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Insight into Carbon Capture and Storage (CCS) Technology

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Abstract

This mini review offers insight into the applications and potential uses of Carbon Capture and Storage (CCS) technologies including petrochemical uses. Carbon capture and storage (CCS) technology is used to reduce greenhouse gas emissions and is one of the paths to reducing anthropogenic carbon dioxide emissions. The discussion presented is exploratory and descriptive, rather than instructive in the use of CCS and identifies that there is an emerging need for training in current uses as well as the need for further research in development of efficient carbon capture solvents.

Keywords: Carbon capture; Carbon storage; Organic chemistry; Petroleum; Anthropogenic carbon dioxide; Emissions

Introduction

The International Conference on Industrial Chemistry [1] outlines that petroleum is a naturally occurring complex mixture made up predominantly of carbon (about 85%) and hydrogen compounds (about 13% by weight), but also frequently containing significant amounts of nitrogen (about 0.5%), Sulphur (0.5%), and oxygen (1%) together with smaller amounts of nickel, vanadium, and other elements. Solid petroleum is often known as asphalt, with liquid known as crude oil and gas, as natural gas. The source of petroleum is biological. Buried organic matter in an oxygen deficient environment and subjected to elevated temperature and pressure for periods extending to millions of years, produces petroleum as an intermediate in the transformation that ultimately leads to methane and graphite. Crude oil and raw natural gas and condensates are naturally occurring substances which potentially contain thousands of individual hydrocarbons.

When petroleum products are burned for energy, they release toxic gases and high amounts of carbon dioxide (CO_2). The released carbon dioxide is a greenhouse gas such that these gasses absorb solar heat reflected by the surface of the Earth and in turn warm the atmosphere. Carbon Capture and Storage (CCS) technology is used to limit greenhouse gas emissions [2] and is one of the pathways for anthropogenic CO_2 emission mitigation [3]. Carbon dioxide is emitted when fuels such as coal, oil and natural gas are used. Coal21 [4] illuminate that Carbon capture and storage (CCS) is a process used to prevent these CO_2 emissions from entering the atmosphere and contributing to climate change. CCS captures CO_2 at a power station or industrial facility such as a steel, Liquefied Natural Gas (LNG) or cement plant. The captured CO_2 is then safely and permanently stored in deep geological underground structures, or by other physical, chemical, or biological means. This process is reflective of natural examples where gases, including CO_2, have been trapped in deep geological structures for millions of years. CCS currently focuses on stationary sources since it is not yet possible to capture CO_2 from mobile sources such as automobiles, heavy vehicles, and aircraft [4].

Since 1996, the CCS approach has been used in Canada (Weyburn-Midale), and since 2000, Norway (Sleipner). Boundary Dam (Canada, 2014) and Petra Nova (USA, 2017) are two coal sector projects which have also begun operations with CCS. Coal21 [4] recognizes that there are opportunities to commercially apply CCS technology, such as the Gorgon Project in Western Australia, which will be the world's largest of its kind. In the Callide Oxyfuel project capturing CO_2 at an operating power station in Queensland, and the CO_2CRC that injects CO_2 into a depleted gas field in the Otway Ranges of Victoria, the technology has also been successfully demonstrated. The Global CCS Institute reports 18 commercial-scale CCS facilities globally in service (Norway, Canada, USA, Saudi Arabia, Brazil, China), with a further 5 being planned. A further 20 are at various stages of worldwide development [5]. Carbon capture and storage is being investigated internationally since it can potentially play an important role in reducing industrial greenhouse gas emissions and tackling climate change. Uses and implementation requirements are the focus of this short insight review.

Industrial and commercial uses of captured CO_2

There are many existing commercially available CO_2 capture technologies that have been developed to produce high purity CO_2 for commercial and industrial markets such as enhanced oil recovery, chemical manufacturing, and food processing. These include the use of CO_2 as a growth medium to produce algae which can then be used as a source of stock feed or for oil production. The captured CO_2 the also be used as raw material for formic acid processing, an organic substitute for inorganic acids such as hydrochloric and Sulphur acids. Certain applications include use as a basis for the processing of large quantities of calcium carbonates and sodium bicarbonates, as an accelerated plant growth supplement to greenhouses, and for soft drink carbonation. Nonetheless, these uses do not compensate for the vast amounts that need to be stored to significantly affect climate change, resulting in a need for storage [5].

Gabrielli, Gazzani and Mazzotti [6] argue that the development of a brand-new science of chemical industry, organic chemistry and catalysis that uses CO_2 as the source of carbon is required. In the interim, they suggest, the CCS route is considered as an alternative. Gabrielli, Gazzani and Mazzotti [6] further describe the possibility of decarbonizing the chemical industry, while continuing to provide the chemical products and services that are essential to our lives and activities. They note that this can be achieved in a variety of ways, one of which is CCS.

The carbon capture and storage chain

The CCS chain consists of three actions: carbon dioxide capture, carbon dioxide transfer, and carbon dioxide emissions safely deposited, underground in depleted oil and gas fields, or deep saline aquifer formations [7]. The Carbon Capture and Storage Association [7] explains that the first stage of the CCS cycle is the capture of CO_2 emitted during the burning of fossil fuels as can occur in industrial processes such as cement production, steel or chemical manufacturing. CCS technologies separate CO_2 from gases in electricity generation processes and these can be done in at least three different ways. These include capture pre-combustion, capture post-combustion, and combustion of oxy-fuel, and similar methods are also used in industrial processes. At an industrial facility, CO_2 is separated and captured, such as natural gas, oil, coal, or biomass [5].

A pre-combustion method involves first converting to a mixture of hydrogen and carbon dioxide solid, liquid, or gaseous fuel using one of a variety of processes such as 'gasification' or 'reforming'. In Post-combustion capture, CO_2 can be collected by collecting it in a suitable solvent from the exhaust of a combustion procedure.

The absorbed CO_2 is released from the solvent and compressed for conveyance and storage. Many CO_2-separation approaches include filtration of the high-pressure membrane, processes of adsorption / desorption, and cryogenic separation. During the process of combustion of oxy-fuel the necessary oxygen is removed from the air before combustion and the fuel is combusted with recycled flue-gas rather than by air. The consequence of this oxygen-rich, nitrogen-free atmosphere is final flue-gas consisting mainly of CO_2 and H_2O (water), thereby creating a more concentrated CO_2 stream for easier purification.

The carbon dioxide must then be transported to a suitable site for storage once captured. Carbon dioxide is currently transported by road tankers, ships, and pipelines for commercial purposes. The systems used in the transportation of pipelines are the same as those used widely to transport natural gas, oil, and many other fluids worldwide. In some cases, existing, but redundant, pipelines may be reusable. Once the carbon dioxide has been transported, it is stored in porous geological formations that are typically located at one to several kilometers below the earth's surface, with pressure and temperatures such that carbon dioxide will be in the liquid or in a 'supercritical phase'. Appropriate storage sites include former gas and oil fields, deep saline formations, or depleting oil fields where the carbon dioxide injected may increase the recovered oil content. Key geological characteristics sought when selecting potential storage sites include a storage reservoir, which is porous and permeable to hold the CO_2, a trapping mechanism for the stored CO_2, and a cap rock to contain the CO_2.

Deep saline aquifers show the largest potential capacity for long-term storage of carbon dioxide. The carbon dioxide is injected to the geological formation under pressure at the storage site. Once injected, the carbon dioxide moves up through the storage site until it reaches an impossible to permeate layer of rock overlaying the storage site. This storage mechanism is called "structural storage", also known as "stratigraphic trapping" and is the primary storage mechanism in CCS. Structural storage is the identical process that has maintained oil and natural gas securely trapped under the ground for millions of years providing confidence that carbon dioxide can be safely stored indefinitely in this way.

As the injected carbon dioxide moves up through the geological storage site toward the cap rock, some of it is left behind in the microscopic pore spaces of the rock. With a mechanism known as "residual storage," this carbon dioxide is tightly trapped in the pores. Over the course of time the carbon dioxide stored in a geological formation will begin to dissolve into the salty water surrounding. This makes the salty water denser and it starts sinking down to the bottom of the storage location. This is regarded as 'dissolution storage' or 'solubility trapping'. Eventually, "mineral storage" happens when the carbon dioxide stored within the storage site is chemically and irreversibly bound to the rock surrounding it. Based on the wide body of peer-reviewed research globally [5],

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for at least 10,000 years, 98 percent of the CO_2 pumped into a well-selected and controlled CCS site would remain underground.

Carbon Capture Methods

Vega, et al. [3] describe that traditional amine-based solvents used for chemical absorption have been used for CO_2 and H_2S removal for a long time and are considered by far the most developed method for CO_2 capture. Within this method, CO_2 is absorbed typically using amines to form a soluble carbonate salt. Amine-based chemical absorption can be applied to reduce carbon dioxide emissions in industrial processes such us fossil fuels power plants, cement production and iron and steel manufacturing. Vega et al. [3] further outline that primary alkanolamines such as monoethanolamine (MEA) and diglycolamine (DGA) have high chemical reactivity, preferred kinetics, medium to low absorption potential and reasonable stability. The first-generation and most well-known amine-based absorbent monoethanolamine (MEA) is highlighted by its high chemical reactivity with CO_2 and low cost.

Secondary alkanolamines such as diethanolamine (DEA) and diisopropanolamine (DIPA), which have a directly bonded hydrogen atom to nitrogen, show intermediate properties like primary amines and are considered an alternative to MEA. Alternatively, tertiary amines such as triethanolamine (TEA) or methyldiethanolamine (MDEA) have a high equivalent weight, resulting in low absorption potential, low reactivity, and high stability [3]. Sterically hindered amines are considered a category of amines that can increase the rate of absorption of CO_2 compared to typical primary and second amines, typically amino alcohols. Non-amine-based solvents are called to those chemical solvents that do not integrate a group of amines into their molecular structure. Sodium carbonate (Na_2CO_3), is the most relevant solvent proposed as an alternative to conventional amine-based solvents. Ionic liquids (ILs) provide another alternative, and these compounds are organic salts with high boiling points and therefore low vapour pressure which can selectively absorb acid gases such as CO_2 and SO_2. New generation solvents such as amino silicones, non-aqueous organic blends, amines with superbase promoters, biphasic solvents, TETA / ethanol blends, phase-change amine blends, and thermomorphic biphasic solvents based on lipophilic amines provide possible improvement in CO_2 capture.

Carbon Capture and Storage Safety

Carbon dioxide is an inert gas that exists naturally in the atmosphere, absorbed within water, or absorbed by plants and trees, which create oxygen via photosynthesis. Carbon capture and storage (CCS) requires storing CO_2 securely embedded in geological storage structures at depths greater than 800m. The CO_2 is initially trapped by structural mechanisms involving a 'cap rock' and as it mineralizes or dissolves into saline water contained within the storage reservoir, the CO_2 is further secured over time. Monitoring and verification plans are generally required prior to any injection operations that should provide detailed responses to non-routine situations, including losses and CO_2 migration, pressure reduction, and other storage markers that may indicate leakage [5].

Conclusion

As noted by the Department of Jobs, Precincts and Regions [5], capturing and safely storing CO_2 can significantly contribute to a move to a lower emissions future. The increasing implementation of CCS technologies requires ongoing workforce upskilling with focus on data analytics, robotics, and remote operations to enhance industry technological capacities [2,8]. Implementation of CCS is evolving in many countries, including Australia, and as the technology evolves, industry must gear itself with the skills and knowledge to effectively implement and use the technology. The CCS technology can play a significant role in organic chemistry industries allowing for sustainable ongoing advancement whilst minimizing environmental impacts. Further research into the human resource competencies is required to implement CCS effectively into a range of industries. Likewise, skills development needs need to be identified to facilitate the development of efficient carbon capture solvents such as amino silicones, non-aqueous organic blends, amines with superbase promoters, biphasic solvents, TETA/ethanol blends, phase change amine blends and lipophilic-amine-based thermomorphic biphasic solvents..

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