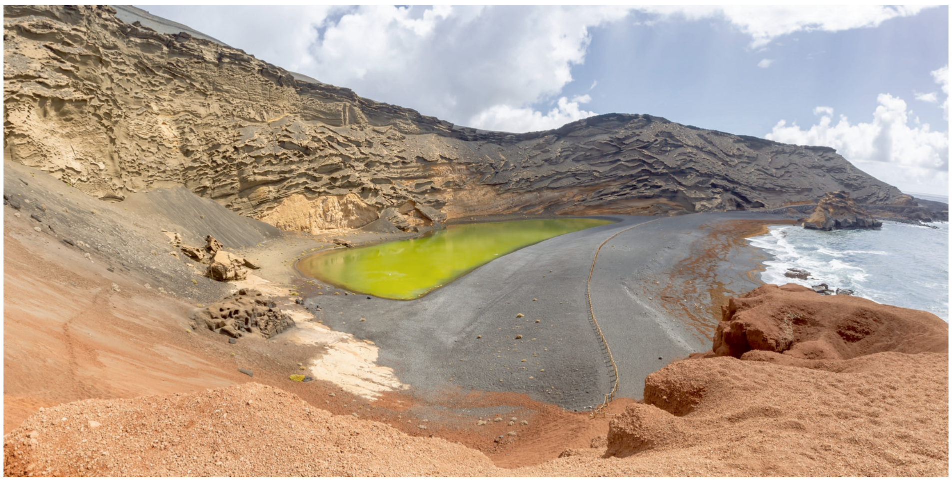
The convergence of biotechnology and carbon capture

Processes evolved by biological organisms over millenia are being adapted to industrial applications to capture CO2 or convert carbon to valuable chemicals. By Stephen B. Harrison, sbh4 consulting.

Learning the lessons of biological evolution and nature has served mankind well for decades. The discovery of the antibiotic effects of the bacterium penicillin led to the development of modern antibiotics. Biotechnology is now instrumental in bringing new medicines to market to save lives.

Biotechnology can also guide the development of energy efficient means to capture CO2 and convert carbon to chemical intermediates such as ethanol. Ethanol can be used to make synthetic aviation fuel (SAF) and other valuable chemicals.



Seawater can be pumped into a lagoon filled with algae. Nutrients in the seawater are absorbed by the algae as they grow. They simultaneously absorb CO2 from the air in a form of direct air capture of CO2.

Enzymatic enhancement of HPC CO2 capture

Hot potassium carbonate (HPC) is a long-established CO2 capture technology. The HPC process was developed in the 1950s and was modified by two engineers: Benson and Field. It subsequently became known as the Benfield Process. In this form, it is now licensed by Honeywell UOP.

The UOP Benfield ACT-1 activator can be added to the potassium carbonate solvent to improve the CO2 absorption rate and increase the CO2 loading. It can reduce the solvent recirculation rate and thereby result in less energy required to heat up and regenerate the solvent in the stripping column. ACT-1 is a proprietary organic additive which is incorporated into the potassium bicarbonate at between 1 and 3%.

Biotechnology has also recently been applied to catalyse CO2 absorption in the HPC process through the use of Carbonic Anhydrase (CA). CA is an enzyme which plays an essential role in humans and many animals. Its function is to remove CO2, which is a byproduct of respiration.

Respiration is the mechanism by which animals convert oxygen that they breathe and food that they eat to energy. It is like an internal combustion reaction, and like combustion it produces CO2. However, the CO2 must be broken down to avoid dramatic pH changes and CA supports that by catalysing the reaction of CO2 with water to form bicarbonate and hydrogen ions: $CO_2 + H_2O \rightarrow HCO_3^- + H^+$.

A proprietary CA enzyme known as 1T1 is used by CO2 Solutions by Saipem on industrial CO2 capture systems. The molecular structure of the 1T1 enzyme has been engineered to maximise its catalytic efficacy to promote the absorption of CO2 into the potassium carbonate solution and whilst also allowing low-cost manufacture of the enzyme. Novozymes, part of the Danish biotechnology giant Novo Nordisk has entered into an agreement with Saipem to manufacture the enzymes.

Algae to capture CO2

Photosynthesis is the conversion of CO2 to higher hydrocarbons with the release of oxygen in the presence of light. Plants use this bioreaction to generate starches that they use to create leaves, branches trunks and roots.

Algae use the same reaction to grow their cell mass, however unlike trees and plants their entire function is dedicated to photosynthesis and they do not expend energy growing physical structures. The implication is that per acre of land, they are much more efficient at capturing CO2 than a forest.

Various types of algae are used in cosmetics and as a meat substitute in vegan and vegetarian foods. The use of pure CO2 gas to accelerate the growth of algae in these commercial utilisation applications has been common for several years. However, a new generation of algae technologies is turning to CO2 capture as their business model.

The Danish startup ALGIECEL has targeted capture of biogenic CO2 as biogas is upgraded to biomethane from anaerobic biogas reactors. Their vision is to utilise the captured CO2 to cultivate algae which will be rich in omega-3 oils. These can be used as nutritional supplements for humans, livestock and farmed fish.

The ALGIECEL PhotoBioReactor (PBR) is a containerised unit designed to match the scale of biogas production on many of Europe's 18,000 biogas reactors. Light for the photosynthesis is provided by energy efficient LEDs to ensure 24-hour operation at maximum CO2 capture and conversion yields.

The British startup Brilliant Planet has also developed a CO2 capture process that relies on algae. However, their intent is not to utilise the products derived from the algae. Instead their vision is 1000-year sequestration.

The Brilliant Planet concept is ideally located next to nutrient-rich seawater in a desert location. Seawater is pumped into a lagoon filled with algae. Nutrients in the seawater are absorbed by the algae as they grow. They simultaneously absorb CO2 from the air in a form of direct air capture of CO2.

CO2 capture is also achieved through a second mechanism. The algae consume bicarbonate ions from the seawater. These ions have been created naturally during absorption of atmospheric CO2. As the lagoon water is released back into the sea, it re-absorbs CO2 from the atmosphere. This is also a natural form of direct air capture of CO2.

The algae are harvested, dried and buried under sand in the desert. The dry, salty algae are acidic and cannot biodegrade in the desert sands. This guarantees that the captured CO2 is permanently sequestered.

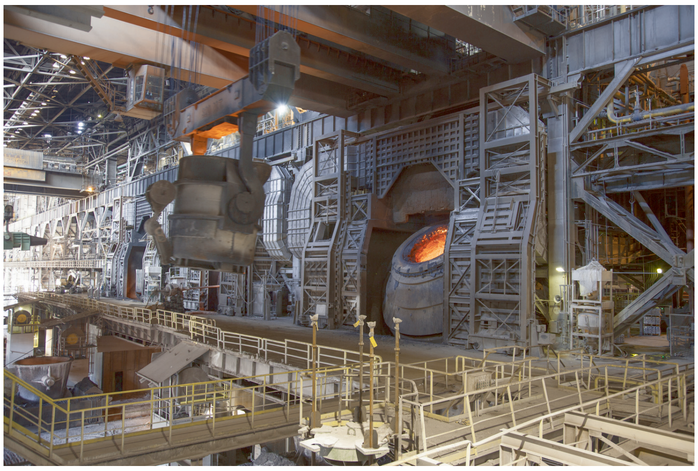
Bio-fermentation of captured carbon to ethanol

Trees and plants absorb CO2 as they photosynthesise. They use the carbon to build carbohydrates, starches, and lignin to build their leaves and structure. Bacteria can also consume CO2 and carbon monoxide (CO) to produce valuable chemicals such as ethanol.

LanzaTech utilises anaerobic acetobacter bacteria in a fermenter to convert CO rich feed gases, such as syngas, to ethanol and a range of biochemicals. Subsequently, the complimentary LanzaJet process can be used to convert the bioethanol to synthetic aviation fuel (SAF) in their proprietary 'Ethanol to Jet' or ETJ process.

The ideal feedstocks for the LanzaTech fermenter are CO-rich. CO2 rich streams can potentially be utilised in combination with hydrogen. But a high CO content in the feed to the bioreactor, or fermenter, reduces the green hydrogen feed requirement. Syngas derived from waste or biomass gasification is generally CO-rich and is a good feedstock for the LanzaTech process.

Iron and steel making also yields CO-rich flue gases which are ideal feedstocks to the LanzaTech process. Blast furnace gas (BFG) contains 20% CO and converter gas (also known as basic oxygen furnace gas or BOFG) contains 60% CO.



Basic oxygen blast furnace gas which is rich in CO can be used in the LanzaTech process to produce valuable bioethanol

At present, the energy rich converter gas (LHV 3 kWh/Nm3) is often utilised on the iron and steel making facility for heat or power generation on a gas engine. Alternatively, it is flared. Blast furnace gas has a lower energy value due to the lean CO concentration and higher CO2 content (LHV 0.9 kWh/Nm3). It can also be always utilised on the facility or is sent to the flare. Utilisation of the BFG in the LanzaTech process can generate valuable bioethanol.

LanzaTech's process was demonstrated at pilot-scale in 2008 using flue gases from the BlueScope Steel mill in Glenbrook, NZ. Since then, LanzaTech has successfully deployed its technology at two 300 tonne per annum demonstration facilities at Baosteel Shanghai and Shougang Steel Caofeidian in China. These LanzaTech fermenters are fed with a range of iron and steel making off gases including BOFG, BFG, and coke oven gas (COG).

Carbon recycling to SAF improves the life cycle analysis

The term CCT or 'Carbon Capture and Transformation' has been used to describe the LanzaTech fermentation process. Whilst it is highly effective at transforming carbon monoxide to ethanol, the LanzaTech process has more in common with carbon utilisation than CO2 sequestration.

LanzaTech operates the Freedom Pines Biorefinery in Soperton, Georgia which uses bio fermenters to generate ethanol and other chemicals. The LanzaJet ethanol to jet SAF production process will soon also be implemented at that location to utilise captured carbon to make fuels that can substitute aviation kerosene, a fossil fuel distilled from crude oil.

The LanzaTech bioreactor utilises CO2 and hydrogen, or CO from syngas to grow bacterial biomass in the main fermenter. Some gases are emitted from this fermenter. This biomass from the main fermenter is subsequently converted to biomethane in a separate anaerobic sludge digester. This energy-rich biomethane is used to fully combust the main fermenter off gases to CO2. This CO2 is then be emitted to the air.

Despite these CO2 emissions, Life Cycle Analysis (LCA) of the LanzaTech process shows that the holistic CO2 emissions reduction is primarily due to the substitution of fossil fuels with fuels derived from ethanol recovered from the fermentation broth.

Also integral to the LanzaTech LCA is consideration of whether the feedstock, such as iron and steel making flue gases are flared, or utilised. If they are flared, their recovery and conversion to ethanol is a significant environmental benefit. However, if they are utilised to make heat and power, they already avoid the use of fossil fuels and the overall CO2 reduction in the LCA is reduced.

More information

sbh@sbh4.de

sbh4.de