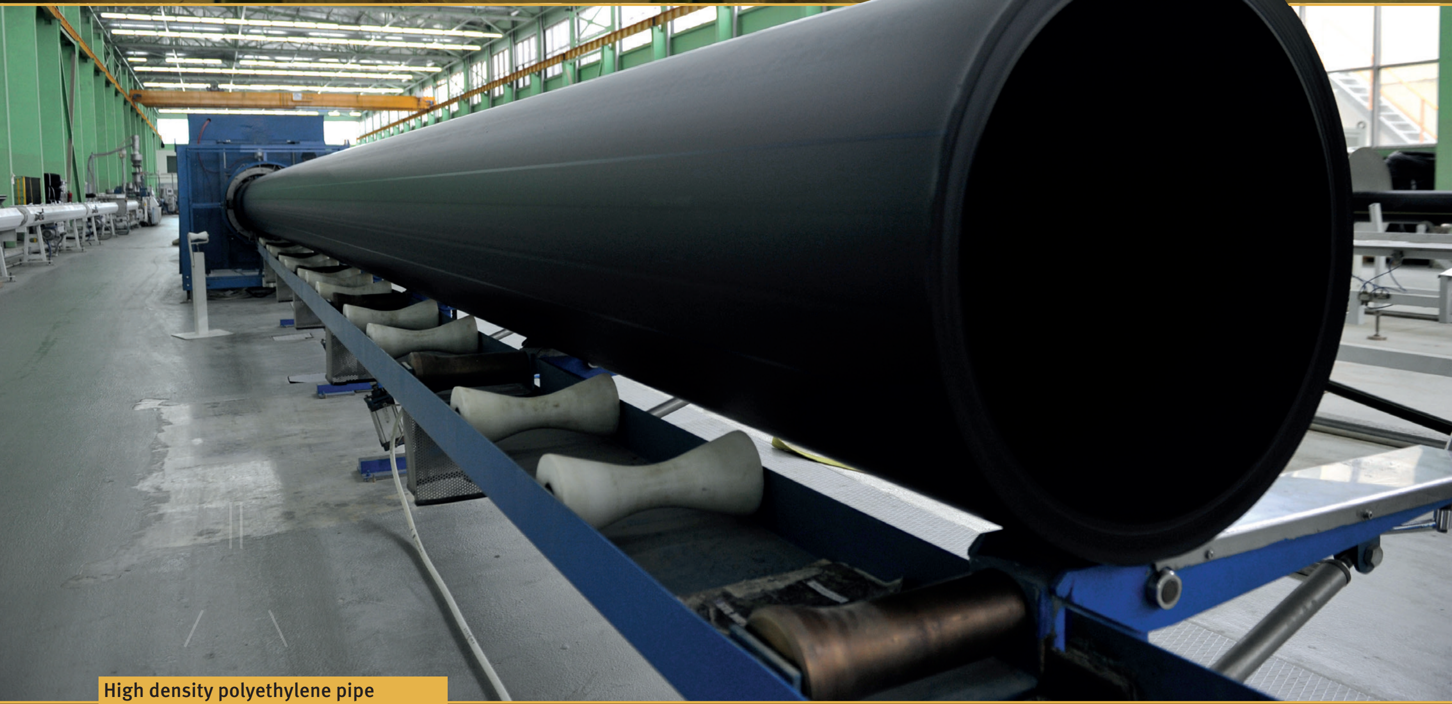


High density polyethylene pipe

What should we be making from CO_2?

As two features elsewhere in these pages illustrate – shining a light on **Synata Bio** and **Solar Foods** respectively – companies around the world are starting to use CO_2 to produce premium materials ready for use in a mix of value chains. **Stephen Harrison** of the consultancy **sbh4** considers what's shaping up

What can you make with carbon dioxide using electrochemistry? It's a big question with many answers today – and plenty of companies are piling into the space.

All the same, industrial scale, electrochemical conversion of CO_2 to hydrocarbons is still in its infancy. Yet some of the striking early moves we are seeing reflect how utilisation today of still-scarce e-hydrocarbons should logically sit at the top of the value pyramid, with sustainable materials, rather than at the bottom with the making and combustion of e-fuels.

At this nascent phase of our journey to Net Zero, it makes sense to allocate the first e-molecules to these premium applications which rely on the chemical properties of the sustainable hydrocarbons, because there is real value to be found.


HDPE liner for fresh water reservoir

In the fossil economy, plastics, pesticides, solvents and pharmaceuticals are all premium applications of hydrocarbons derived from crude oil. These materials use the chemical properties of petroleum products rather than reverting to their energy value. And we can say that these applications can be a guide to the most beneficial use of the initial e-hydrocarbon tonnage the world produces.

Electrochemistry and sustainability

In the past few years, with Net Zero sharpening interest, electrochemistry has emerged as a hot field of interest for scientific research. For example, it lies behind some of the most promising long-duration energy storage innovations in battery technology.

Electrochemistry is of course also fundamental to the electrolysis of water to make green hydrogen. And CO_2 can also be transformed to other chemicals using electrolysis powered with renewable electricity. E-hydrocarbons, often badged as 'sustainable materials,' are the result.

The type of catalyst which is used to split the CO_2 and recombine the component ions determines the outcome. For example, carbon monoxide (CO) is generated with gold or silver catalysts. A copper-based catalyst can produce ethylene, ethanol or methane. Tin and bismuth combine to catalyse the formation of formic acid.

Of course, the idea is that electrochemistry can be used to convert CO_2 to sustainable materials using energy from renewable electricity. This is the driver behind its emergence as a rising star of science in a world gunning for Net Zero.

Green syngas

Syngas is one of the most important chemical intermediates today. It is produced in vast tonnages from steam methane reforming of natural gas and gasification of coal to make methanol and olefins. These are subsequently transformed to plastics, solvents and other value-added hydrocarbons.

When CO_2 is electrochemically transformed to CO, the CO can then be blended with electrolytic green hydrogen to yield e-syngas. This e-syngas has the same chemical characteristics as grey syngas and is a building block to make methanol, Fischer Tropsch fuels or higher value e-hydrocarbons.

Solid oxide electrolysis (SOE) was the first technology to be used commercially to electrolytically reduce CO_2 to carbon monoxide (CO). Topsøe and other pioneers developed high temperature SOE cells and stacks.

This SOE technology was an evolution of solid oxide fuel cells, which have been developed by several companies, including Bloom Energy. Solid oxide fuel cells have now been deployed many thousands of times in Japan and South Korea. The use case is generally to convert methane from imported LNG to heat and power for commercial buildings and tower blocks.

Staying cool

Let's consider some emerghing examples. Twelve, a US startup, has developed something it calls The Opus System. It is a low-temperature process to electrochemically reduce CO_2. Operation at a low temperature allows an ion-permeable membrane electrolyte to be used and avoids the energy losses associated with high temperature operation of the SOE system.

The Opus System is like the polymer electrolyte membrane (PEM) technology which is used to electrolyse water to make green hydrogen. As with PEM, it relies on catalysts to enhance the efficiency of the electrolysis and selectively produce the required product.

Under the trade name CO2Made, Twelve has launched several high-value products made from electrochemically recycled CO_2. Their polycarbonates are used to make lenses for glasses which are being marketed by PANGAIA. Automotive fascia components and structural foam are also being produced for Mercedes Benz cars. And sustainable surfactants are being made for Procter & Gamble's Tide range of detergents.

E-ethylene

And here are some more potential electrochemistry-driven cases. In the industrial packaged gases sector, a mixture of ethylene and nitrogen is sold as a cylinder gas for fruit ripening. In the petrochemical sector, ethylene is a fundamental chemical intermediate.

To make ethylene as a commodity chemical, hydrocarbons from crude oil are cracked in a steam-rich environment. This breaks the long chains and introduces the double bond that makes ethylene extremely reactive. Its reactivity is key to its usefulness as a building block to make polymers and plastics such as polyethylene.

Replacement of plastics such as ▶

polyethylene with innovations in bioplastics or alternative renewable materials is an ongoing process. However, not all chemicals produced from ethylene can easily be substituted with bio-based products.

Production of e-ethylene from electrochemical reduction of CO_2 will enable the substitution of grey ethylene with sustainable e-ethylene. This will ensure that essential medicines and agricultural chemicals can continue be produced as there is a progressive movement away from fossil-fuel feedstocks in the petrochemical sector.

The French startup Dioxycle is one that has developed an electrochemical process to convert CO_2 to sustainable ethylene. Catalysts within its system yield e-ethylene directly from the electrolyser. That e-ethylene can be used as a drop-in replacement for grey ethylene. It can be converted to pharmaceuticals, fabrics, water pipes and drinks bottles in existing factories, using conventional processing equipment.

From CO_2 to formic acid

Oxylum, a start-up based in Belgium, has for its part been working on the electrochemical conversion of CO_2 into chemical feedstocks. In its first business case it focuses on the production of green formic acid as an energy vector and circular chemical.

Formic acid has a variety of use cases. For example, it is added to animal feeds to reduce the need for antibiotics and is a processing agent for textile dyeing and finishing. It also has applications in the pharmaceutical sector, as a cleaning agent and for de-icing runways.

A potential new application of formic acid is as a hydrogen carrier. Formic acid is a food additive and, with appropriate packaging and precautions, it can be used safely in a diverse range of settings. It may therefore have some advantages over ammonia and methanol as a hydrogen carrier, due to its convenient storage and handling properties.

The process that Oxylum uses to convert CO_2 to formic acid relies on electrochemical reactions. Oxylum's work has moved the dial by developing superior catalysts which increase the energy efficiency, reaction conversion and selectivity towards formic acid.

Future-proofing bottled gas

Propane, or LPG, is a core product in many packaged gases businesses. Future-proofing this 'bottled gas' business is a challenge that many industrial gases operators will face. The good news is tht e-propane can be produced from electrolysis of CO_2 and water. The electrochemical system is catalysed by an imidazolium-functionalized tri-molybdenum phosphide nanoparticle catalyst.

The use of an anion exchange membrane (AEM) is integral to some electrochemical process to make e-propane. This is like the cell architecture used in anion exchange membrane electrolysers for hydrogen generation from water.

In geographies with abundant solar, wind or hydro power, the electrochemical pathway may be cost-effective to convert CO_2 to sustainable propane. Affordable production of sustainable propane would enable clean cooking, would dis-incentivise de-forestation and, through circular use of CO_2, would support Net Zero aspirations. However, at present e-propane is produced at a significant cost premium compared with LPG. Technical innovation and industrial scale deployment of CO_2 electrolysis are required to come closer to fossil-fuel price parity.

BPM is cutting-edge electrolysis

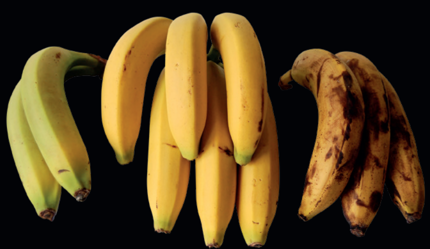
Traditional alkaline electrolysers and commercially available AEM systems have an alkaline electrolyte with similar pH on both sides of the membrane. There are inherent problems with this configuration when performing CO_2 electrolysis.

Ethylene production from hydrocarbons

The cutting-edge of electrochemical conversion of CO_2 to hydrocarbons is the use of a bipolar membrane, or BPM. The BPM is built of different ionomer polymers on the anode and cathode sides. This allows different electrolytes, with different pH values, on either side of the BPM and solves many of the issues that would otherwise arise.

Speed holds the key

These are all positive stories, even if the speed to growth will hold the key to the scaling of the associated impact. What we can say that innovation is racing ahead now to develop the next generation of CO_2 electrolysis membranes, catalysts and cell architectures,. And it is a journey that will continue to improve the conversion of CO_2 to hydrocarbons. gw



Ethylene is a fruit ripening gas