Emerging carbon dioxide utilisation applications

Synthetic e-fuels and plastics

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Carbon dioxide capture from emissions sources will increase by several orders of magnitude between now and 2050, as the world decarbonises fossil fuel usage. Much of that captured carbon dioxide (CO_2) will be sent underground for permanent storage in geological formations, and much of it will be utilised for emerging CO_2 applications.

There have been shortages of CO_2 in the past decade as supply and demand have fallen out of balance for several months. Thinking forward to the supply and demand balance, even if we were to drink carbonated beverages twice as often as we do and switch all food freezing from liquid nitrogen and mechanical chillers to CO_2-based processes, there would still be a significant excess of CO_2 captured in comparison to the global demand that exists from the current portfolio of CO_2 applications.

Are there any potential new large-scale applications that might soak up some of the captured CO_2 which will inevitably become so abundant in the future? To make a significant dent in the amount of CO_2 that will become available, these applications will need to be extremely high-demand utilisation cases. At present, about 80% of the CO_2 captured globally is used for enhanced oil recovery (EOR). That dwarfs the amount of captured CO_2 that is routed to the food and beverage industry. It also makes the total amount of CO_2 that is used for pH control in water treatment, welding, greenhouse growing, solvent extraction of medical cannabis or specialty gases SFC laboratory applications look tiny. Is there an emerging EOR-scale application for CO_2 out there?

Perhaps there is. The production of synthetic e-fuels from steam and CO_2 on solid oxide electrolysers (SOEs) has the potential to become a mega-scale consumer of CO_2. Similarly, the electrochemical conversion of CO_2 can yield polymers and plastics. These emerging applications have realistic prospects of becoming major CO_2 consumers. In each case, renewable electricity and SOE combine to play a role displacing crude oil or other fossil fuels in the respective value chains.

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Electrochemistry waves a magic wand

Solid Oxide Electrolysis (SOE) technology is sometimes referred to as High Temperature Electrolysis (HTE). It could equally well be called High Efficiency Electrolysis. It consumes water in the form of steam and derives a significant percentage of its energy from the heat of the steam.

This means that approximately one third less electrical power is required to produce hydrogen gas, compared to a polymer electrolyte membrane (PEM) electrolyser or an alkaline electrolyte cell (AEC) system.

SOE also has high potential in a diverse range of Power-to-X applications because it can either be configured to produce hydrogen when fed with steam or to produce syngas when fed with a mixture of steam and carbon dioxide. Syngas is a mixture of carbon monoxide and hydrogen which can be converted to hydrocarbons using the Fischer-Tropsch process. SOE can therefore integrate seamlessly to produce feedstocks for chemical processes or to create liquid fuels, referred to as synthetic e-fuels.

In terms of technical maturity, AECs have been used for decades in association with chlorine production. Chlorine is used in ▸

drinking water sterilisation and plastics manufacturing: chlorine is an ingredient in the ubiquitous PVC polymer. PEM systems have gained traction in the past 10 years and are catching up with AECs in terms of scale and the installed base of electrolyser capacity. The SOE is the infant in the family. But with its good energy efficiency and its potential to produce syngas, in addition to the ability to make pure hydrogen, it has all the right reasons to be nurtured and given the chance to compete with its older siblings.

Synthetic e-fuels for aviation

It is clear that hydrogen will be used as a fuel to decarbonise many heavy-duty mobility applications such as trains buses and trucks. However, there are still open questions about which fuels will enable the most cost-effective decarbonisation of flight and shipping.

Airbus has proposed hydrogen fuelled aircraft with liquid hydrogen storage in cryogenic tanks. ZeroAvia has attracted some high-profile investors who are excited by its hydrogen-powered aircraft. However, the commercialisation of hydrogen-fuelled aviation is some way off.

Biofuels are already used as an alternative to crude-oil as jet fuel. Despite producing CO_2 emissions during combustion, they are regarded as carbon neutral because growth of the crop that was used to produce them extracted CO_2 from the atmosphere. Synthetic e-fuels produced using renewable power, steam, CO_2 and the magic of electrochemistry on the SOE, followed by the Fischer-Tropsch process would be an alternative to biofuels. These liquid fuels would be drop-in replacements for jet fuel derived from crude oil. They would also have a very high energy density meaning that jets could achieve high range with a high number of paying passengers. However, biofuels and synthetic e-fuels, do not eliminate the problem of voltaile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM) and NOx emissions from aeroengines. This mix of pros and cons means it is not yet clear which fuels will dominate as we decarbonise flight.

CO_2 could decarbonise shipping

If international shipping were a country, it would fit between Japan and Germany as number six on the list of the world's largest CO_2 emitting nations. With such a huge impact on the environment a carbon-neutral fuel for ships will be a major relief to global warming and lend tremendous support to achieving The Paris Agreement climate goals.

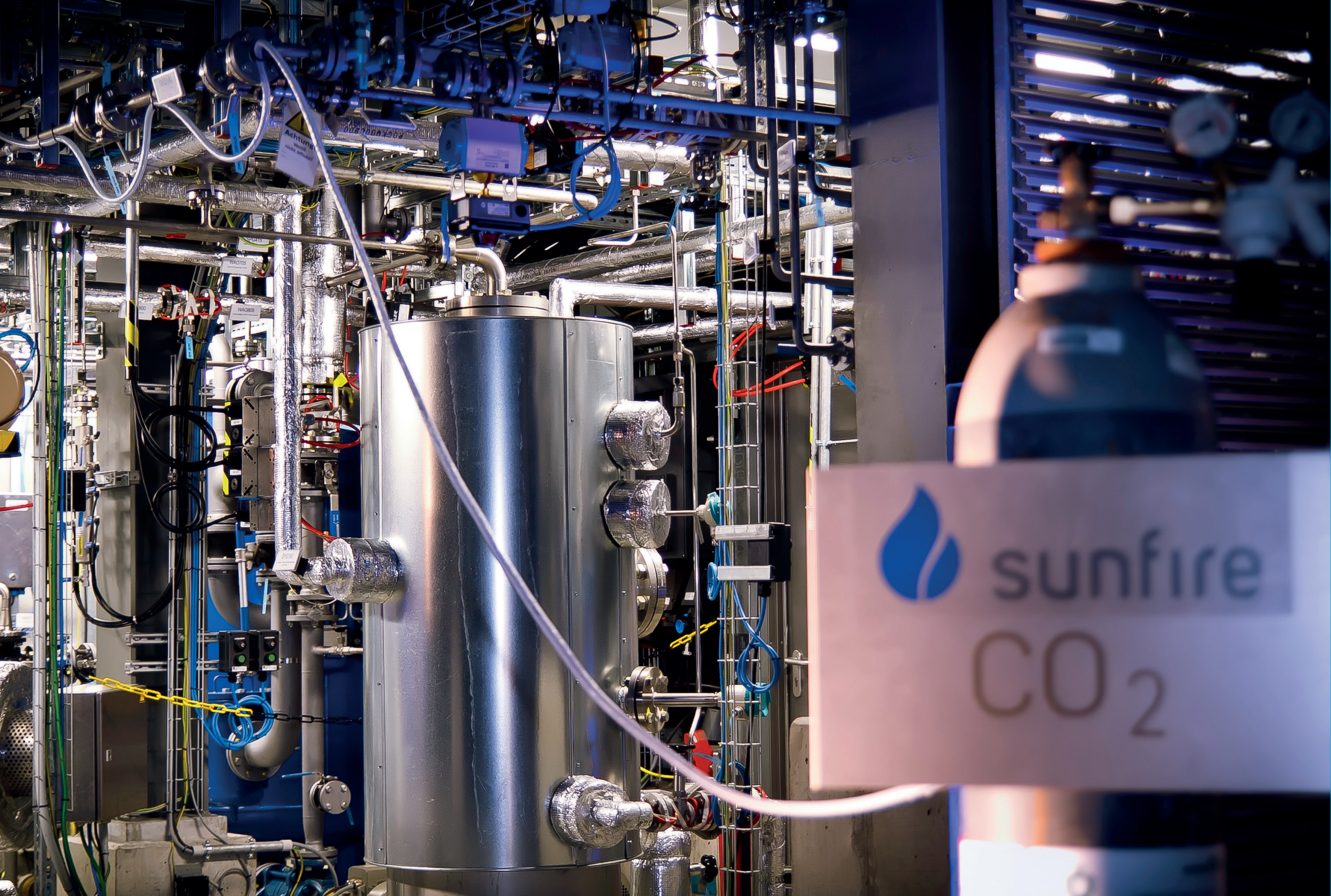
Ammonia is receiving a lot of attention as a potential marine fuel that will not produce CO_2 emissions from the ship. If it is produced from green hydrogen or from natural gas on steam methane reformers fitted with carbon capture and storage systems, the use of ammonia as a maritime fuel will indeed support decarbonisation.

Methanol is currently used as a fuel on several ships. Alongside LNG, it is regarded as a cleaner burning bunker fuel than traditional heavy fuel oil. The route to methanol production is though syngas. Here, again, an SOE fed with CO_2 and steam holds the key to 'green' methanol production. However, the electricity flowing to the electrolyser must be from a renewable source for the methanol to carry the coveted 'green' label.

Methanol and ammonia are both relatively easy to store as liquid fuels onboard ships. On the other hand, ammonia vaporises easily to form a highly toxic gas whereas methanol is much less volatile, and its vapours are significantly less toxic. One point to methanol. But the use of ammonia as a fuel yields no CO_2 emissions, whereas methanol burns to form CO_2. One point to ammonia. As with aviation, there are many potential fuel options to decarbonise shipping – including synthetic e-fuels which might prevail in aviation. Each option has its pros and cons and the situation in 2030, 2040 and 2050 is difficult to predict. But the use of CO_2 to produce methanol or e-fuels is in the mix with a fighting chance.

Socks from CO_2

Many petrochemicals and polymers are derived from crude oil. The German chemicals giant, Covestro, has been working with RWTH Aachen University and the CAT Catalytic Centre to develop catalysts and technologies that can incorporate CO_2 into polymers.



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Whilst the potential for this pathway has been known for many years, it has been difficult to find the right catalysts to encourage the reaction to take place with minimal energy input. This is the breakthrough that Covestro and its research partners have achieved in recent years.

The process that Covestro and its research partners have developed can substitute approximately 20% of the crude oil with CO_2 to produce a polyol, which Covestro has named cardyon®. This polymer is already being used as to produce soft polyurethane foam for mattresses and upholstered furniture. Polyols are reacted with isocyanates to yield polyurethane. Applications of cardyon® also extend to harder foams for components in automotive interiors and as a binder for synthetic sports flooring. Moving beyond beds, the next stage of development will be directed towards flexible fibres, for example those used in socks and medical fabrics.

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The use of captured CO_2 means this is a circular economy application which is reducing the demand for crude oil in plastics and polymer production. At present, the CO_2 content in cardyon® is limited to about 20% but Covestro is investing in further R&D which has the potential to increase the proportion of circular CO_2 in the polyol. Its research will also expand the field of application for the polymers that are produced from cardyon®.

Industrial gases – always innovating

The range of emerging applications for CO_2 is proof that industrial gases are on the move.

Our industry has its roots in oxygen and acetylene; town gas and hydrogen followed; chemical production pathways and gasification gave way to cryogenic distillation and steam methane reforming. Production units scaled up, products such as argon and CO_2 were added to the portfolio and, new applications emerged.

Industrial gases will continue to innovate. We face challenges to decarbonise our operations and we have opportunities to play our role in a decarbonised future. These emerging applications of CO_2 are some, of many, examples that demonstrate the industrial gases sector can continue to innovate and make a positive difference in the world. gw