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Geosequestration John Kaldi¹

Introduction

Coal, oil and natural gas currently supply around 85% of the world's energy needs. Moreover, given the relatively low cost and abundance of fossil fuels together with the huge sunken investment in fossil-fuel based infrastructure, it is likely that fossil fuels will continue to be used for at least the next 25 to 50 years. The burning of fossil fuels is, however, the major source of anthropogenic (man-made) carbon dioxide (CO₂). CO₂ is the main «greenhouse» gas released to the atmosphere. One promising means by which to reduce anthropogenic CO₂ emissions, and so the atmospheric buildup of CO₂, is geosequestration. Geosequestration, also known as carbon capture and storage (CCS), involves the long-term storage of captured CO₂ emissions in deep subsurface geologic reservoirs. Carbon sequestration can be pursued as part of a portfolio of greenhouse gas abatement options, where this portfolio also includes improving the conservation and efficiency of energy use and utilising non-fossil energy forms such as renewable (solar, wind, tidal) and nuclear energy.

Geosequestration comprises a number of steps: first, the CO₂ is captured at the source, where this can be a power plant or other industrial facility; the captured CO₂ is then transported, typically via pipeline, from the source to the geologic storage site; next, the CO₂ is injected deep underground via wells into the geologic reservoir; and, finally, the CO₂ is stored in the geologic

reservoir, where its movement is carefully monitored and the quantity stored is regularly verified.

CO₂ capture

CO₂ capture can be carried out at point (stationary) source of CO₂ such as a power plant. It involves trapping, or «capturing», the produced CO₂ rather than allowing it to be released to the atmosphere. This captured CO₂ is then compressed to make it more dense and so easier, and less costly, to transport to the geologic storage site.

Anthropogenic CO₂ that can be captured is produced by three main types of activity: industrial processes, electricity generation, and hydrogen (H₂) production. Industrial processes that lend themselves to CO₂ capture include natural gas processing, ammonia production and cement manufacture. It is to be noted however that the total quantity of CO₂ produced by these processes is limited. A far larger source, accounting for one-third of total CO₂ emissions, is fossil-fuelled power production. The types of power plants that are best suited to CO₂ capture are pulverized coal (PC), natural gas combined cycle (NGCC) and integrated coal gasification combined cycle (IGCC) plants. Finally, a potentially large future source of CO₂ for capture will be H₂ production, where the produced H₂ is used to fuel a hydrogen economy i.e., is used in turbines to produce electricity and in fuel cells to power cars. Technologies for capturing CO₂ from electricity generation fall into two general categories: post-combustion and pre-combustion.

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- **Post-combustion:** Currently, the most widely used post-combustion technology for CO₂ capture is chemical absorption. This capture process involves the flue gas being blown through a solvent such as monoethanolamine (MEA) in an absorption column and the CO₂ in the flue gas being absorbed in the MEA solvent by formation of a chemically bonded compound. A very similar process using MEA has been used for decades to remove acid gases, such as CO₂ and hydrogen sulphide (H₂S), from natural gas streams. Chemical absorption is most likely to be used for pulverised coal (PC) and natural gas combined cycle (NGCC) power plants.
- **Pre-combustion:** In the case of integrated gasification combined cycle (IGCC) plants, it would be possible to utilise the pre-combustion CO₂ capture method of physical absorption. This capture method involves gasifying the coal to produce a synthetic gas (syngas) composed of carbon monoxide (CO) and hydrogen (H₂). The CO is reacted with water to produce CO₂ and H₂, and the H₂ is sent to a turbine to produce electricity. CO₂ is captured by means of dissolving it in a physical solvent such as methanol. A number of IGCC and coal gasification facilities exist world-wide to produce syngas and various other by-products. One such example of a gasification facility is an ammonia manufacturing plant.

While the capture of CO₂ for carbon geosequestration is a relatively new concept, CO₂ capture for commercial markets has been practised here in Australia as well as overseas for many years. In Australia, CO₂ capture for commercial markets occurs at natural gas wells and ammonia manufacturing plants. The captured CO₂ is used for various commercial processes including carbonation of beverages and dry ice production. In the United States, CO₂ capture at power plants using chemical absorption based on the monoethanolamine (MEA) solvent has been practised at some plants since the late 1970s, with the captured CO₂ being used for enhanced oil recovery (EOR).

There are also now plans in the United States to build the world's first IGCC plant that will not only produce electricity but also hydrogen fuel, with the CO₂ generated in the process being captured and sequestered underground.

CO₂ transport

CO₂ transport involves moving, or «transporting», the captured CO₂ from the CO₂ point source to the geologic storage site. The CO₂ is typically transported in a compressed form via pipeline, although the CO₂ could also be transported by truck, rail or, in the case of a geologic storage site located offshore, ocean tanker.

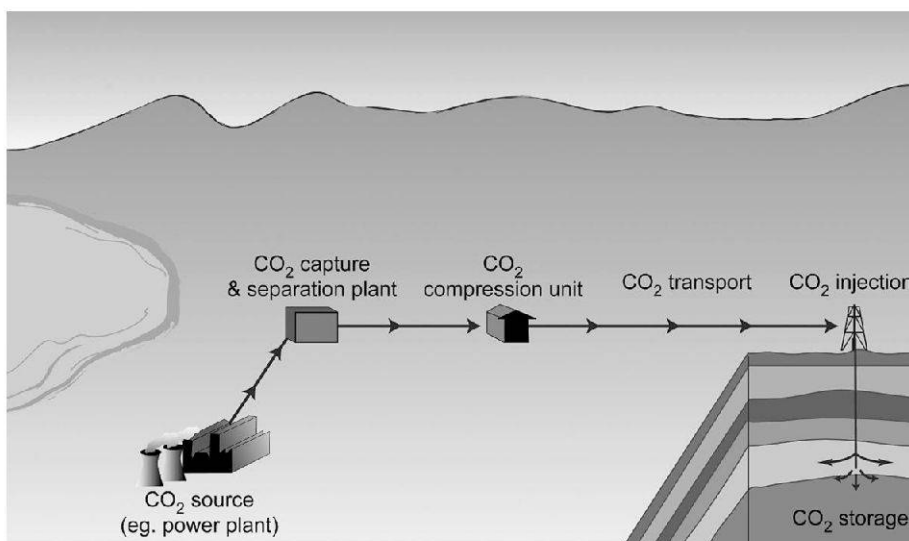


Fig. 1: A simplified view of the steps involved in the geosequestration process. Image courtesy of CO₂CRC.

Transport via pipeline: CO₂ is transported via pipeline as a supercritical or dense phase fluid. Above the critical point, which occurs at a temperature of 31.4°C and a pressure of 7.38 MPa, CO₂ exists in the supercritical/dense phase. CO₂ in this phase has a significantly higher density than either gaseous or liquid CO₂. Transporting the CO₂ in this phase, and also at higher density, has significant economic benefits. The transport of CO₂ by pipeline already occurs quite extensively in the United States as well as, to a smaller extent, in other countries where CO₂ is used for enhanced oil recovery (EOR) operations. In the United States, there are some 2,400 km of CO₂ pipelines to supply 72 EOR projects using CO₂ floods. Many of these pipelines have been in operation since the early 1980s. Most of the transported CO₂ is obtained from

high-pressure, high-purity natural underground deposits, with a small percentage of the CO₂ from anthropogenic sources. The longest and one of the most significant CO₂ pipelines currently in operation is the Weyburn Pipeline, which is 325 km in length and transports 2.7 million m³ of CO₂ per day from the Great Plains Synfuels plant in North Dakota, USA, to the Weyburn CO₂-enhanced oil recovery project in Saskatchewan, Canada.

CO₂ injection

CO₂ injection involves taking the CO₂ from the surface and putting, or «injecting», it deep underground into a reservoir rock. The CO₂ is injected into the reservoir via a single well or array of wells. Both enhanced oil recovery (EOR) using CO₂ floods and acid

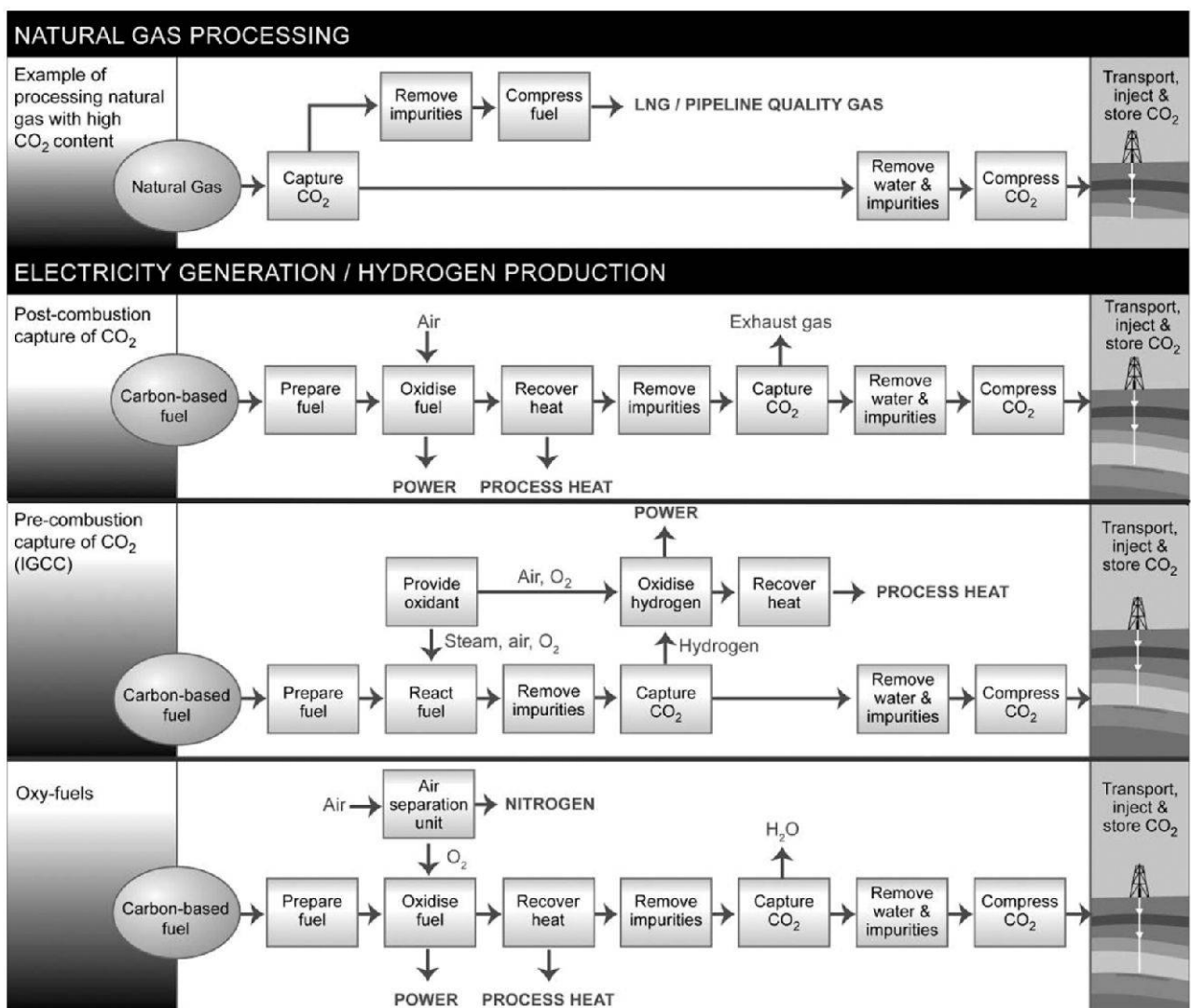


Fig. 2: Overview of carbon dioxide capture processes. Image courtesy of CO2CRC.

gas injection (AGI) are mature technologies that involve significant quantities of CO₂ being injected underground and are therefore very good analogues for CO₂ injection as part of geosequestration activities. The first project using CO₂ for EOR began in 1972 and by 2000, there were 84 operational projects worldwide (72 in the United States) injecting an estimated total of more than 15 million tonnes of CO₂ per year. In the case of AGI, the first project came online in 1989 and in 2001, over 360,000 tonnes of acid gas, around 90% of which is CO₂, was injected into geologic reservoirs at more than 30 different locations across western Canada.

CO₂ storage

CO₂ storage involves keeping the CO₂ secured deep underground in a geologic reservoir. In addition to the careful selection of the subsurface formation, a comprehensive monitoring system needs to be put in place to ensure that the CO₂ remains in the subsurface.

The main geological constraints for finding the «right» place to store CO₂ include: a reservoir rock, a trap, and an impermeable caprock. The reservoir rock needs to be porous and permeable. Porosity is a volumetric measurement of the percentage of pore space in a rock that is available for storage. Permeability is the fluid transmissibility of the rock, and is important to allow the injection of CO₂, and its subsequent dissemination into the pore system of the reservoir rock.

Since the stored CO₂ is less dense than the formation water, it will naturally rise to the top of the reservoir, and a trap is needed to ensure that it does not reach the surface. CO₂ can be trapped by a number of different mechanisms, with the exact mechanism depending on the formation type. The most common traps are structural (anticlinal or fault juxtaposition), stratigraphic (pinchout of reservoir rock against non-reservoir) or hydrodynamic (CO₂ is entrained in the groundwater flow and is constrained above

and below by impermeable seal lithologies). Two other important trapping mechanisms are solubility and mineral trapping. Solubility trapping involves the dissolution of CO₂ into the reservoir fluids, while mineral trapping involves the reaction of CO₂ with minerals present in the host formation to form stable, solid compounds such as carbonates. As the CO₂ moves through the reservoir along the flow path, a proportion of the CO₂ dissolves in the formation water and some of this dissolved CO₂ becomes permanently fixed by reactions with minerals in the host rock. If the flow path is long enough, the CO₂ might dissolve completely or become fixed by mineral reactions before it reaches the basin margin, essentially becoming permanently trapped in the reservoir.

A caprock is required to seal the CO₂ within the trap. Caprocks are generally very fine grained rocks with low porosity and, even more importantly, low permeability. The caprock must be of sufficient thickness and ductility to prevent microfractures and through-going faults from developing as possible CO₂ leakage pathways.

Obviously, active and depleted oil and natural gas fields, which generally have proven geologic traps, reservoirs and seals are ideal sites for storage of injected CO₂. In such fields, it is important to ensure that hydrocarbon resources do not occur or have already been produced from the specific target formation. Also, care must be taken that all existing wellbores are adequately cemented (to prevent CO₂ reflux) before sequestration operations begin.

Monitoring

Monitoring of the activities of stored CO₂ includes petrophysical, seismic, and surface geochemical methodologies. Wellbore properties such as pressure, temperature, resistivity and sonic responses will be recorded in injection and observation wells. Seismic monitoring, using an array of methodologies, will allow tracking of movement of CO₂

in the subsurface. Geochemical sampling at surface localities will allow rapid detection of any seepage or leakage in the unlikely circumstance that this should occur.

Existing CO₂ Sequestration programs

The first commercial-scale project dedicated to CO₂ storage in a geologic reservoir has been in operation at the Sleipner West Field since 1996. Sleipner West is a natural gas field operated by Statoil and located in the North Sea about 250 km off the coast of Norway. The natural gas produced at the field has a CO₂ content of about 9% that, in order to meet commercial gas specifications, must be reduced to 2.5%. It has been standard practice in natural gas production for the by-product CO₂ to be vented to the atmosphere. At Sleipner, however, the CO₂ is compressed and injected via a single well into the Utsira Formation, a 250 m-thick, brine-saturated sandstone located at a depth of

800 m below the seabed. About one million tonnes of CO₂ has been injected annually at Sleipner since operations began in October 1996, with a total of 20 million tonnes of CO₂ expected to be sequestered over the lifetime of the project.

CO₂ Sequestration Sites in Australia

An Australia-wide study of sedimentary basins conducted over the past five years has assessed 100 sites for the suitability for the safe, long-term storage of CO₂. The majority of these sites were found to be potentially suitable. Ideally, these areas have reservoir rocks such as porous and permeable sandstones that are overlain by caprock seals of non-permeable rocks such as shale. A detailed evaluation at these and other sites to determine the most suitable areas for geosequestration is underway. Areas being evaluated in detail include the Sydney Basin in NSW; Central and South-

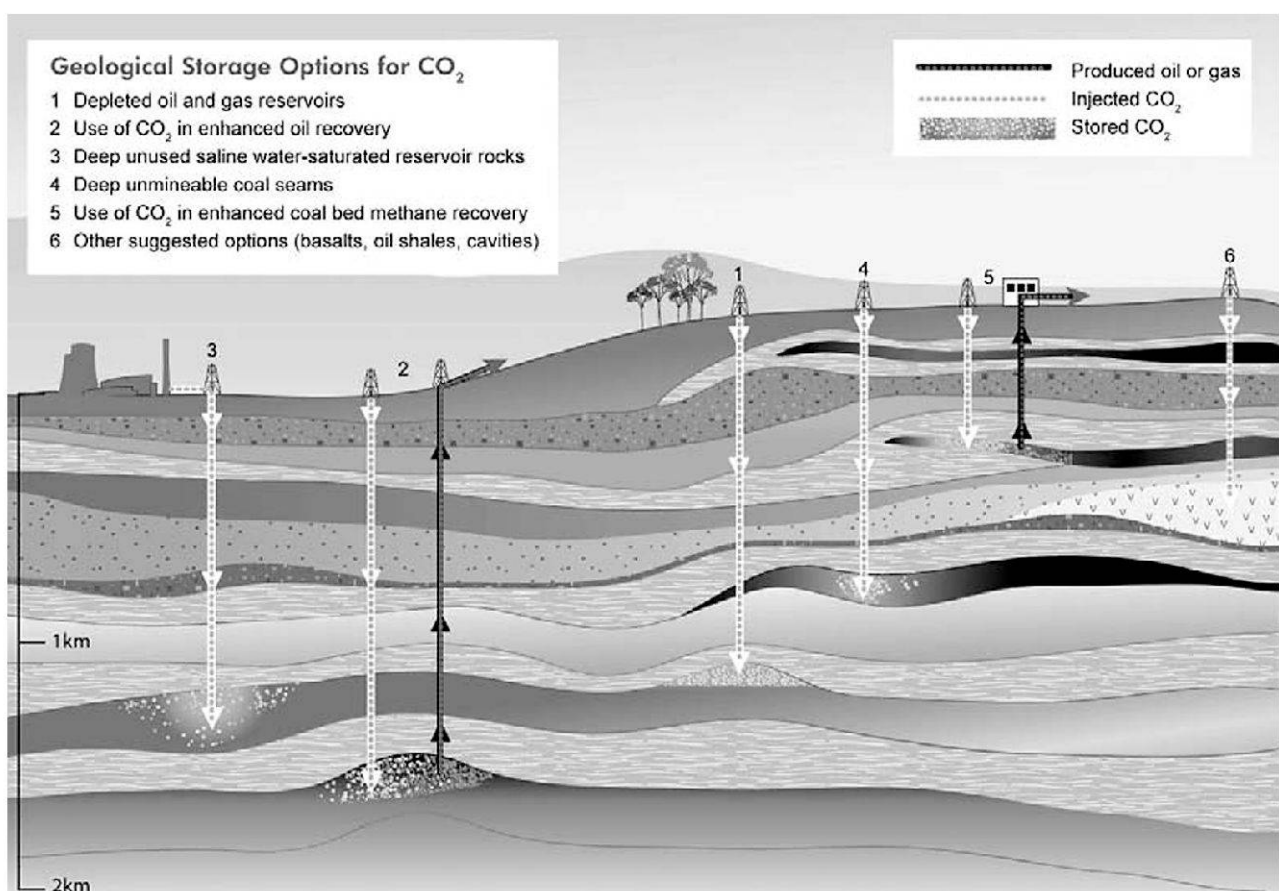


Fig. 3: CO₂ storage options. Image courtesy of CO2CRC.

East Queensland; the Perth Basin in Western Australia; and the Otway Basin spanning southern Victoria and into the Southern Ocean.

Risks

Concerns surrounding CO₂ geosequestration relate to the potential for unanticipated CO₂ leakage as well as the possibility of induced seismicity and CO₂ migration. The risks associated with CO₂ storage, although considered very low, are characterised by a greater degree of uncertainty than those connected with CO₂ transport and injection. This is first due to the fact that once the CO₂ enters the geologic reservoir, its fate is transferred from largely human control to a natural system. Second, unlike for CO₂ transport and injection, enhanced oil recovery (EOR) using CO₂ floods and acid gas injection (AGI) do not provide a great level of understanding or expertise in safe and effective management of CO₂ storage; the quantities of CO₂ stored are smaller and the time periods involved are shorter than required for carbon geosequestration. Through the

development of improved models of the long-term behavior of CO₂ in reservoirs and the study of analogs such as natural CO₂ deposits, scientists are however gaining a better understanding and further minimizing the risks of CO₂ storage.

It is highly unlikely that any geologic CO₂ storage project would result in a catastrophic release of CO₂. A common misconception is that an accidental leak from a CO₂ storage site could lead to an event analogous to the type that occurred in 1986 at Lake Nyos, Cameroon. The slow accumulation of CO₂ in this volcanic lake came to exceed the lake's finite capacity to contain the gaseous buildup and the vented CO₂ was not able to diffuse to safe levels before it reached nearby populated areas. There are two major reasons why this type of catastrophic release of CO₂ is unlikely to be repeated at a CO₂ storage site.

First, while the forces acting within Lake Nyos tended to cause a CO₂ pressure buildup, the pressure of CO₂ injected into a geologic reservoir should be reduced as it moves away from the injection well and is diffused over large areas of the formation. Second, Lake

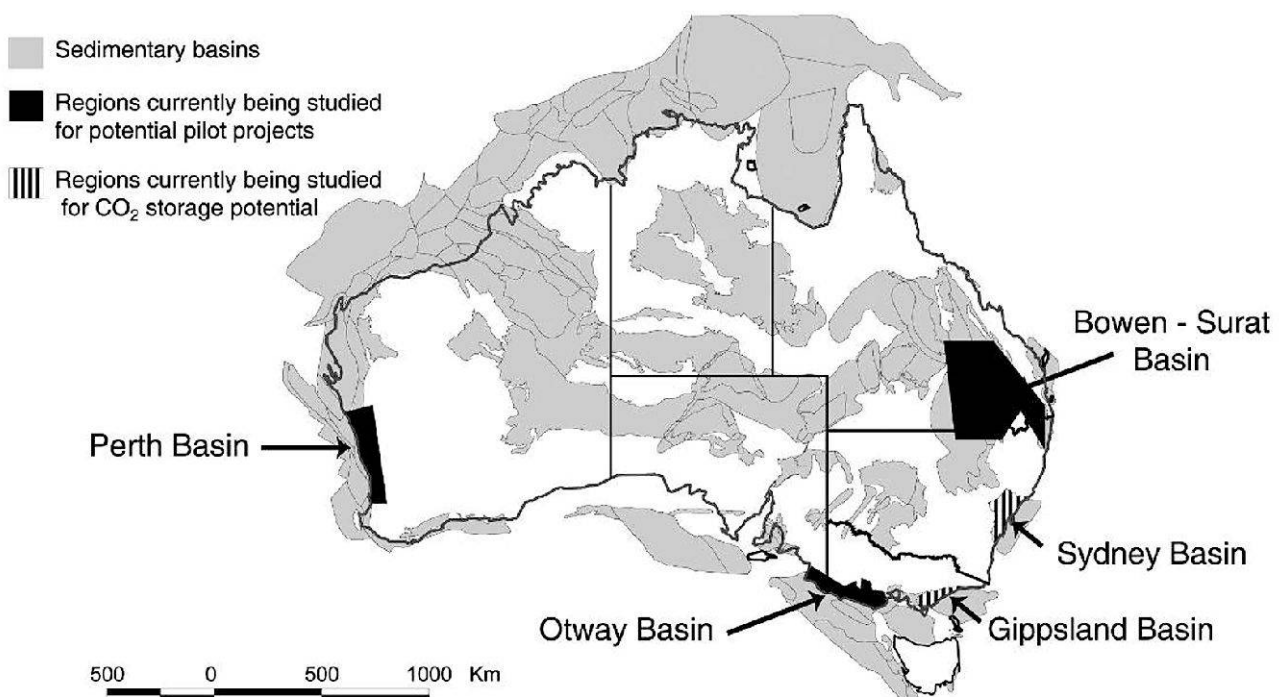


Fig. 4: Regions currently being studied for potential pilot projects or for determination of likely CO₂ storage potential. Image courtesy of CO₂CRC.

Nyos is located in mountainous terrain whereas any geographical setting that might allow CO₂ to accumulate in low-lying areas would in general be avoided for a CO₂ storage project. Finally, it is to be noted that there is no record of a catastrophic CO₂ release from a natural CO₂ deposit and such a release from a CO₂ storage project should be able to be prevented through careful site selection, operation and monitoring.

It is not expected that induced seismicity will be a significant problem at geologic CO₂ storage sites. Induced seismicity has been documented in enhanced oil recovery (EOR), acid gas injection (AGI), natural gas storage and waste injection operations. These induced seismic events have been caused by poor engineering practices such as the injection of the CO₂ at too high pressure, which in turn can result in microfracturing of the reservoir rock and/or small movement along existing fracture lines. It is to be noted however that most of the recorded events have been of a very small magnitude and have caused no harm. Moreover, the risk of induced seismicity can be reduced through careful siting and placement of injection wells, adherence to proper pressure guidelines and a sound understanding of the geomechanical properties of the storage reservoir.

Summary

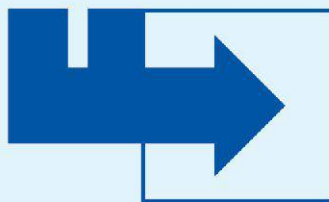
- Geosequestration could play a significant role in any portfolio of options for CO₂ emissions reduction.
- By reducing CO₂ emissions while still allowing for the continued use of fossil fuels, carbon geosequestration allows time for the transition to renewable energy sources from fossil fuels.

- Effective geosequestration of CO₂ involves: capture of CO₂ at stationary source locations; transportation of CO₂ from the source to the geological storage site; injection of CO₂ into subsurface reservoirs; storage of CO₂ in the subsurface; restoration of geosequestration sites; and effective monitoring and verification of CO₂ storage.
- Geosequestration sites ideally have simple geology. This means they should have no active faults, to avoid movement and leakage; the right sort of porous and permeable rocks to allow the injection and absorption of the CO₂ and the necessary rocks and geometries to trap the CO₂.
- Given the large number of known geologic formations suitable for geosequestration, the opportunity exists for significant volumes of CO₂ storage in Australia.
- Much of the technology needed for carbon geosequestration projects is already at quite an advanced stage of development.
- Geosequestration research will lead to the establishment over the next four years of one or more geosequestration pilot projects in Australia.

Acknowledgment

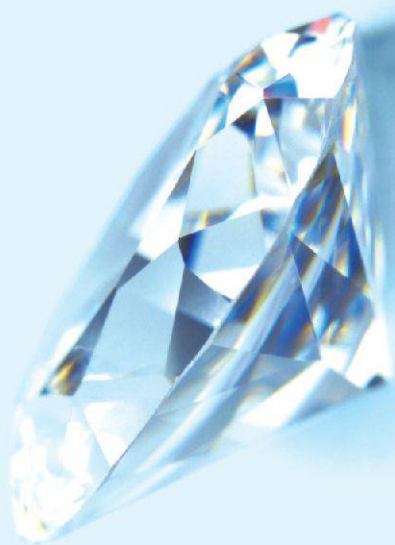
The point of this article is not to debate the issues of renewable energy versus fossil fuels, or the effects of greenhouse gases on global warming or climate or the environment. The reason for submitting this piece is to help provide geoscientists, who are likely as not to find themselves involved in public and/or private debates and discussions on the topic of geosequestration, with some basic information on the main issues involved in this timely and possibly poorly understood topic. In this piece I have blatantly and unabashedly used the work of many researchers from the CO₂CRC and its precursor the GEODISC Program of the APCRC. To these able colleagues, I give full credit for the details of the science; any errors are, of course, mine.

For further information on geosequestration, please refer to www.co2crc.com.au

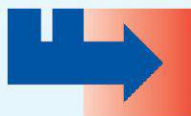


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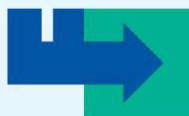
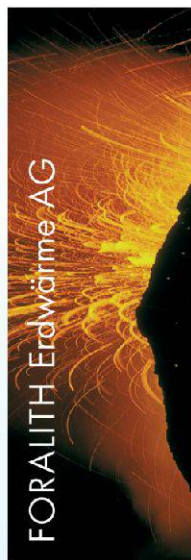
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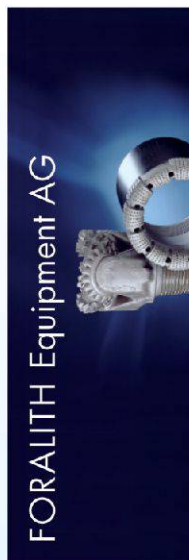
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