Important scientific advances in CCUS over the past 3 years

The report from the Carbon Dioxide Capture and Conversion (CO2CC) Program gives an update of the recent progress made in CCUS technologies, from the various advances in capturing CO2, to the use of CO2 as a feedstock for valuable commodities or for Enhanced Oil Recovery, and the safe storage of CO2 to prevent its return to the atmosphere.

The report, "Catalogue of most important scientific advances in CCUS over the past 3 years" presents recent developments in each aspect of the CO2 supply chain, using recent scientific papers, news, press releases, patents, and technical/economic reports to assess the technical and economic feasibility of each technology.

Many studies are focusing on the implementation of CCS to the top-emitting industries including iron and steel, cement, petroleum refining, and petrochemical. Unlike fossil fuel power plants, many industries have few or no CO2-free alternatives to manufacture products.

An overview of each technology is presented at the beginning of each section, followed by the recent advances, while current projects and future hurdles of each technology are outlined at the end of each section. Finally, the conclusion of each chapter includes the most important findings and the challenges related to each technology.

Chapter one outlines the developments in CO2 capture technologies which can be divided into three categories: post-combustion capture, pre-combustion capture and oxyfuel-combustion. The report covers a range of potential solutions including absorption, adsorption, membrane separation, calcium looping, chemical looping, and direct air capture (DAC).

Post-combustion capture (PCC) offers a mature technology which can be easily retrofitted to existing plants. For industrial applications, carbon capture via absorption is the most commercially mature technology to date, and in recent years a steady increase of CCS projects using this technology has been observed.

Developments in Carbon Capture and Utilization (CCU) technologies is the subject of Chapter two, which includes utilisation of CO2 to produce fuels, chemicals and construction materials. A careful assessment of the lifecycle emissions of each product and process is required to ensure the lifetime CO2 emissions of the product do not exceed the amount of CO2 utilised.

Growing interest in new technologies for CO2 utilisation, such as the production of synthetic fuels, chemicals and construction materials has been reflected in the increasing support from governments, industry, and investors. Carbonated aggregates, synthetic fuels and concretes represent the largest near-term opportunities for CO2 utilisation in terms of emissions reduction and market size.

The recent progress in CO2 storage methods including enhanced oil recovery (EOR), geological storage and natural sequestration is presented in Chapter three.

Ocean sequestration involves the injection and deposition of CO2 into the water at depths below 1 km, however environmental concerns mean that geological sequestration in saline aquifers or depleted oil & gas reservoirs remains the most mature technology and is the focus of all existing projects. Recent developments have focused on the effect of location, monitoring methods and site characterisation.

Nature-based solutions include reforestation, afforestation, biochar, and enhanced weathering rates of rock minerals. Geological CO2 storage when compared to nature-based solutions has clear advantages in the sense that nature-based solutions require continual interventions, significant land areas and has a low capacity of CO2 stored annually.

Despite the efforts made in membrane materials development and their fabrication, what is vital for large scale post-combustion capture (PCC) are effective techno-economic analysis of process flowsheets and pilot scale assessment of different system configurations using real flue gas streams.

Outlook: key takeaways from the report

- Converting CO2 to useful chemicals and or plastics could, under certain circumstances, have an impact on decreasing CO2 emissions.
- Currently various pathways for CO2 conversion to fuels are being explored. Electrocatalysis, photocatalysis and a combination of thereof are the most well studied pathways with the former being the most suitable for large scale deployment.
- In the United States, more than 70% of CO2 used for EOR is sourced from natural underground reservoirs due to the absence of infrastructure for capture from industrial emitters close to oil fields.
- Incentives to store CO2 through tax credits or a carbon market could shift CO2-EOR projects from producing more oil with less purchased CO2 to achieving a secondary goal of storing more CO2.
- Despite EOR being a long-established technology, CO2 monitoring, quantifying and reporting standards must be improved to validate the potential emissions benefit to meet climate change targets.
- There are a small number of active (Sleipner, North Sea, Norway; Snohvit, Barents Sea Norway) and completed (K12-B, North Sea Netherlands) offshore CO2 injection projects in Europe that provide confidence in the performance of offshore injection and storage.

Advances in CO2 capture

Post combustion capture is a mature technology with decades of use in industrial processes that can be easily retrofitted. The conventional PCC processes include liquid absorption, solid adsorption, and membrane separations. Currently, chemical absorption via amine solvents is the most mature PCC process technology. Chemical absorption offers high capture efficiency and high selectivity; however, it has significant solvent regeneration energy demand and thus high CO2 capture costs.

Many screening experiments have been performed for different solvents. Nevertheless, all solvents studied so far continue to exhibit several drawbacks such as low kinetics and stability issues when exposed to acidic gases like SOx and NOx as well as the presence of oxygen in the flue gas.

The membrane separation method can be applied to pre-combustion, oxy-combustion, and post–combustion carbon capture processes. This often has easy operation, however during operating it has a small processing capacity, poor selectivity, and low stability.

Several next-generation technologies including calcium looping, chemical looping and direct air capture are also reviewed.

Advances in CO2 utilisation

There is growing interest in CCU as a climate change mitigation tool where the captured CO2 is converted into valuable products rather than sequestered underground. Prize initiatives such as the NRG COSIA Carbon XPrize have been key enablers in promoting CO2 conversion technologies.

CCU provides a revenue stream for CO2 capture projects which could help to de-risk the early development of CCUS supply chains. The core challenge of utilisation technologies is that CO2 is one of the most thermodynamically stable carbon compounds. Therefore, converting CO2 into a high value product can involve a large amount of energy and materials (i.e., catalysts and other chemicals).

The three primary options for CO2 utilisation are conversion to fuels, chemicals, and building materials. The production of fuels could increase the CO2 demand by up to 2050Mt per year, while carbon conversion into chemicals represents a large CO2 sequestration potential of approximately 500 Mt/year. It is important to note that CO2 based fuels will eventually end up releasing CO2 to the atmosphere, thus conversion of CO2 into fuels can only be a carbon-neutral technology.

The most common fuels derived from CO2 conversion are methane (CH4) and methanol (CH3OH), although CO (syngas) and ethanol can also be produced via CO2 reduction. Various new conversion pathways and catalysts are being explored, however process scalability, costs, and above all energy use are still limiting the large-scale deployment of these technologies.

CO2 can be used as an alternative feedstock to natural gas and oil for chemicals synthesis. Captured CO2 can be used in mature processes (such as urea production), emerging technologies (such as formic acid production), and innovative processes that have emerged due to the need to reduce anthropogenic CO2 emissions.

Lastly, the production of cement and aggregate are considered by some to be the largest near term opportunity for CO2 utilisation in terms of potential for emissions reduction and market size. Many start-ups focus on carbonated aggregates and CO2-cured concrete technologies, with Solidia, Carbon8 systems and CarbonCure being near or having achieved commercial deployment.

Advances in CO2 storage

Geological sequestration is relatively well understood and recent developments focus on the effect of location, monitoring methods and site characterisation. Furthermore, several studies recently focused on estimating storage capacity and showed that this is not a limitation.

Future research should focus on developing a deeper understanding of impurities and their effect on CO2 storage. In addition, it is important to develop mathematical models to mimic actual reservoir conditions and establishing databases where important information of storage sites is collated.

There has been renewed interest in EOR from unconventional reservoirs like the Bakken shale, the use of computer aided techniques for co-optimisation of oil recovery and CO2 sequestration, and the recovery of methane from methane hydrates by the exchange of CO2. There are currently 24 large-scale CO2-EOR projects in various stages of development.

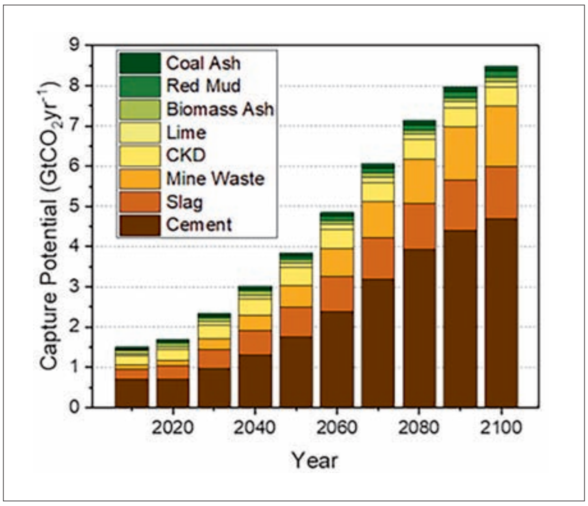

Figure 1 - CO2 capture potential of alkaline materials for the baseline shared socioeconomic pathway (SSP) where the world follows a path in which social, economic and technological trends do not shift markedly from historical patterns (SSP-2). (Source: Adapted from Renforth, 2019)

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Carbon mineralisation is a long-term and non-toxic method of storing CO2 in solid form which has the potential to mitigate health and environmental hazards in specific contexts. Carbonation of alkaline industrial wastes reduces chemical contamination and hence environmental hazards (Fig 1).

Next articles

This is a series of articles summarising recent key reports from The Catalyst Group Resources' Carbon Dioxide Capture and Conversion (CO2CC) Program. Look out for "Permanent Sequestration of CO2 in Industrial Wastes/Byproducts" in the next issue.

More information

More information about this report and other services of the CO2CC Program can be found at:

www.catalystgrp.com/tcg-resources/member-programs/co2-capture-conversion-co2cc-program/