracting (EPC) costs.

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

Conventional electrolyser innovation has been

Hybrid electrolyser technology

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

The C-Cell membrane-electrode has a high surface area to catalyse the oxygen evolution reaction. This is generally the rate-limiting step of classical electrolyser designs. The membrane-electrode is thinner than advanced 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 high efficiency of the technology by enabling operation above 100°C. The operating temperature 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.

In addition to hydrogen generation, the C-Cell yields oxygen at more than 99% purity at pressure, meaning it can potentially be used to feed adjacent refinery processes that benefit from oxygen enrichment, such as steam generation and fired heaters in distillation column reboilers.

Reduction in Capex and Opex

Use of lye rather than pure water as the electrolyte in the C-Cell enables the electrolyser to operate between 100 and 150°C. The elevated temperature results in higher electrical conductivity of the electrolyte lye and improved reaction kinetics.

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 1.55 volts (specific energy consumption of 41.55 kWh per kg). With a high current density and small stacks, users benefit from both a compact size and reduced materials requirements. These lead to capital cost savings.

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

Efficiency in electrochemistry

Back to Chiral Energy, electrochemical processes rely on the transfer of electrons. If they spin in random directions, their movement is chaotic. Creating an orderly flow of electrons can be achieved by chirality-induced spin selectivity, or the 'CISS' effect. This is a phenomenon where the chirality of a molecule influences the spin of electrons that pass through it.

When a chiral molecule is applied to the electrolyser electrode, the spin of the electrons flowing through the electrode is systematically aligned, and they flow smoothly with less friction. The result is less wasted energy and a more efficient conversion of electricity to hydrogen.

The term 'chirality' is used to describe two physical manifestations of a molecule that has

Figure 3 The two helical screws in a screw compressor are opposite chiral shapes

the same amount of chemical atoms connected in the same way, but the shapes of the two molecules are mirror images of each other and cannot be superimposed. An analogy from the refining industry would be to consider the two helical screws of a screw compressor. Their shapes are similar, but they rotate in opposing directions to compress a gas (see **Figure 3**).

In the field of electrochemistry, it can be understood that aligning the rotational direction of electron spin is a downscale of chiral objects, such as a compressor screw. Aligning the spin of electrons is the key to energy-efficient electrolysis. As electrons flow through the Chiral Energy electrode nano-coating, their spin orientation is aligned by the chiral molecules in this layer. When electrons arrive at the catalyst, they can perform their electrochemical reaction more efficiently.

Chiral coating and synergy with established catalysts

In PEM and alkaline electrolysers, catalysts are used to reduce the amount of energy required to split water into oxygen and hydrogen. Electrolyser OEMs and electrode component producers have developed proprietary catalyst formulations that split water with maximum efficiency and maximise the operational life of the electrode (see **Figure 4**).

In PEM electrolysers, the use of platinum group metals (PGMs) is common. In alkaline electrolysers, PGMs can be used to enhance the catalytic effect of nickel, an earth-abundant metal. So, making these catalysts more effective means better use of critical raw materials.

The Chiral Energy nano-structure electrode coating is an additional layer on top of the conventional catalyst. As such, it works with

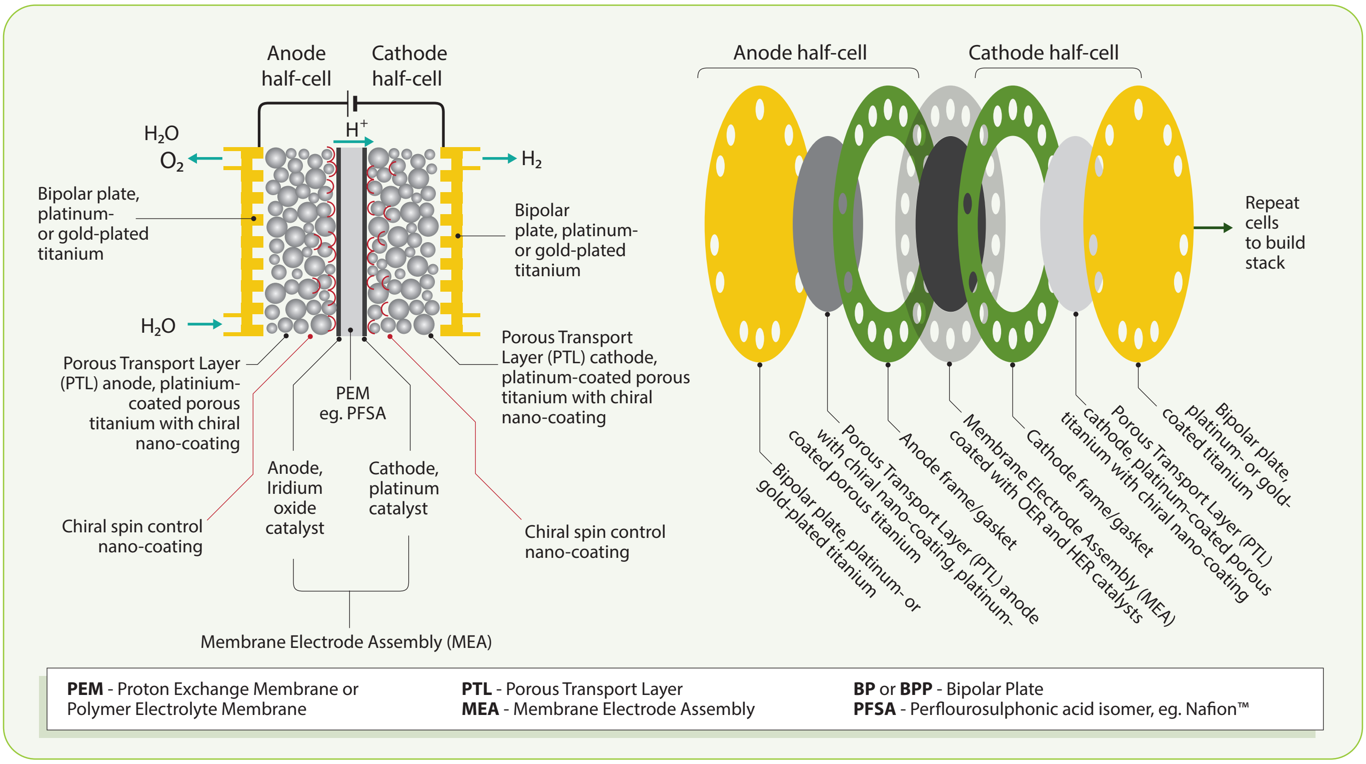

Figure 4 PEM electrolyser stack architecture and critical components with chiral-coated electrodes

existing catalysts to leverage supply chains, research, and previously invested capital.

C-Cell supply chain leverage

At the core of the CRT C-Cell membrane-electrode is a mesh of porous stainless steel or nickel. 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 3D 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.

To create an electrolyser stack, multiple C-Cells are bound together. Each one will be about 1.5m in length and 15mm in diameter.

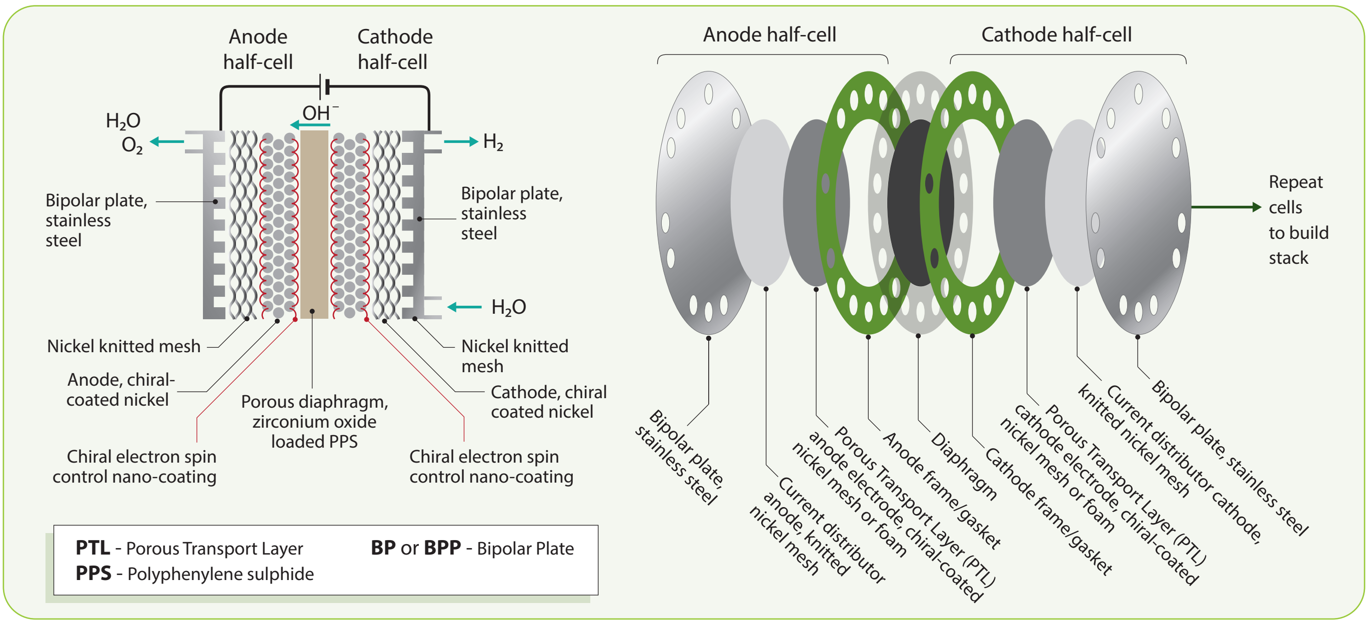

Figure 5 Alkaline electrolyser stack architecture with chiral-coated electrodes

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.

Moreover, cheaper membrane fabrication methods compared to traditional membrane casting processes, as well as the design of the C-Cell that enables manufacturability and ease of assembly, reduce Capex substantially.

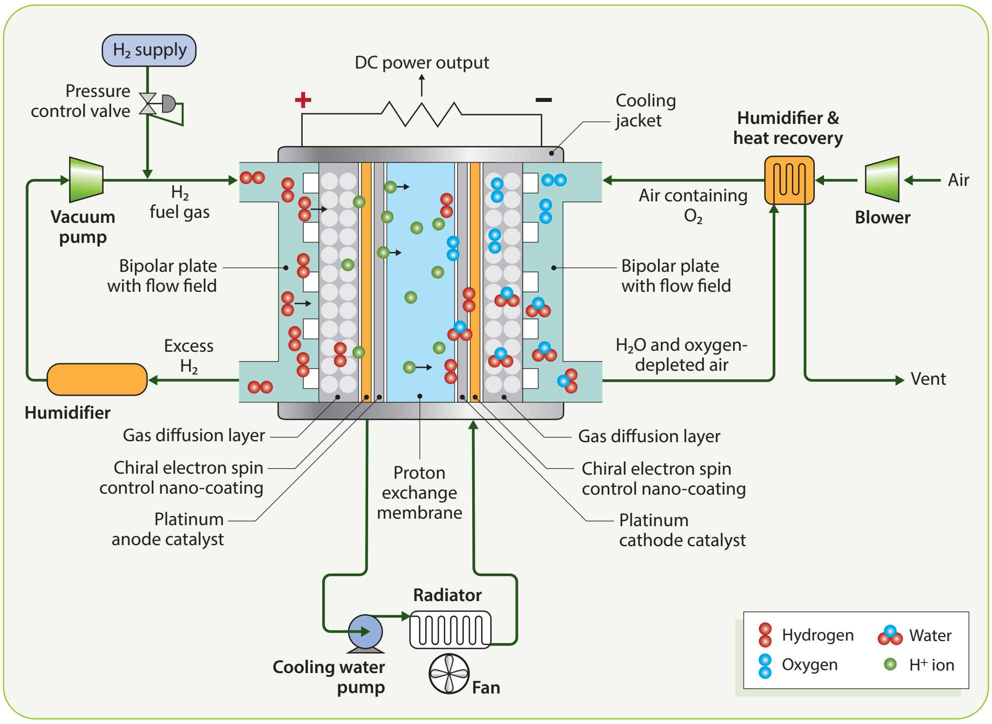

Figure 6 PEM fuel cell with chiral-coated electrodes

Relevance for a range of technologies

The Chiral Energy spin-selective nano-coating is equally relevant to PEM, pressurised alkaline, and low-pressure advanced alkaline systems. It can operate comfortably at all electrolyser temperatures, from the lower end of the range at 60°C for PEM systems to the upper end at 90°C for alkaline electrolysers. It is also unaffected by the highly alkaline electrolyte in alkaline electrolyser stacks (see **Figure 5**). Furthermore, it can support current densities that are commercially relevant to all systems, including the higher current densities observed in advanced alkaline electrolysers and the most modern PEM systems.

Many PEM and pressurised alkaline systems operate in the range of 15 to 35 barg. The Chiral Energy electron spin filtration nano-coating can operate under these conditions and therefore has relevance to a wide range of industrial electrolysers. 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. There is no electrochemical limitation on the operating pressure. The limit is governed by the structural integrity of the stack and the required pressure testing to achieve safety certification.

Electrochemical applications beyond electrolysis

Both companies technologies span beyond electrolysis. The CRT C-Cell can be leveraged to produce highly durable AEM and PEM membranes. 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 extend beyond hydrogen electrolysers and fuel cells. It also has potential to be used in RedOx flow batteries and CO_2 recycling via carbonate electrolysis, which can convert CO_2 into e-fuels and renewable chemicals.

Through a deep understanding of how the CISS effect works, Chiral Energy has applied it to many electrochemical processes that will be central to electrification and decarbonisation. It is a foundation technology to enhance many types of electrical and electrochemical equipment, such as fuel cells (see **Figure 6**) and batteries, as well as hydrogen electrolysers.

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