Carbon capture and utilisation

Xolile Fuku explains how carbon emissions can be put to good use for a more sustainable world

It's now well established that carbon dioxide (CO_2) is a greenhouse gas that contributes to global warming and other effects of climate change. The global mean CO_2 level reached 410 ppm in 2019, up from 340 ppm in 1980, and it has continued rising despite the economic slowdown caused by the COVID-19 pandemic. To address the climate crisis, more than 190 countries, including South Africa, have joined the Paris Agreement adopted in December 2015, pledging to reduce CO_2 emissions with the goal of limiting global warming to well below 2°C, preferably 1.5°C.

Such a political goal necessitates a paradigm shift, aided by technology advancements. One approach is to undertake carbon capture and storage (CSS), also known as carbon capture and sequestration. This involves capturing CO_2 before it reaches the atmosphere, converting it to a fluid and storing it deep underground in geological formations, where it will remain for centuries.

Another approach is to view CO_2 as an abundant carbon resource rather than a pollutant. Carbon capture and utilisation (CCU) aims to recycle the CO_2 for use in the manufacture of high-value products, including chemicals, plastics and fuels.

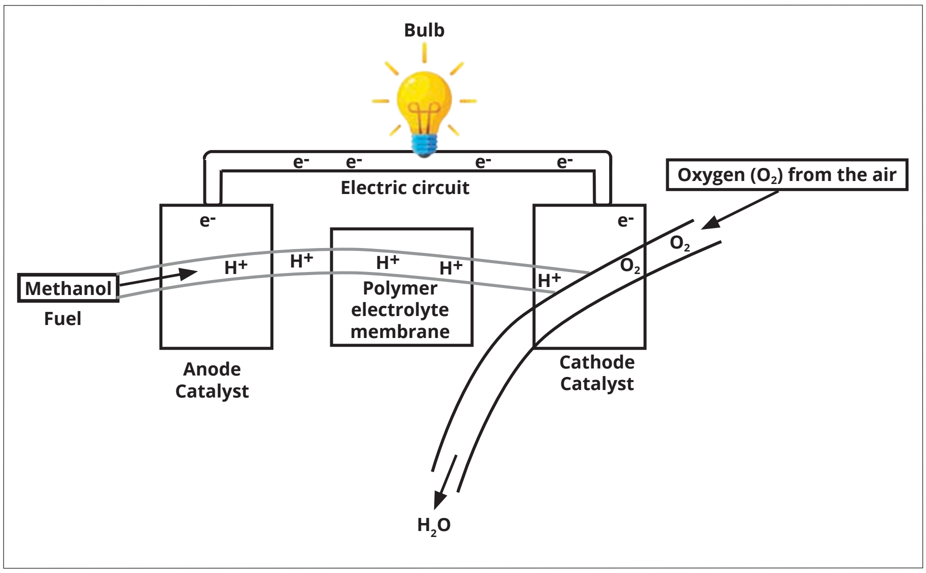
There are three main types of carbon capture: post-combustion, pre-combustion, and oxy-fuel combustion. In post-combustion capture, CO_2 is separated from the flue gas, or exhaust, emitted from the combustion process. In this case, CO_2 can be separated out via absorption, adsorption, cryogenic and membrane separation. Pre-combustion capture entails gasification of carbon-based fuels to produce syngas – a mixture of H_2, CO and CO_2 – that is processed further to separate out CO_2. Finally, in oxy-fuel combustion the fuel is burned in pure oxygen or oxygen-rich air, so the emitted flue gas contains mainly CO_2 and water vapour, making it easier to separate out the CO_2.

Once the CO_2 has been captured, it can be converted into useful, value-added products in a variety of ways. One such product is methanol (CH_3OH), the most basic member of the group of organic compounds known as alcohols. It is mainly used to produce other chemicals such as formaldehyde and acetic acid, used in everyday products like plastics, paints, car parts and construction materials, but methanol is also an emerging energy fuel.

Currently, nearly all methanol production is derived from fossil fuels, involving either steam reforming of natural gas or gasification of coal to produce syngas. However, in much the same way that solar energy can be used to produce 'renewable hydrogen' (see page 14), there is potential for producing 'renewable methanol' from green hydrogen and CO_2 using a combination of photovoltaic and electrochemical components. Another option is to produce biomethanol from biomass feedstocks such as agricultural waste, landfill biogas and sewage sludge.

Being a biodegradable and clean-burning fuel, methanol's environmental and economic benefits are increasingly making it a desirable alternative for powering vehicles and ships. It can be used in conventional internal combustion engines, but also in fuel cells that transform chemical energy into direct current electrical energy.

The *Stena Germanica*, a ferry owned by the Swedish company Stena Line, has been using methanol as fuel since 2015.



Schematic of a direct methanol fuel cell system.

Most fuel cells are fuelled by hydrogen and oxygen (air), which produce water as a by-product when combined. The direct methanol fuel cell (DMFC), on the other hand, is an electrochemical cell that generates energy through methanol oxidation and oxygen reduction. This eliminates the requirement for an external hydrogen fuel supply and opens the door to tiny devices ranging from a few watts to several kilowatts in capacity. Probable applications include use in video cameras, drones, boats and caravans, where batteries can often only be used for short operating periods before recharging is required. By contrast, fuel cells are capable of continuous operation provided they are supplied with fuel.

Methanol can also be used for cooking and heating in homes, offering an opportunity to address a significant social and environmental issue. According to the World Health Organisation (WHO), nearly three billion people heat their homes and cook with fuels like coal, wood, waste, dung and paraffin, burned in open flames and basic stoves, and almost four million people per year die prematurely from illnesses caused by indoor air pollution. The majority of those impacted are women and children.

In South African townships, paraffin is not only one of the worst contributors to pollution-related disease, but also results in large shack fires every year when combined with faulty stoves. Methanol has therefore been proposed as a paraffin replacement. If produced through either CCU technologies or from renewable sources, it could aid in the mitigation of climate change by lowering carbon emissions, while also reducing local air pollution and enhancing energy security.

Dr Xolile Fuku is a senior lecturer at UNISA's Institute for Nanotechnology and Water Sustainability (iNanoWS). His research focuses on energy storage and conversion systems as well as electrochemical and biological sensors.