Geosequestration of CO2 : A key strategy for the sustainability of the energy industries

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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 (CO_2). CO_2 is the main "greenhouse" gas released to the atmosphere.

One promising means by which to reduce anthropogenic CO_2 emissions, and so the atmospheric buildup of $CO_{2,}$ is geosequestration. Geosequestration, also known as carbon capture and storage (CCS), involves the long-term storage of captured CO_2 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 CO_2 is captured at the source, where this can be a power plant or other industrial facility; the captured CO_2 is then transported, typically via pipeline, from the source to the geologic storage site; next, the CO_2 is injected deep underground via wells into the geologic reservoir; and, finally, the CO_2 is stored in the geologic reservoir, where its movement is carefully monitored and the quantity stored is regularly verified.

CO_2 capture

CO_2 capture can be carried out at point (stationary) source of CO_2 such as a power plant. It involves trapping, or "capturing', the produced CO_2 rather than allowing it to be released to the atmosphere. This captured CO_2 is then compressed to make it more dense and so easier, and less costly, to transport to the geologic storage site.

Anthropogenic CO_2 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 CO_2 capture include natural gas processing, ammonia production and cement manufacture. It is to be noted however that the total quantity of CO_2 produced by these processes is limited. A far larger source, accounting for one-third of total CO_2 emissions, is fossil-fuelled power production. The types of power plants that are best suited to CO_2 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 CO_2 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.

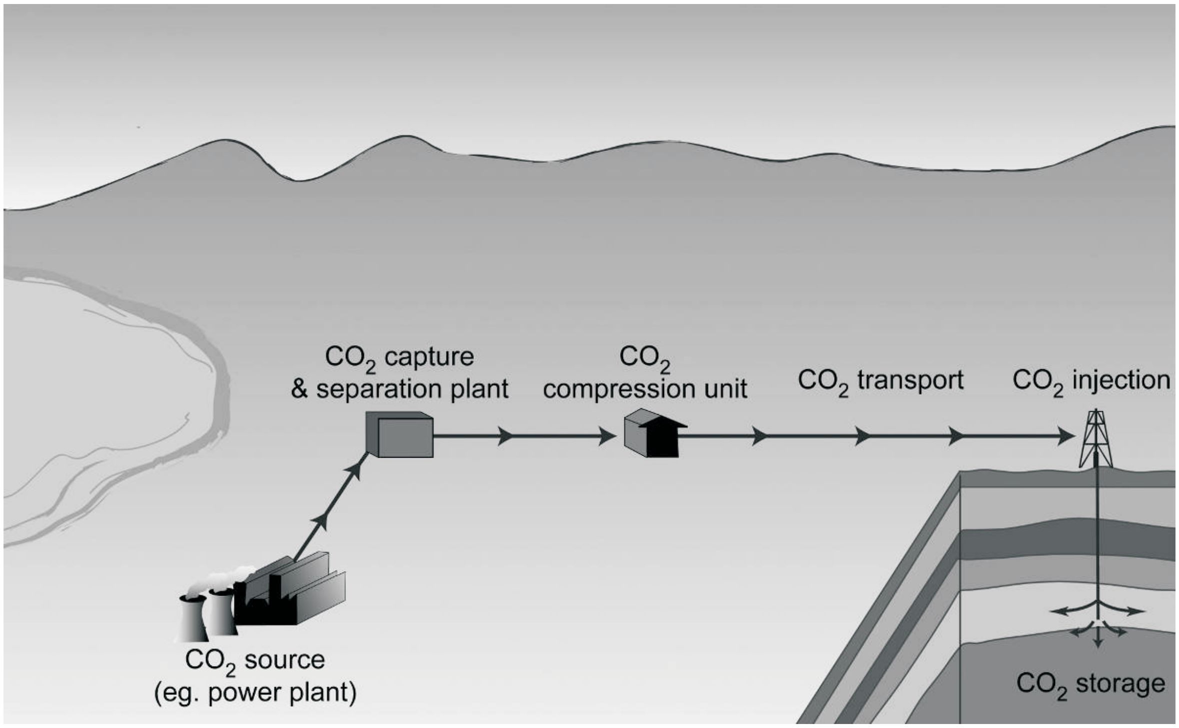

Figure 1- A simplified view of the steps involved in the geosequestration process. Image courtesy of CO2CRC.

Technologies for capturing CO_2 from electricity generation fall into two general categories: post-combustion and pre-combustion.

–Post-combustion

Currently, the most widely used post-combustion technology for CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 and H2, and the H2 is sent to a turbine to produce electricity. CO_2 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 CO_2 for carbon geosequestration is a relatively new concept, CO_2 capture for commercial markets has been practised here in Australia as well as overseas for many years. In Australia, CO_2 capture for commercial markets occurs at natural gas wells and ammonia manufacturing plants. The captured CO_2 is used for various commercial processes including carbonation of beverages and dry ice production. In the United States, CO_2 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 CO_2 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 CO_2 generated in the process being captured and sequestered underground.

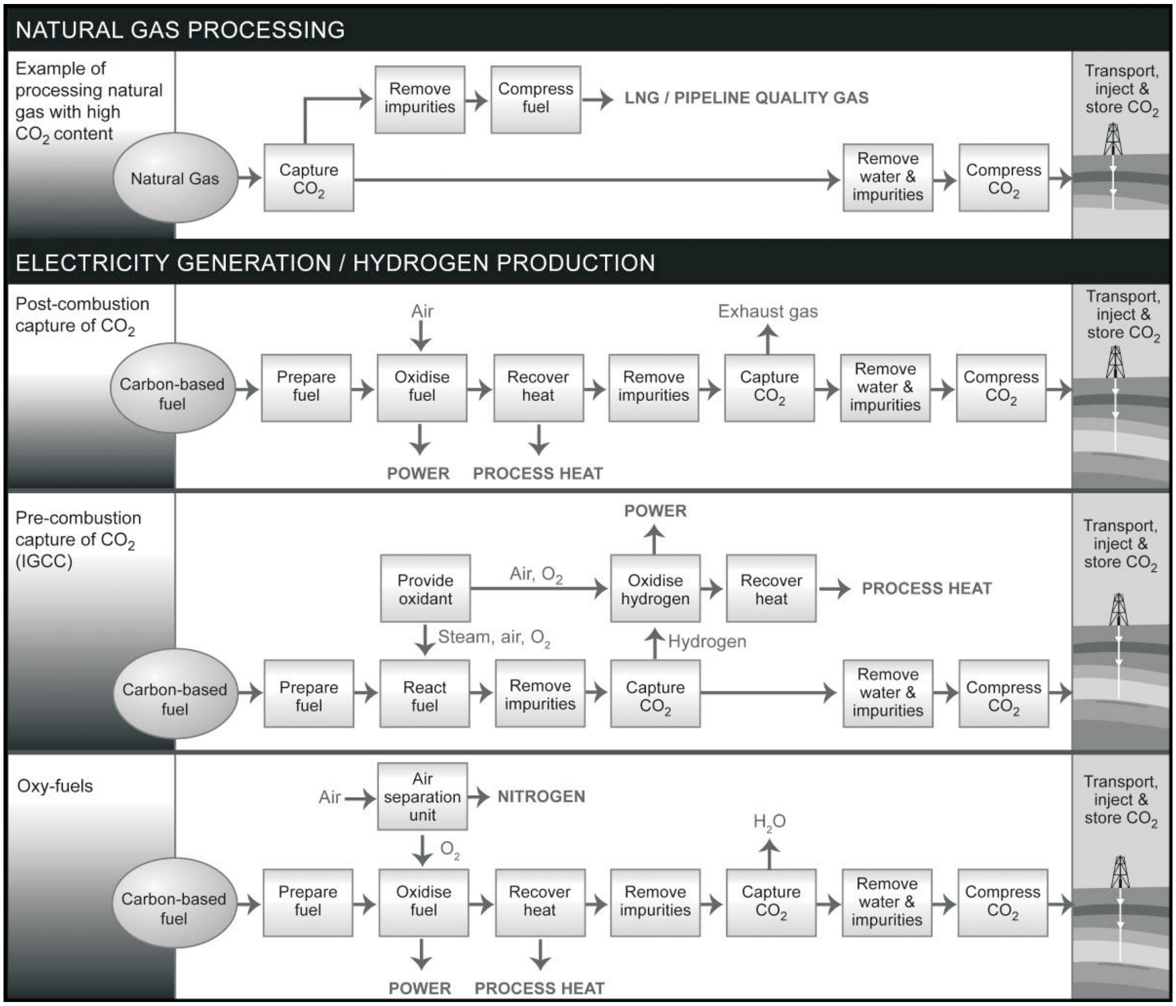

Figure 2 - Overview of carbon dioxide capture processes. Image courtesy of CO2CRC.

CO_2 transport

CO_2 transport involves moving, or "transporting", the captured CO_2 from the CO_2 point source to the geologic storage site. The CO_2 is typically transported in a compressed form via pipeline, although the CO_2 could also be transported by truck, rail or, in the case of a geologic storage site located offshore, ocean tanker.

-Transport via pipeline

CO_2 is transported via pipeline as a supercritical or dense phase fluid. Above the critical point, which occurs at a temperature of 31.4ºC and a pressure of 7.38 MPa, CO_2 exists in the supercritical/dense phase. CO_2 in this phase has a significantly higher density than either gaseous or liquid CO_2. Transporting the CO_2 in this phase, and also at higher density, has significant economic benefits.

The transport of CO_2 by pipeline already occurs quite extensively in the United States as well as, to a smaller extent, in other countries where CO_2 is used for enhanced oil recovery (EOR) operations. In the United States, there are some 2,400 km of CO_2 pipelines to supply 72 EOR projects using CO_2 floods. Many of these pipelines have been in operation since the early 1980s. Most of the transported CO_2 is obtained from high-pressure, high-purity natural underground deposits, with a small percentage of the CO_2 from anthropogenic sources. The longest and one of the most significant CO_2 pipelines currently in operation is the Weyburn Pipeline, which is 325 km in length and transports 2.7 million m^3 of CO_2 per day from the Great Plains Synfuels plant in North Dakota, USA, to the Weyburn CO_2-enhanced oil recovery project in Saskatchewan, Canada.

CO_2 injection

CO_2 injection involves taking the CO_2 from the surface and putting, or "injecting", it deep underground into a reservoir rock. The CO_2 is injected into the reservoir via a single well or array of wells. Both enhanced oil recovery (EOR) using CO_2 floods and acid gas injection (AGI) are mature technologies that involve significant quantities of CO_2 being injected underground and are therefore very good analogues for CO_2 injection as part of geosequestration activities. The first project using CO_2 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 CO_2 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 CO_2, was injected into geologic reservoirs at more than 30 different locations across western Canada.

CO_2 storage

CO_2 storage involves keeping the CO_2 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 CO_2 remains in the subsurface.

The main geological constraints for finding the "right" place to store CO_2 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 CO_2, and its subsequent dissemination into the pore system of the reservoir rock.

Since the stored CO_2 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. CO_2 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 (CO_2 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 CO_2 into the reservoir fluids, while mineral trapping involves the reaction of CO_2 with minerals present in the host formation to form stable, solid compounds such as carbonates. As the CO_2 moves through the reservoir along the flow path, a proportion of the CO_2 dissolves in the formation water and some of this dissolved CO_2 becomes permanently fixed by reactions with minerals in the host rock. If the flow path is long enough, the CO_2 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 CO_2 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 CO_2 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 CO_2. 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 CO_2 reflux) before sequestration operations begin.

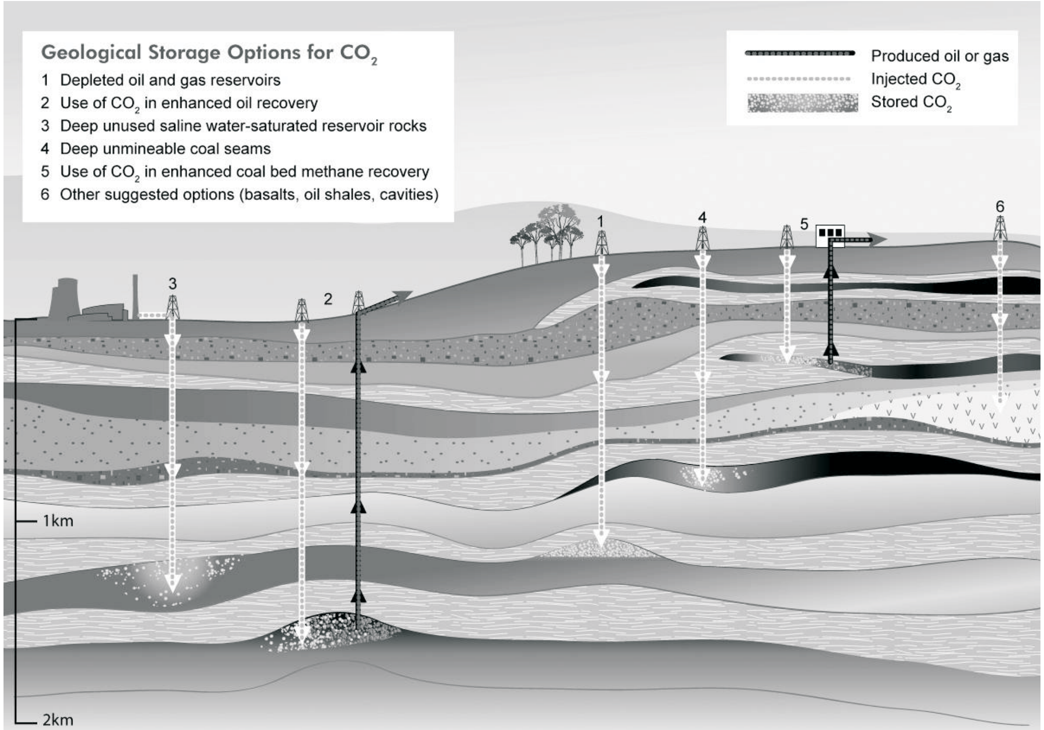

Figure 3 – CO_2 storage options. Image courtesy of CO2CRC.

Monitoring

Monitoring of the activities of stored CO_2 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 CO_2 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 CO_2 sequestration programs

The first commercial-scale project dedicated to CO_2 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 CO_2 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 CO_2 to be vented to the atmosphere. At Sleipner, however, the CO_2 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 CO_2 has been injected annually at Sleipner since operations began in October 1996, with a total of 20 million tonnes of CO_2 expected to be sequestered over the lifetime of the project.

CO_2 sequestration sites in Australia

An Australia-wide study of sedimentary basins conducted over the past five years has assessed close to 100 sites for their suitability for safe, long-term storage of CO_2.

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

Risks

Concerns surrounding CO_2 geosequestration relate to the potential for unanticipated CO_2 leakage as well as the possibility of induced seismicity and CO_2 migration. The risks associated with CO_2 storage, although considered very low, are characterised by a greater degree of uncertainty than those connected with CO_2 transport and injection. This is first due to the fact that once the CO_2 enters the geologic reservoir its fate is transferred from largely human control to a natural system. Second, unlike for CO_2 transport and injection, enhanced oil recovery (EOR) using CO_2 floods and acid gas injection (AGI) do not provide a great level of understanding or expertise in safe and effective management of CO_2 storage; the quantities of CO_2 stored in these methodologies are smaller and the time periods involved are shorter than required for large-scale carbon geosequestration. Through the development of improved models of the long-term behavior of CO_2 in reservoirs and the study of analogs such as natural CO_2 deposits, geosequestration scientists are gaining a better understanding and further minimizing the risks of CO_2 storage.

It is highly unlikely that any geologic CO_2 storage project would result in a catastrophic release of CO_2. A common misconception is that an accidental leak from a CO_2 storage site could lead to an event analogous to the type that occurred in 1986 at Lake Nyos, Cameroon. The slow accumulation of CO_2 in this volcanic lake came to exceed the lake's finite capacity to contain the gaseous buildup and the vented CO_2 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 CO_2 is unlikely to be repeated at a CO_2 storage site. First, while the forces acting within Lake Nyos tended to cause a CO_2 pressure buildup, the pressure of CO_2 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 Nyos is located in mountainous terrain whereas any geographical setting that might allow CO_2 to accumulate in low-lying areas would in general be avoided for a CO_2 storage project. Finally, it is to be noted that there

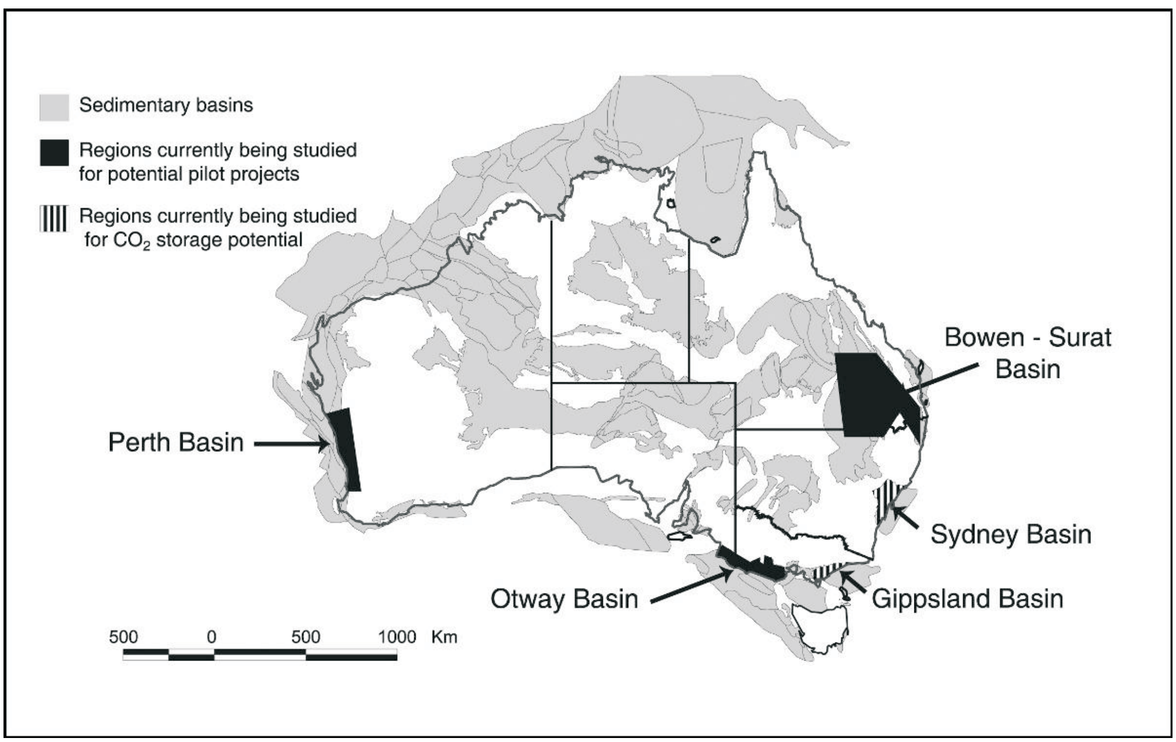

Figure 4 – Regions currently being studied for potential pilot projects or for determination of likely CO_2 storage potential. Image courtesy of CO2CRC.

is no record of a catastrophic CO_2 release from a natural CO_2 deposit and such a release from a CO_2 storage project should be able to prevented through careful site selection, operation and monitoring.

It is not expected that induced seismicity will be a significant problem at geologic CO_2 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 CO_2 at too high a 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 CO_2 emissions reduction
- By reducing CO_2 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 CO_2 involves: capture of CO_2 at stationary source locations; transportation of CO_2 from the source to the geological storage site; injection of CO_2 into subsurface reservoirs; storage of CO_2 in the subsurface; restoration of geosequestration sites; and effective monitoring and verification of CO_2 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 absorbtion of the CO_2 and the necessary rocks and geometries to trap the CO_2.
- Given the large number of known geologic formations suitable for geosequestration, the opportunity exists for significant volumes of CO_2 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 technical and managerial individuals, 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

Speaker

Dr John Kaldi obtained his Bachelor's and Master's degrees from City University of New York and Ph. D from Cambridge University, England. He has worked with Saskatchewan Geological Survey in Regina, Shell Canada in Calgary, with ARCO Oil & Gas in Texas, USA & in Jakarta, and with VICO Indonesia as chief geologist. He became Director of the National Centre for Petroleum Geology and Geophysics at University of Adelaide, Australia in 1998 and then the Inaugural Head of the Australian School of Petroleum, at the University of Adelaide. He currently, he holds the prestigious chair of Geosequestration.

Dr Kaldi is the present Chair of the AAPG International Regions Committee, Past-President of AAPG Asia Pacific Region, and a Delegate to the AAPG House of Delegates. Dr Kaldi received AAPG's Special Commendation Award for Significant Contributions to Petroleum Geology in 1997 and has just been announced as recipient of the 2006 AAPG Distinguished Service Award.

Dr Kaldi has recently retired as a South Australian State Soccer Referee and is now pursuing his sporting glories as an over-the-hill squash player!