House of Representatives Science and Innovation Committee

Inquiry into Geosequestration

CO2CRC submission by

Dr Peter J. Cook CBE, FTSE

Chief Executive

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

CO2CRC

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CO2CRC

CRC for Greenhouse Gas Technologies

Core Research Participants

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University of New South Wales

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Summary

This submission is provided by the Cooperative Research Centre on Greenhouse Gas Technologies (CO2CRC), a world leader in geosequestration research, and in the development and demonstration of key CO_2 technologies.

CO_2 can be captured from flue gases using a range of pre- and post-combustion systems and a variety of separation techniques (solvents, membranes). But application of these techniques to stationary sources such as power stations is expensive (currently 70-80% of the total cost of geosequestration). Therefore, research by CO2CRC and other organisations in Australia and overseas is focused on bringing down these costs. In the case of geological storage, the technology is more mature and cost is less of an issue, but it is important is to demonstrate to the community that geological storage is safe and effective.

Geosequestration has the potential to enable us to make deep cuts in CO_2 from stationary emissions. Given that the IEA considers there will be an increasing use of fossil fuels in the future, geosequestration will be an essential component of the global mitigation strategy. Australia is fortunate in having abundant coal and gas resources and extensive geological storage opportunities; it is therefore well-positioned to include geosequestration in its portfolio of low-emission technologies.

Geosequestration will benefit the environment, but there will be an increase in the cost of electricity. CO2CRC and others have a target for geosequestration of A$20/tonne CO_2 avoided, compared to A$50/tonne or more at present for CO_2 capture a conventional coal-fired power station. There are some lower-cost opportunities relating to high-purity streams and these should be used to encourage early implementation of geosequestration wherever possible. Modelling by CO2CRC suggests that we need a target of commencing comprehensive implementation of geosequestration by 2015, if we are to contribute to meeting a global atmospheric target of 550 parts per million CO_2 by 2100.

Whilst it is impossible to express 100% certainty about any natural or engineered system, the risk arising from a geosequestration project is seen as very low – comparable to many other industrial and resource operations that are accepted as quite "routine" by the community. Similarly, the rate of leakage is expected to be very small (of the order of 1% or less leakage of total stored CO_2 over 1000 years). Nonetheless, it is important to have effective monitoring and verification in place to assure the local community and the public at large that there is no significant leakage.

Geosequestration is underway at various locations around the world, mostly related to oil or gas projects. A number of coal-based projects are proposed. In Australia, the Gorgon Project is expected to be the first commercial project using geosequestration on a large scale. The CO2CRC has a demonstration storage project underway in the Otway Basin of southwest Victoria, with injection of CO_2 planned to commence in 2007. The proposed ZeroGen project in Queensland and the Monash coal-to-liquids project in Victoria could involve major geosequestration activity. The Government's LETDF scheme is likely to encourage a number of other significant geosequestration projects over the next five years.

There is a skill base shortage in the area of geosequestration, both because it is a new topic and because its core skills are the same skill set that is sought by a booming resource sector. The skill shortage is also a reflection of the general difficulty of attracting Australian university students to science and engineering courses. Action is needed to address the skill shortages. At the same time there is an urgent need to start to train scientists from countries such as India and China that have a need to take steps to limit their rapidly growing greenhouse gas emissions.

A "geosequestration business" is starting to develop, which represents an opportunity for Australia in terms of the provision of advice and services. However, the main commercial benefit to Australia from geosequestration will arise from the decrease of up to 30% in mitigation costs that could result from its inclusion in Australia's portfolio of greenhouse gas measures.

1. Background to the Submission

This Submission is provided by Dr Peter J Cook, Chief Executive, on behalf of the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC). The CO2CRC was established in October 2003 under the Government's Cooperative Research Centre Scheme. It has built its programs on the earlier activities of the Australian Petroleum Cooperative Research Centre (APCRC) which commenced the GEODISC program in 1999, Australia's first research program focused on geosequestration.

CO2CRC brings together the collective skills and experience of a large number of companies, universities, research bodies and government departments, primarily based in Australia, but including New Zealand and other overseas organisations and a number of major international companies. Its industry base is primarily oil and gas, coal and power companies and its skill base rests on geoscience, engineering and economics. Through these skills, CO2CRC undertakes research and development activities on the capture and geological storage of CO_2 and has embarked on a major demonstration project. It is extensively involved in international geosequestration activities and also has major activities underway in communications, education and training. CO2CRC also has a commercial arm (Innovative Carbon Technologies Pty Ltd) which holds Centre intellectual property and carries out a range of consulting activities in Australia, New Zealand and internationally. CO2CRC brings together more than 100 researchers and support staff from Australian and New Zealand organisations and collaborates with many other researchers in Canada, the USA, the European Union, Japan and China.

The CO2CRC has as its Core Industry/User Participants Anglo Coal, Australian Coal Association Research Program, BHP Billiton, BP Developments Australia, Chevron, Department of Primary Industries – Victoria, New Zealand Resource Consortium, Origin Energy, Rio Tinto, Solid Energy, Stanwell Corporation, Schlumberger, Woodside, and Xstrata Coal.

The CO2CRC Core Research Participants are CSIRO, Curtin University, Geoscience Australia, Monash University, the University of Adelaide, the University of Melbourne, and the University of New South Wales.

It also has a number of Supporting Participants including Australian Greenhouse Office, Australian National University, CanSyd, Meiji University, The Process Group, University of Queensland, and URS.

CO2CRC has one of the world's largest, most comprehensive and most highly regarded programs on geosequestration and that experience and body of knowledge is brought together to address the Terms of Reference of this Inquiry. However, it should be noted that this Submission does not claim to represent the views of CRC participants. It has been developed by the Executive Staff of CO2CRC and represents their collective views, based on many years of experience in the science, technology and commercialisation of geosequestration.

2. What is Geosequestration?

Geosequestration is the process of capturing carbon dioxide (CO_2) from major stationary sources (such as power stations), transporting that CO_2 (usually by a pipeline) and then injecting it into a suitable geological formation (Figure 1). Other terms used for the process include carbon capture and storage (CCS); carbon (or carbon dioxide) capture and geological storage (CCGS), carbon capture and geological sequestration and geological disposal. In short, there is no universal agreement on nomenclature. European nomenclature prefers the term "storage". However storage has the connotation that at some stage the CO_2 will be retrieved whereas in fact this is unlikely to be technically or economically feasible in most circumstances. Additionally the term "storage" could be taken to encompass ocean storage (where the CO_2 is stored in the deep water column of the ocean) as well as geological storage. In the USA, the term "geological sequestration" seems to be increasingly popular. Here, the term "geosequestration" is taken to encompass capture, transport and geological storage (or sequestration) of CO_2. This submission will consider these three elements within the context of the Terms of Reference for the Inquiry.

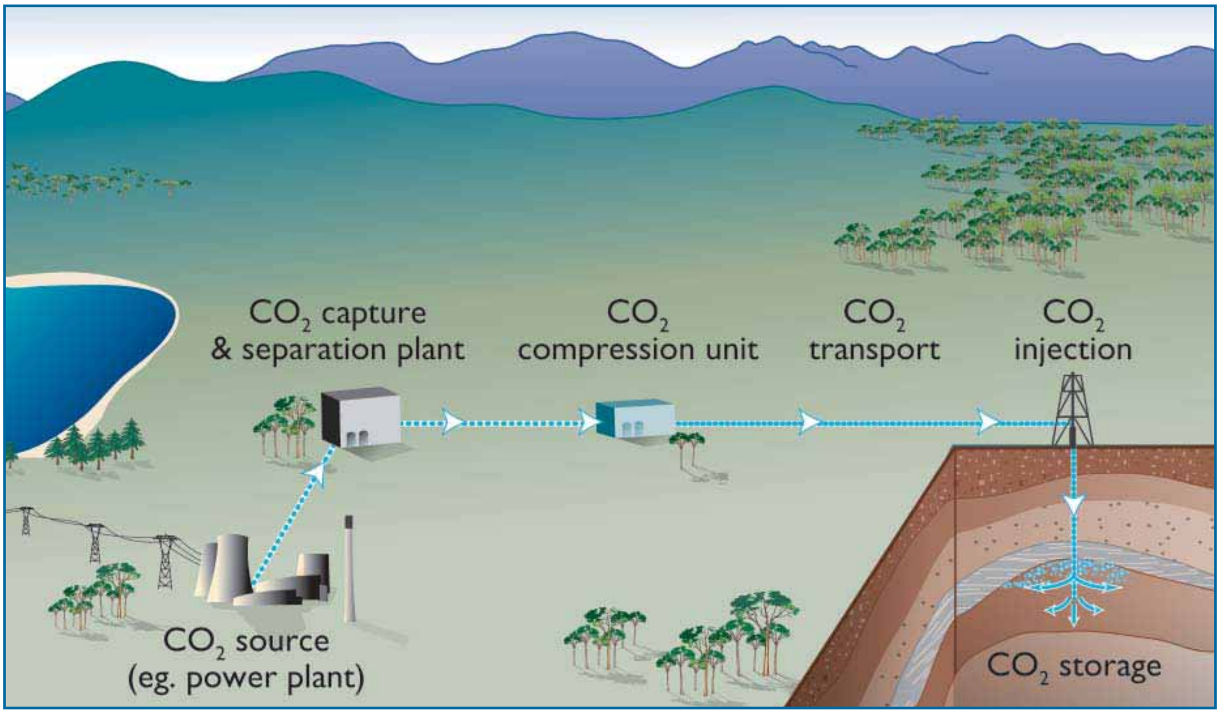

Figure 1. Simplified overview of the geosequestration process.

Ocean storage is not considered in this Submission for several reasons. First, it is outside the scope of the Inquiry. Second, the technology is very immature and certainly not at a position where it is ready to be applied. Third, there are serious doubts that ocean storage is an environmentally viable mitigation option, as it is likely to lead to acidification of the ocean, with attendant negative impacts on the marine fauna.

However it is important to point out that deep geological storage of CO_2 can be undertaken under the ocean seafloor; this is not ocean storage, as the injected CO_2 is not expected to ever enter the ocean; it is locked away under the ocean floor. This is an important distinction, as many geological storage sites are known to occur offshore, under the continental shelf including under the Australian continental shelf.

A further technology referred to as "mineral storage," involves the chemical reaction of CO_2 with finely ground minerals or rocks (alumino silicates). This technology has some similarities with geosequestration, but would be undertaken as a surface chemical process. It has been examined on a number of occasions but is not seen at present as an economically viable option. Mineral storage will not be considered here.

3. What is the Science Underpinning Geosequestration?

3.1 Capturing CO_2

The starting point for geosequestration is storage of relatively pure CO_2. In a few instances, industrial processes emit fairly pure CO_2 and that CO_2 can be captured and separated relatively cheaply. Such processes include the manufacture of some fertilizers and natural gas processing. The latter is especially significant because it provides a relatively pure stream of CO_2 at little additional incremental cost. The reason for this is that CO_2 must be separated from methane to meet sales gas specifications. It is also for this reason that some of the earliest geosequestration projects are based on natural gas activities (Sleipner in Norway; In Salah in Algeria). In Australia the Gorgon LNG project is currently planned to be the first large scale commercial geosequestration project in Australia. Around the world, there are a number of major geosequestration projects underway or announced (Figure 2).

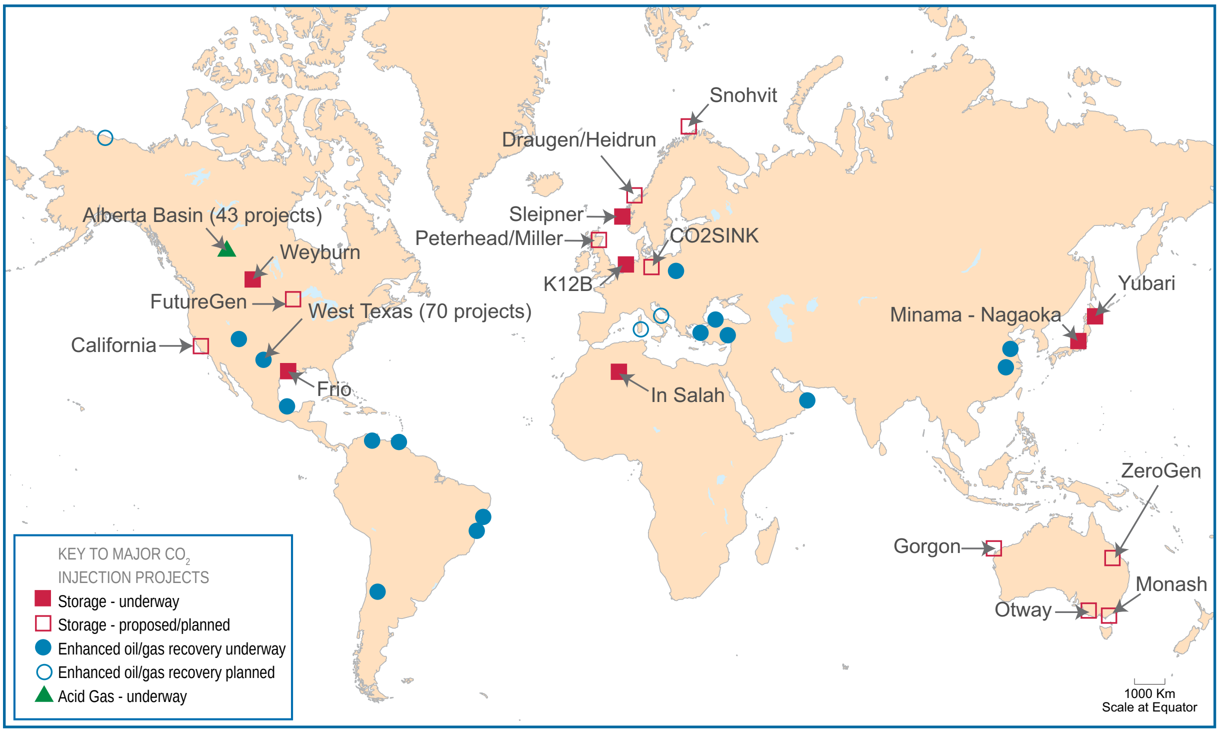

Figure 2. Distribution of major CO_2 injection projects that are underway or proposed around the world.

The issue of separation of CO_2 from natural gas is likely to be significant to Australia in the future, as approximately half of our identified natural gas resources have high concentrations of CO_2. This means virtually all natural gas used for liquefied natural gas (LNG) will need to have the CO_2 removed. Domestic gas sales have higher sales gas specifications for CO_2, but in many cases in the future will still have unacceptable CO_2 concentrations. Therefore, as natural gas production increases so will the amount of pure CO_2 separated at the production facility. For these reasons, natural gas processing is a potential "early mover" in the application of geosequestration in Australia.

Other early opportunities may arise from cement manufacturing (modern plants emit up to 50% CO_2 in the emission stream) and iron and steel plants. In the future, as gas-to-liquid (GTL) and coal-to-liquids (CTL) or coal-to-chemical processes become established, there will be a major new stream of CO_2 to be handled. These also offer significant early opportunities for application of geosequestration otherwise they will produce major increases in emissions.

However the great majority of Australia's anthropogenic CO_2 is emitted from coal-fired power stations. The recovery of CO_2 from power generation plants, which represent the biggest single emissions sector (approximately half of Australia's total greenhouse gas emissions), can potentially be addressed by applying separation technologies to the existing style of plant or by changing the generation technology to simplify the CO_2 removal process. These power plant CO_2 removal applications are referred to as post-combustion, pre-combustion and oxyfuels combustion (Figure 3).

Applying CO_2 capture to a typical existing power plant is referred to as post-combustion capture, in which the low pressure (1 atmosphere) exhaust gases (currently emitted directly to the air at about 10-15% CO_2) are passed through a separation process that removes CO_2. The current benchmark separation technology is a process called solvent absorption (described below). Post-combustion facilities can potentially be retrofitted to existing power plants or provided as a feature of new plants in the future. There are no existing power stations fully equipped for post combustion capture of CO_2, but several are proposed and many small units exist.

Two modified forms of power generation plant are being investigated to simplify the CO_2 removal step. The first is termed pre-combustion capture and, for coal, the plant is specifically referred to as Integrated Gasification Combined Cycle (IGCC). These systems operate at much higher pressures (25-65 atmospheres) and this makes CO_2 separation easier and cheaper. In this type of plant, the fuel is not combusted but reacted at high pressure and temperature to form a synthesis gas largely containing CO, CO_2 and H_2. This gas stream is then reacted further with water to convert the residual CO to CO_2 and H_2, allowing the CO_2 to be captured and sent to storage. The H_2 is combusted to produce power, with water as the main exhaust to the atmosphere. There are several hundred plants processing syngas in operation around the world at the present time, but these are mainly used for the production of chemicals, with only a few gasifiers used for the production of electricity.

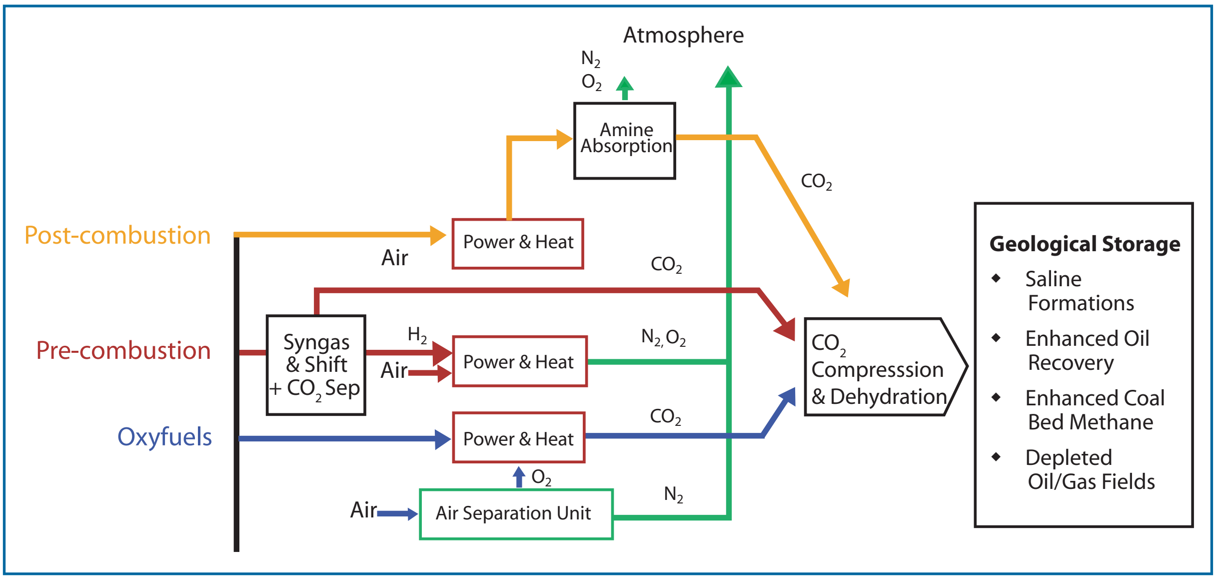

Figure 3. Capture Applications (after CO_2 Capture Project and IEA GHG R&D program).

The second type of new generation plant under consideration is referred to as an oxyfuels plant. This technology is similar to that used in existing power plants except that rather than combusting the fuels in air, combustion occurs in an oxygen atmosphere. This removes the nitrogen that makes up much of the air (and which would otherwise dilute the flue gases), hence the CO_2 separation step becomes simpler, but there is the expense of adding the pre-combustion air separation plant to provide the pure oxygen. Changes are required to the boiler and associated flue gas handling system to accommodate the higher flame temperatures arising from combustion with oxygen. The resultant flue gas is highly concentrated in CO_2 and can be purified in the process of compressing and condensing the CO_2 for storage.

While the scale of the capture plant required for any of these power plant applications is larger than any plant currently installed, there appears to be no insurmountable technical challenges to doing so, but there are cost impediments.

All moves to a low emission economy will result in additional costs, whether they involve greater use of renewables, lower carbon intensity fuels or geosequestration. Uncertainties relating to introduction of new technologies arise from questions about cost, acceptability to the community and effectiveness as a possible mitigation strategy or technology. In the case of the power generation sector increased cost will result in higher electricity costs whatever form of low- or no-emission technology is used, but obviously there is a need to apply the most cost-effective option.

The cost of CO_2 capture is currently the most expensive component of the overall cost of geosequestration (approx. 70-80%) and this is the driver of capture research, both locally and overseas. In the electricity sector the removal of CO_2 will increase costs of generation and result in a lower carbon emission rate from the plant. These figures are inter-related as shown below in an example.

Table 1. Example of cost of capture and the cost of generation (CO2CRC).

	Power Plant without Capture	Power Plant with Capture
Cost of Generation (A$/MWh)	30	57
Emission Rate (t CO_2/MWh)	1.0	0.1
Cost of Capture (A$/t CO_2 avoided)	NA	30

In this example, additional equipment and operating expenses are needed to reduce the amount of CO_2 being emitted from the power plant. In doing so the cost of generation increases by $A27/MWh for the resultant reduction of 0.9 t CO_2/MWh. The cost of capture is calculated by dividing $A27 by 0.9 to produce the result of $A30/tonne CO_2 avoided.

The selection criteria between the various applications discussed above was initially considered to be one solely based on cost (Table 2). The differences in cost are due to the easier task of CO_2 capture at the higher pressures and concentrations of CO_2 in the pre-combustion process. However as research progresses, not only have the base cost figures been reduced but so has the cost differentials between the applications. The expectations are that these costs still have further significant reduction potential.

Table 2. Indicative CO_2 capture costs and ranges (Source: IPCC Special Report on CCS, 2005).

	Post Combustion	Pre-Combustion[1]
Range (Hi/Lo (US$/t avoided)	29-55	13-37
Reference Value (US$/t avoided)	44	23

[1] The costs for Oxyfuel combustion in the IPCC Report were more qualified, due to fewer studies, but the costs are expected to approach those of post-combustion for coal applications.

While cost will still play a major part in the selection of the preferred applications used by the power generators, other considerations such as the integration of the technologies within the power plants and the opportunities for the use of syngas and/or hydrogen, are likely to become increasingly important. The impact and relationship of the costs of generation of electricity and capture costs require a broader view when considering the impact on the economy. Specifically, it is necessary to apply the total capture and storage cost in any analysis and then consider the cost impact to the end user of the low emission power. Aspects of this are developed further under section 4.2.

3.2 Separation technology

While the option of deploying different power generation applications exist to reduce capture costs, different cost reducing separation technologies are also being researched for each application (Table 3).

Table 3. Capture separation technologies and their relevance to various applications.

	Application			
Separation Technology	Natural Gas Separation	Post-Combustion	Pre-Combustion	Oxyfuels
Solvent Absorption	✓	✓	✓	
Membranes	✓	✓	✓	✓
Adsorption		✓	✓	✓
Cryogenics / Hydrates	✓		✓	✓
Chemical Looping			✓	✓

3.2.1 Solvent absorption

This technique is a cyclical process in which CO_2 is absorbed from a gas stream directed into a liquid, typically an amine. The gas stream, with most of the CO_2 removed, is then emitted to the atmosphere. The CO_2-laden liquid is processed to remove the CO_2, which is then concentrated for storage. The resulting CO_2-free liquid is used again for absorption and the process continues. This technique is widely used in a range of applications, including small scale CO_2 removal from flue gas.

3.2.2 Membranes

Membranes, made of polymers or ceramics, can be used to effectively sieve out CO_2 from gas streams. The membrane material is specifically designed to preferentially separate the molecules in the mixture. A range of configurations exist, either simply as gas separation devices or incorporating liquid absorption stages. This process is commercially used for the separation of CO_2 from natural gas but has not yet been applied to flue gas applications.

3.2.3 Adsorption

This separation technique is based on a cyclical process in which CO_2 is adsorbed from a gas stream onto the surface of a solid, typically a mineral known as zeolite. The gas stream, with most of the CO_2 removed, is then emitted to the atmosphere. The CO_2-laden solid, typically in a fixed bed, is then purified in stages using changes in either pressure or temperature to remove and concentrate the CO_2 for storage. This technique is used commercially in a number of gas separation processes, including those processing syngas, however it has not been used for flue gases.

3.2.4 Cryogenics/low temperature

This technique is based on the use of low temperatures to cool, condense and purify CO_2 from gas streams. It has been applied to moderately concentrated CO_2 streams in the natural gas sector and is being investigated for use in wider ranges of applications.

3.2.5 Chemical looping

Chemical looping is similar in some ways to the oxyfuels approach in that oxygen is removed from air prior to combustion by reacting it with metal particles in a fluidised bed forming a metal oxide. This captured oxygen, in the form of metal oxide, is then contacted with the fuel, such as natural gas in a separate fluidised bed, effectively combusting the fuel, releasing energy and producing CO_2 and water. In the process, the metal oxide is reduced back to the metal, which is available to be recycled to once again react with the air. The CO_2 is relatively easily separated using a process similar to that used for oxyfuels.

In summary, the costs of CO_2 capture are low for "pure" CO_2 streams such as those derived from gas separation of GTL and CTL systems, and from some industrial processes. The cost of CO_2 capture for conventional power stations is higher because the CO_2 concentration is low. Retrofitting of capture systems to existing power stations is possible but it adds costs in the order of 20% to that for new-built power plants. CO_2 capture costs from IGCC are likely to be the lowest. There are a number of separation options and a great deal of research is underway into the most cost-effective options, but for the present all options remain "on the table". CO2CRC research targets for capture are A$20/tonne CO_2 avoided or less. As mentioned previously the true measure of the impact on the community is derived from the combined cost of capture and storage and the CO2CRC research targets for this is also A$20/tonne CO_2 avoided (see Section 4.2).

3.3 Transport of CO_2

Unless the source of separated CO_2 lies directly above or adjacent to a site for injection, it is necessary to transport the CO_2 to the injection site, usually by pipeline (Figure 1). In this case, the CO_2 is compressed to a dense fluid prior to transport, and water (and possibly some contaminants) will be removed. The pipeline transport of CO_2 is a well understood and practiced activity. In the USA, for example, there are several thousand kilometres of CO_2 pipelines, used to transport CO_2 for use in enhanced oil recovery. In Australia, transport by pipeline is accepted, and widely used for natural gas. Therefore, pipeline transport of CO_2 in Australia is likely to be acceptable to the community.

Transport by road or rail may be technically feasible for small scale projects but is likely to be prohibitively expensive. Transport by ship may be feasible in some circumstances. At the present time there is at least one European vessel dedicated to the transport of high purity CO_2 for food processing. In the same way that LNG is transported around the world it would be technically feasible to transport large quantities of CO_2 from a coastal emission source to an offshore storage site. The costs of such a scheme are likely to be high; nonetheless it cannot be completely dismissed and may represent an option for the future. However for the foreseeable future, transport of CO_2 by pipeline is the most practical and economic option.

The issue of transport does have potential implications to the future siting of power stations. At the present time, siting of a power station depends on factors such as the market for the electricity, the source of the fossil fuel (usually coal), the location of cooling water and the planning regime. In the future, consideration will also have to be given to the location of a potential geosequestration site. Indeed it would be prudent for all future power stations in Australia to be sited with full consideration being given to future geosequestration options.

3.4 The geological storage of CO_2

Prior to storage, the emitted gas stream is concentrated to 95% or more of CO_2 and compressed to a dense supercritical fluid – a liquid which has a density (depending on the pressure) of around 0.5 -0.7 grams/cc (water has a density of 1gm/cc). Provided the CO_2 is injected to a depth of 800 m or more, it will remain in this dense form, which means that far more CO_2 can be stored than if it were to be injected in a gaseous state. There are a range of geological formations and situations that can be used for geological storage (Figure 4).

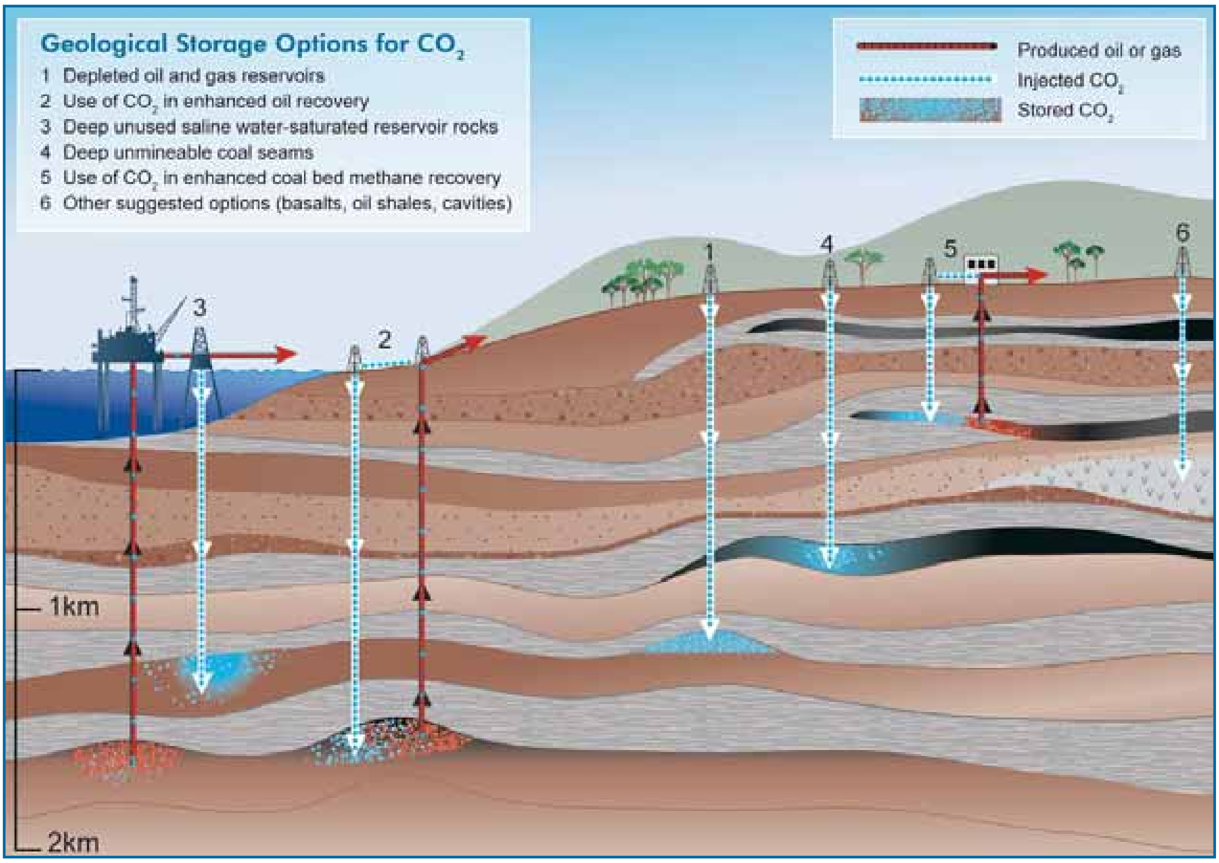

Figure 4. Options for geological storage of CO_2.

3.4.1 Options for storage

The storage of CO_2 involves keeping the CO_2 secured deep underground in an appropriate geological formation. The main geological conditions for this include a porous and permeable reservoir rock, a trap, and an impermeable caprock. Expertise in locating such geological formations is well established within the oil and gas industry, and geoscientists and engineers utilise mature technology to identify and evaluate specific sites for their geosequestration potential. Each site is evaluated for its potential storage volume as well as to ensure that conditions for safe and effective long-term storage are present.

Since the injected CO_2 is less dense than the formation water, it will slowly rise to the top of the geological reservoir, and a geological trap is needed to ensure that it does not escape and reach the surface or potable groundwater. The most common traps found in Australia are structural (e.g. an anticline), stratigraphic ("pinchout" of a reservoir rock) or hydrodynamic (CO_2 entrained in the formation water). An overlying impermeable top seal is required to keep the CO_2 within the storage formation. Such seals are generally very fine grained rocks with low porosity and low permeability. The seal must be of sufficient thickness to prevent microfractures and through-going faults from developing as possible CO_2 leakage pathways.

Depleted oil and natural gas fields, which generally have proven geologic traps, reservoirs and seals are potentially excellent sites for storage of injected CO_2. In some circumstances it may be possible to combine geological storage of CO_2 with enhanced oil recovery or enhanced gas recovery. This has not been carried out to date in Australia but is an area of research for CO2CRC because of the potential to beneficially combine geosequestration with increased production of hydrocarbons. CSIRO, the University of Queensland and CO2CRC are also undertaking reseacrh into the use of CO2 storage to enhance the production of coal bed methane. When injecting into a depleted field care must be taken that all existing wellbores are adequately cemented before sequestration operations begin, to ensure that there is no leakage of CO_2 from old wells.

In addition to "structural" trapping mechanisms, CO_2 storage can result from solubility and mineral trapping. Solubility trapping involves the dissolution of CO_2 in deep saline formations (Figure 4). This is the most important large-scale storage opportunity for Australia. Recent research has shown that as the CO_2 moves through the geological formation, a proportion of the CO_2 dissolves in the saline formation waters. Modelling has shown that with time, the CO_2-rich water becomes progressively denser which then causes downward fingering of the denser CO_2-rich waters. Mineral trapping involves the reaction of CO_2 with unstable minerals present in the host formation to form stable, solid compounds such as carbonates. Once the CO_2 has formed such minerals it is permanently locked. A key point about both of these mechanisms is that they ensure that over time the CO_2 becomes progressively more stable and even more unlikely to leak out of the storage formation. CO_2 can also be adsorbed onto fine organic particles in coal. This may be an important storage option for parts of eastern Australia, possibly combined with production of coal bed methane, but more research is needed.

3.4.2 Monitoring and verification

Monitoring the stored CO_2 is necessary to provide reassurance to the community that the technology is safe and sustainable. It can be done using an array of established direct and remote sensing technologies deployed at the surface and in the borehole. These technologies record properties such as pressure, temperature, electrical resistivity and sound responses in injection and observation wells. Other monitoring involves seismic, microseismic, petrophysical well logs and geophysical sampling, to allow tracking of movement of CO_2 in the subsurface prior to, during and post-injection. Prior to any injection of CO_2 it is necessary to carry out baseline surveys of the distribution, type and origin of any existing CO_2 in a potential storage site, through soil gas sampling and other analyses. Areal CO_2 migration and trapping are assessed and geochemical sampling at surface localities will allow rapid detection of any seepage or leakage in the unlikely event that this should occur.

A systematic risk assessment for all geosequestration sites considers the engineered and natural systems. The engineered systems consist of the wells, the plant and the gathering line; the natural system includes the geology of the site, the reservoir formation, the overlying and underlying formations and the groundwater flow patterns. These criteria need to be agreed in conjunction with the relevant regulatory authorities and applied to the project through all phases to address responsibilities, liabilities and to provide assurance of safe storage to the satisfaction of the public at large. Monitoring and verification is very important to the acceptability and success of geosequestration.

Individual storage sites need to be well characterised with respect to the physical and chemical processes which will take place during and after injection. Similarly, all the technologies available for monitoring the stored CO_2 need to be evaluated and the most appropriate ones selected. In addition, the risks associated with all phases of the process must be identified and understood. The IPCC Special Report considers risk arising from geosequestration is likely to be low. Bearing all of these issues in mind there are no technical impediments to the uptake of geosequestration.

4. The Potential Environmental and Economic Benefits and Risks of Geosequestration

4.1 Environmental benefits

Australia only emits 1.6% of the world's total greenhouse gas emissions. However, its industries are energy intensive; it is a major user of electricity, and it has one of the world's highest per capita rates of greenhouse gas emissions. State and Federal Governments are committed to decreasing Australia's CO_2 emissions. But there is no wish to implement measures that will place a major impost on the economy or result in Australian industry becoming uncompetitive. In a future carbon-constrained world, Australia's exports of coal ($24 billion in 2005). LNG ($6 billion in 2005) and aluminium ($5 billion in 2005) could all be affected if other countries applied levies or some other form of impost on Australian energy or energy-intensive exports. However, unless steps are taken to limit greenhouse gas emissions, particularly CO_2, major climate-change-related costs could be imposed on the economy and the environment as well as on tourism and agriculture and on people's lives. For all these reasons, the Australian Government is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) which aims to "stabilise the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

Despite the Framework Convention and the Kyoto Protocol, world energy demand is increasing by up to 1.7% a year and the IEA predicts that 85% of that increase will be derived from greater use of fossil fuels. In Australia, energy demand is projected to increase by 50% by 2020, requiring at least $37 billion in new energy investments (Australia's Energy Future, 2004) mainly for the provision of base load coal-fired power.

A range of mitigation measures will be required by Australia, including greater energy efficiency, switching to lower carbon intensity fuels, greater use of renewables and geosequestration. Geosequestration is not a "silver bullet" but it does have the potential to enable Australia and other nations to make deep cuts in emissions yet maintain the economic benefits of using much of the existing energy infrastructure and deploying low cost fossil fuels in the transition to a carbon neutral future.

Obviously the primary environmental benefit of geosequestration lies in its capacity to decrease CO_2 emissions to the atmosphere. Since the start of the industrial revolution, the atmospheric concentration of CO_2 has risen from 270 parts per million (ppm) to 380 ppm in the present day. If current trends continue the concentration is likely to double (or more) over the century. CO2CRC has undertaken modelling of the potential global impact of geosequestration, using as its starting point the IPCC IS92 and SRES projections. Our work strongly supports the view that geosequestration can have a major impact on emissions. By way of example, use of the IS92a projections (which presumes very extensive use of renewables, nuclear and energy efficiency) produces a CO_2 concentration of 712 ppm by the year 2100, or far above the range of 450-550 ppm that is considered desirable. Our modelling suggests that the global deployment of geosequestration could bring that down to 550 ppm by 2100. However, to achieve this there are several necessary steps:

- a very intensive period of research, development and demonstration between now and 2015 to bring down the costs of geosequestration;
- from 2015 onwards all new power stations would be equipped with low emission technology including geosequestration. Over the subsequent 40 years all existing power stations would be phased out to be replaced with low emission power generation;

- additionally it is proposed that from 2035 onwards, low emission transportation, based on geosequestration-enabled hydrogen or electricity generation, would be progressively introduced over the subsequent 20 years; and,
- by 2055, all electricity generation and transportation would be "geosequestration enabled".

Together these measures (plus others incorporated in the IS92 and SRES models) could result in an atmospheric CO_2 concentration of 550 ppm.

Key components of this strategy include that we must start down this road now and that there is no time to spare if we are to have commercially viable geosequestration systems in place by 2015. At the same time care must be taken during this period to balance the need for early action with technology development and the prevailing policy position. However, it is also important for industry and the community to be made aware that this is the path forward, so that there is adequate time to introduce the technology and absorb costs. Finally, implementation must be aim to global; it would be unrealistic to expect every country to adopt precisely the same time scale, but all must agree on the objective of 550ppm by 2100.

Could steps be taken to implement low-emission technologies before 2015? Yes, in some circumstances, it will be possible to identify early opportunities but these "low hanging fruit" will relate mainly to processes that produce high CO_2 concentrations, or in specific cases where there may be incentives such as enhanced oil recovery. The larger target of power generation is probably not implementable on a significant scale much before 2015.

The other major target is vehicular transportation. Here the connection with geosequestration rests with vehicles being powered either through electricity (centrally generated and hence amenable to the application of geosequestration) or through hydrogen (generated via the shift reaction from fossil fuels to produce hydrogen and CO_2 which then is geosequestered). Could large scale low-emission transport be introduced before 2035? Perhaps, if incentives were provided, or if the cost of conventional liquid fuels were to rise significantly. Hybrid cars obviously have the potential to make a significant impact on emissions. However, there are many hurdles to be overcome before transportation becomes fully "zero emission".

A common hope for the so-called "hydrogen economy" is that the hydrogen would be generated from wind or solar. Whilst this is currently technically feasible on a small scale it is most unlikely to be able to meet the needs of a full scale hydrogen economy unless there is an extra-ordinary technical break-through. For the foreseeable future it is likely that a hydrogen economy will be fossil-fuel-based and that geosequestration will be an essential component to avoid CO_2 emissions. Given that Australia has massive coal and natural gas resources and a very large geosequestration storage capacity, Australia could potentially benefit economically from early deployment of geosequestration – and contribute to solving a global environmental problem.

Are there potential environmental hazards likely to arise from the widespread deployment of geosequestration? Use or modification of any natural system carries a risk, and there can never be 100% certainty. A road may be affected by a landslide; a dam or water treatment plant may fail. However, the community usually judges the benefits of a dam, a road, or a water supply to outweigh any risks associated with them. CO_2 is not a pollutant; it is an essential component of life and we add it to drinks and use it in other foods. However at high concentrations it can asphyxiate humans and other animals. Any geological storage site must be planned to not leak, but at the same time no absolute guarantee can be given for the system. Nevertheless, the chances of CO_2 leaking from a well-characterised site are very low. Evidence for this comes for example from the fact that geological traps can hold oil and natural gas (including CO_2) for many millions of years. As pointed out earlier, because of the way that CO_2 behaves in solution the chances of CO_2 leaking to the surface actually diminish over time.

There has been at least one major natural escape where CO_2 was released from an African volcanic lake (Lake Nyos) and asphyxiated thousands of people and domestic animals. This incident is quite often quoted by those opposed to geosequestration as an example of what can happen should a leak of CO_2 occur from a storage site. This occurrence is in no way analogous to geosequestration sites being researched world-wide. CO2CRC modelling indicates that it is extremely unlikely that a catastrophic leak could ever occur in any areas being considered for geosequestration, because of the nature of the geology in which the CO_2 would be stored. The main lessons from the Lake Nyos event is that CO_2 should not be stored in unstable volcanic environments (particularly volcanic lakes); there is no prospect of CO_2 being stored in such a geological location in Australia.

Additional confidence in geosequestration is provided by the fact that around the world, including Australia, there are many hundreds of locations (some under major cities) where natural gas is stored underground, often at depths far shallower than the depths at which CO_2 will be geologically stored. There have been few incidents involving underground natural gas storage despite the flammable and potentially explosive nature of natural gas compared to the relatively inert nature of CO_2.

Whilst catastrophic leakage of CO_2 from a geological storage site is highly unlikely, it is necessary to ensure that all reasonable steps are taken to limit the possibility of low/slow rates of CO_2 leakage over an extended period. This could for example affect the root zone of plants, or organisms within the soil. Leakage into a freshwater aquifer could affect the acidity of the water and/or make it "fizzy". However, careful choice of the storage site would minimise the prospect of any of these happening and an appropriate monitoring regime would ensure that were leakage to occur, it would be quickly detected. Remedial action could potentially be taken to deal with a leak, but would not necessarily be done if there was a slow rate of leakage which had no deleterious effects. The IPCC concluded that it was likely that sites could be chosen that had a cumulative leakage rate of 1% (or less) of the total amount of CO_2 stored over 1,000 years. Such a slow rate is very unlikely to have an adverse impact on the environment.

4.2 The economics of geosequestration

The IPCC Special Report on Carbon Capture and Storage (2005) states that the scale of uptake of these technologies is likely to be limited unless a price of carbon dioxide in the range US$25-30/tonne CO_2 avoided exists or mandated limits are placed on CO_2 emissions. The CO2CRC has set itself research targets for the capture and storage of CO_2 below these levels - A$20/tonne CO_2 avoided. This figure is set to optimise the uptake of this low-emission technology in the final energy mix used by the community.

As pointed out earlier, the cost of capture from a conventional coal-fired power station is likely to constitute 70-80% of the total cost of geosequestration. However, the cost of a geosequestration project is site (and process) specific. For example, where the primary emission stream is CO_2-rich and the storage site nearby, the total cost of capture and geological storage is likely to be no more than a few dollars a tonne CO_2. If, however, the emission is low in CO_2 and the storage site is hundreds of kilometres away then the cost could be A$100 or more a tonne of CO_2, and therefore probably non-viable economically, compared to other mitigation options. By comparison, the cost of CO_2 capture associated with gas processing or cement manufacture or a coal-to-liquids storage is likely to be a small proportion of the total cost of such a geosequestration project. A study by CO2CRC of the likely cost of CO_2 storage projects in Australia (Figure 5) indicated a wide range of capital and operational costs, driven primarily by the distance between the source of the CO_2 and the storage site, but with many potential projects costing US$10 or less per tonne of CO_2 avoided (capture costs are additional). Not surprisingly, costs of onshore projects are significantly less than the cost of offshore projects.

The IPCC Special Report (2005) examined the issue of geosequestration costs in some detail, but it is difficult to compare these costs directly with Australian costs for various reasons, including the cost of equipment, currency variations and the cost of electricity. The CO2CRC has now established a range of tools and techniques to generate Australian-based cost studies and to provide indicative translations between local and overseas studies. One interesting feature is that due to the relatively low intrinsic fuel costs in Australia the local capture costs, being a composite of capital, operating and fuel costs, do not necessarily convert directly using the prevailing exchange rate.

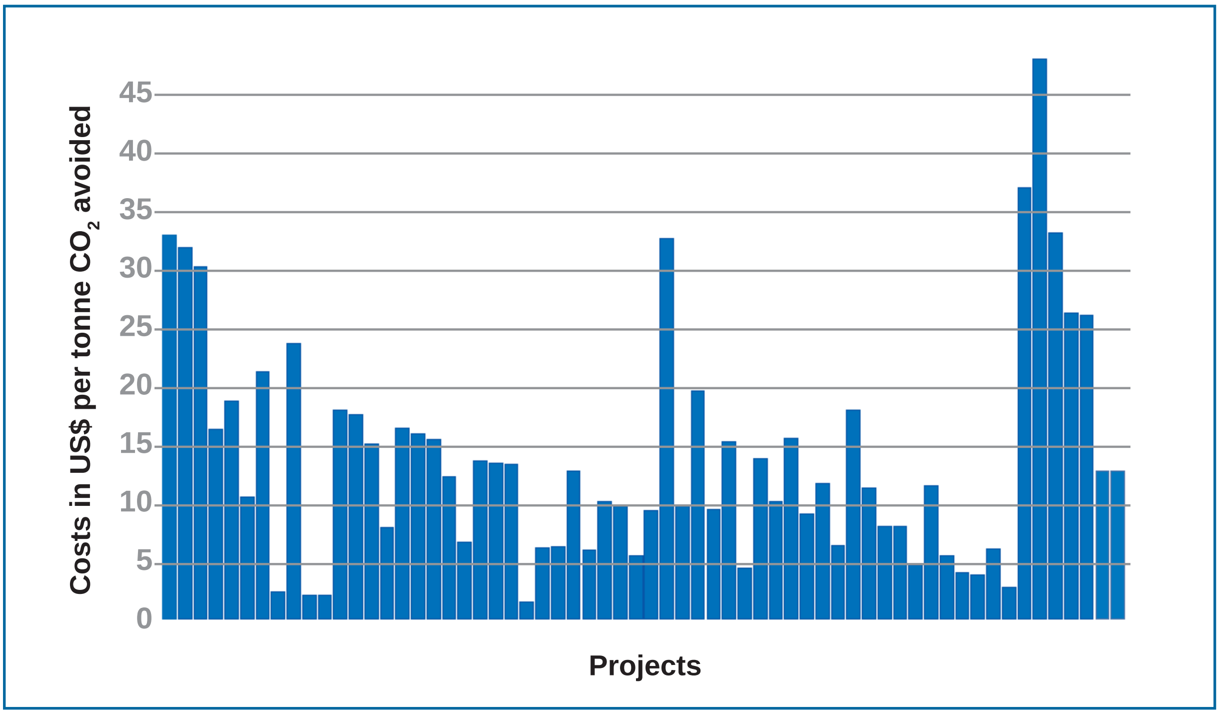

Figure 5. Potential cost of Australian geological storage projects (after Allinson et al).

Will costs come down? Based on the evidence provided by other comparable technologies the answer is yes. Costs are most likely to come down in the capture area. In the transport and storage areas there is less scope for price reduction because of the maturity of these technologies, with the scope for price reduction resting more with economies of scale.

The CO2CRC has undertaken, and continues research into what it refers to as "low-emission hubs" (Figure 6).

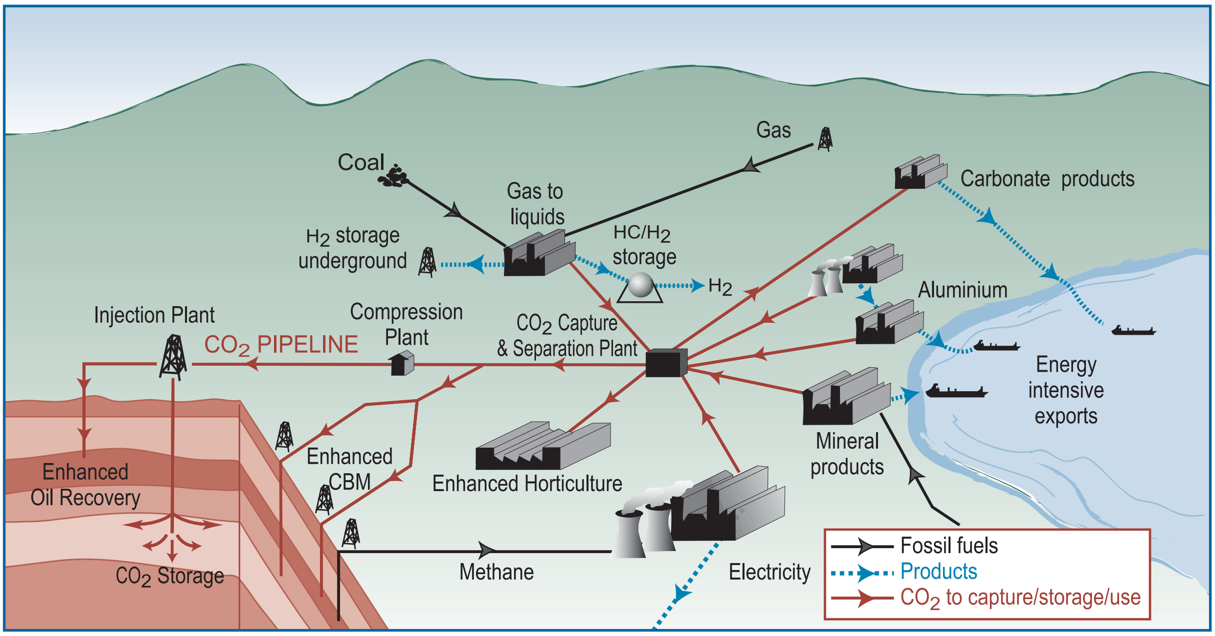

Figure 6. Low-emission vision for the future.

These are regions with high concentrations of emission sources which can potentially adopt a coordinated approach to decreasing CO_2 emissions. Areas in Australia which offer scope for this approach include the Latrobe Valley, Kwinana, the Burrup Peninsula, the Sydney-Newcastle region, southeast Queensland and the Gladstone-Rockhampton district. A low-emission hub approach would require capturing CO_2 from a mixed gas stream using a variety of capture technologies. Industrial processes most suited to this approach could include electric power generation, natural gas processing, furnaces, boilers, aluminium smelters, cement kilns and sugar mills. If a number of these were brought together (Figure 6) then economies of scale could be achieved. Estimating the cost of a hub configuration by CO2CRC has been based on engineering estimates of the size and number of different pieces of hardware and equipment and the number and type of injection wells. Estimates of the unit costs of equipment, services and drilling were also made, depending on current drilling rig rates, the type of equipment and hardware and their unit costs at current market prices. As is the case with any large scale construction project, the costs of equipment and services are subject to significant uncertainty and change over time because of market forces.

Costs are usually expressed in dollars per tonne of CO_2 avoided. The costs of geosequestration can vary significantly depending on the situation. CO2CRC has published preliminary central estimates of the costs of a "low-emission hub" composed of large sources of CO_2 in the Latrobe Valley in Victoria. Our cost estimates are given in Table 4 and are based on a project of 40 years duration and a Gippsland Basin storage capacity of 2 billion tonnes CO_2 (in fact the storage capacity of the Gippsland Basin is probably 6 billion tonnes CO_2 or more).

Table 4. Summary of costs of a large scale low-emission regional geosequestration project.

Capital costs	A$2,914 million (2005)
Operating costs	A$290-298 million (2005 per annum)
Annual CO_2 injected	15 million tonnes per year
CO_2 injection period	40 years
Cost per tonne CO_2 avoided	A$38/tonne

These then are indicative of the costs of a large regional geosequestration hub in Australia and are in line with cost estimates made by other researchers for CCGS in other countries.

Cost will depend on the industrial process involved and are subject to large uncertainties. They exclude the effects of any taxes that might apply to projects. The costs set out in Table 4 are for Australian conditions using current technologies. There are good grounds for expecting the costs of capturing CO_2 to fall in the future as technological improvements are made. The 2005 IPCC Special Volume (page 16) states "Over the next decade the cost of capture could be reduced by 20% – 30% and more should be achievable by new technologies that are still in the research or demonstration phase." Assuming a 30% reduction and given that capture costs are a significant proportion of the total costs of geosequestration, we might expect that the average costs of geosequestration in the Latrobe area will fall to A$30 per tonne CO_2, (showing progress towards our target of A$20/tonne CO_2 avoided). Individual processes producing relatively pure CO_2 (such as CTL) would have significantly lower total mitigation costs (cf. a recent CO2CRC study which indicated a cost of approximately A$8-12/tonne CO_2 avoided).

The IPCC Special Volume states "Inclusion of CCS in a mitigation portfolio is found to reduce the cost of stabilising CO_2 concentration (in the atmosphere) by 30% or more". In the absence of a price on carbon it is difficult to set a dollar value on that 30% reduction or on the economic benefits to be derived from geosequestration generally. Funding geosequestration research is an essential part of risk minimisation, recognising that a future price on carbon or being forced to deploy expensive low emission technology could have a profound impact on the profitability of a company, on the value of exports and on the Australian economy in general. Government and industry recognise that geosequestration has a major potential role to play because it could enable Australia (and other countries) to continue to use much of the existing energy infrastructure (including use of cost-effective fossil fuels) yet make deep cuts in emissions.

What then are the “order of magnitude” benefits from geosequestration? ABARE (2006) modelling uses a carbon price of US$59-99 a tonne of CO_2. Nature (2006) suggests that around US$80 billion needs to be spent on geosequestration and low-emission hubs. The 2006 House of Lords considers that achieving a 550 parts per million (ppm) CO_2 concentration by 2100 will cost between US$2-17 trillion. The recent Allen Consulting Report (2006) estimates a potential benefit of A$50 trillion to Australia by adopting a lower carbon future, and economic modelling by the Australian Business Roundtable on Climate Change (2006) suggests that early action to decrease emissions will be worth A$2 trillion to the Australian economy by 2050.

Whilst these macro-economic figures are useful indicators, placing a meaningful dollar value on geosequestration activities requires an imputed price for carbon (or CO_2 avoided). The EU Emissions Trading Scheme (EU ETS) price (mean of 28 Euros) and the Victorian Renewable Energy Target (VRET) credit scheme, indicates an imputed price of A$47 a tonne CO_2. Improved technologies, such as geosequestration, are expected to bring costs down by A$20 a tonne CO_2 mitigated. A 30% saving (IPCC, 2005) on an inputed A$47 cost would correspond to a saving of A$14 a tonne of CO_2. Therefore a saving range of A$10-20 for every tonne of CO_2 mitigated through geosequestration (rather than an alternative mitigation option) is realistic. Using these figures suggests that if 140 million tonnes of CO_2 (50% of Australia’s total stationary emissions) were geologically stored, at a cost that is 30% (A$14) less than the mitigation alternatives, there would be a saving of about $2 billion per annum to the Australian economy.

The question is often asked: how much will the cost of electricity rise if geosequestration was used? This seemingly simple question is not easy to answer as it all depends on where one is in the electricity system. By way of example, a geosequestration cost of A$20/tonne CO_2 avoided would mean an increase in electricity price of about 50% at the generator, about 25% on the retail price and about 15-20% on the domestic price. However, it is important to note that a unilateral decision by an electricity generator to produce “low emission electricity” including geosequestration would be a courageous move under current electricity market conditions. The public may not necessarily wish to pay an extra 15-20% for “clean electricity” if they were offered the choice. What then are the options to enable geosequestration uptake in the absence of a price signal for carbon?

- Allow the extra cost of “clean electricity” to be spread across all producers in order to get geosequestration underway. For example, if the increased cost of electricity arising from one 1,000 megawatt power station equipped with geosequestration were averaged across all generators, the increase in domestic electricity cost would be less than 1%.
- Governments could mandate that an agreed percentage of electricity would in future be “low emission”, without specifying whether that is achieved through renewable energy, through the application of geosequestration or through any other technology. The market would then decide on the most effective options(s).
- Government could refuse to licence any conventional coal or gas-fired power station (after say 2015) that does not have geosequestration.

CO2CRC does not have a firm view on which (if any) of these options should be used, although it does see an urgent need to accelerate deployment of geosequestration as an essential component of Australia’s mitigation portfolio. But as is the case for all other mitigation options, there will be a financial cost to the community. Whether the cost of geosequestration deployment is more or less than other mitigation options will depend on:

- The location of the facility;
- Nature of the facility
  - whether the emission stream is concentrated or dilute CO_2;

- In the case of power generation whether or not it is required to be "base-load";
- The extent to which future technology developments bring down costs;
- Whether or not a price signal or emission ceiling of some sort is applied by Government;
- The cost of the other low emission options.

These factors and others will determine what proportion of Australia's future mitigation effort is likely to rest on geosequestration, but our considered view is that under most scenarios, geosequestration is likely to be a cost effective option, particularly for base load power, gas separation, CTL and other processes that produce a CO_2-rich emission stream.

4.3 Are there risks associated with geosequestration?

Perhaps the greatest, but so far unquantified risk would arise if we took no action, or inadequate action, to limit greenhouse gas emissions, resulting in major (and expensive) consequences arising from climate change. Therefore there is a significant risk in doing nothing about CO_2 emissions.

Are there risks associated with the implementation of geosequestration? As pointed out earlier the use or adaptation of the natural environment, including the deep subsurface geological environment, always carries a risk, but because there are associated benefits (economic, environmental, etc) society is willing to make the "trade-off" of risk versus reward.

In the case of geosequestration, there is a risk that CO_2 might leak out of a storage site but the use of modern analogs (natural gas storage; deep fluid injection; enhanced oil recovery operations) and geological analogs (oil and gas fields; deep brines) indicate that the risk of CO_2 leakage from a carefully chosen storage site is extremely small, and of the same magnitude (or less) than many comparable ongoing industrial activities that are widely accepted by the community.

Is there a risk that the storage capacity will be insufficient for the demand, or that it will not be in the geographic area of greatest need? In its Special Report, the IPCC concluded that the world's storage capacity is adequate to meet all likely geosequestration needs for the next 100 years. Is that capacity always located where it is needed i.e. in the region where most of major CO_2 emission sources are located? In fact the answer overall is yes, because most fossil energy resources, water and good building sites are typically located in sedimentary basins, which is where the CO_2 storage "resources" are also located. While this observation is valid, there are of course exceptions and in many areas we do not know if there is storage in suitable locations, because the basic geological studies have yet to be undertaken.

4.4 What of Australia?

The work of CO2CRC indicates that Australia has a very large storage capacity – probably adequate for ongoing storage of hundreds of years of Australia's CO_2 emissions. The areas with the greatest known storage capacities occur off Victoria, Western Australia and the NT. There is also likely to be significant storage capacity in parts of Queensland and northeast South Australia. The least known State in terms of storage capacity and the one with the greatest storage need is New South Wales. The reason for this uncertainty is that the geology is complex and in part characterized by low porosities and permeabilities. However a primary difficulty arises because there has been little oil exploration in NSW and consequently we know virtually nothing about the deep geology of the State. For example the sedimentary basin known as the Sydney Basin extends offshore where there may (or may not) be significant storage capacity but we know very little about that Basin. The fact that it lies offshore of some of the largest CO_2 emission sources suggests that there is real benefit at the state and national level in better understanding this Basin (both offshore and onshore) in order to establish the NSW storage resource potential. This knowledge could greatly decrease the risk that NSW has insufficient storage capacity. The problem of greenhouse gas emissions is of course a national issue and there is a need to decrease the level of uncertainty (and risk) regarding storage capacity throughout Australia. However, overall our preliminary assessments suggest that most existing major emission "nodes", such as the Latrobe Valley, the Burrup Peninsula, Kwinana, southeast Queensland and Gladstone-Rockhampton, will have adequate storage capacity located within 200-500 km. For the present the storage situation for the Newcastle-Sydney region is unclear but CO2CRC hopes to undertake a program of storage assessment in the near future.

The other risk to Australia could arise from an inability to bring down the cost of geosequestration to a level where it is economically viable. However, the risk of this happening is deemed to be low, on the basis that all other comparable technology has undergone marked decreases in costs. The converse of this is that a financial risk could arise if inappropriate and/or expensive technology was introduced due to premature uptake of geosequestration technology. The key to minimising this risk lies in undertaking research, development and demonstration as speedily and effectively as possible. The Government's LETDF initiative to introduce demonstration of low emission technology is an important step forward and will help Australian industry to understand the potential and the challenges of low emission technology. However there is still much R&D to be undertaken, and in addition it is crucial that the community understand the science of geosequestration and is comfortable with the technology as a mitigation option.

With this in mind the CO2CRC proposes to undertake a large scale demonstration of geological storage of CO_2 in the Otway Basin of Western Victoria (Figure 7), with injection of up to 100,000 tonnes CO_2 into a depleted gas field (Figure 8). CO2CRC has already obtained over $20 million cash from Federal and State bodies and industry as well as in-kind support in excess of $6 million. It is seeking additional funds to enable this project (total cost in excess of $35 million) to reach its full potential. In summary the proposed Otway Basin Project involves CO_2 production from a natural gas well; transport by pipeline; injection into a deep porous/permeable geological formation overlain by an impermeable seal and the monitoring and verification (M&V) of the behaviour of the stored CO0-rich gas. Gas would be injected for 6 months in the first phase of the project. In the second phase, the CO_2 will be separated and purified to 97% CO_2 and then injected. Up to 100,000 tonnes of CO_2 will be injected until 2009 and monitoring will continue until mid 2010. Involvement of federal and state regulators, extensive community engagement and communication are key features of the project.

At least one new injection well will be drilled to approximately 2000 metres (Figure 8); a second will be drilled for additional monitoring if funds allow. Injection, logging, monitoring and modelling technologies will be evaluated for their cost effectiveness and accuracy and industry (including SMEs) will have the opportunity to learn from the project and develop commercial opportunities from the findings.

New technologies will be developed and deployed and a comprehensive and integrated monitoring system will be implemented for the protection of the environment and quantification of stored CO_2 to validate carbon accounting. Major industry partners and Small and Medium Enterprises (SMEs) will work with CO2CRC to ensure this major project is carried out to the highest industrial and commercial standard. In order to undertake the project and address operational liability issues, the CO2CRC established (December 2005) a world-first operating company (CO2CRC Pilot Project Ltd – CCPL) for the purpose of injecting CO_2 underground.

The Otway Basin Project will be one of the most advanced projects of its type in the world. It will lead to an outcome of profound importance – the early deployment of geosequestration technology in Australia. The project will provide "proof of concept" at an industrial scale and under Australian conditions. Major industry beneficiaries will be the petroleum, coal and power sectors but government policy and regulation and the community will also be major beneficiaries through the cost effective application of greenhouse gas technologies. Importantly, this will decrease commercial and policy risks associated with geosequestration in an open and cost effective manner.

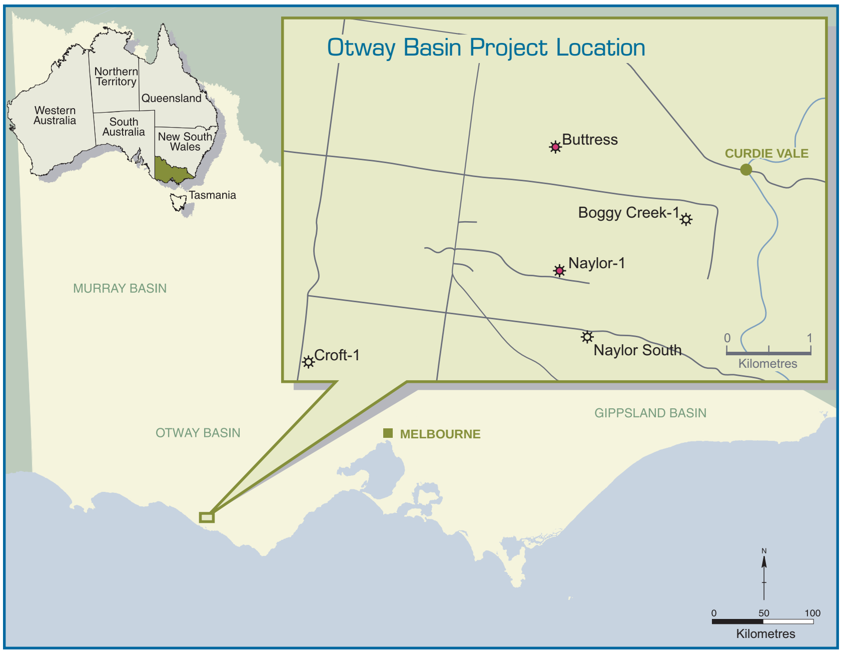

Figure 7. Location of the Otway Basin Pilot Project.

A number of important commercial projects involving geosequestration have also been announced including the ZeroGen Project (Stanwell), the Gorgon Project (Chevron, Shell, Exxon), the Monash Project (AngloCoal) and the Oxyfuels Project (CS Energy). Others are under development or under consideration as part of LETDF.

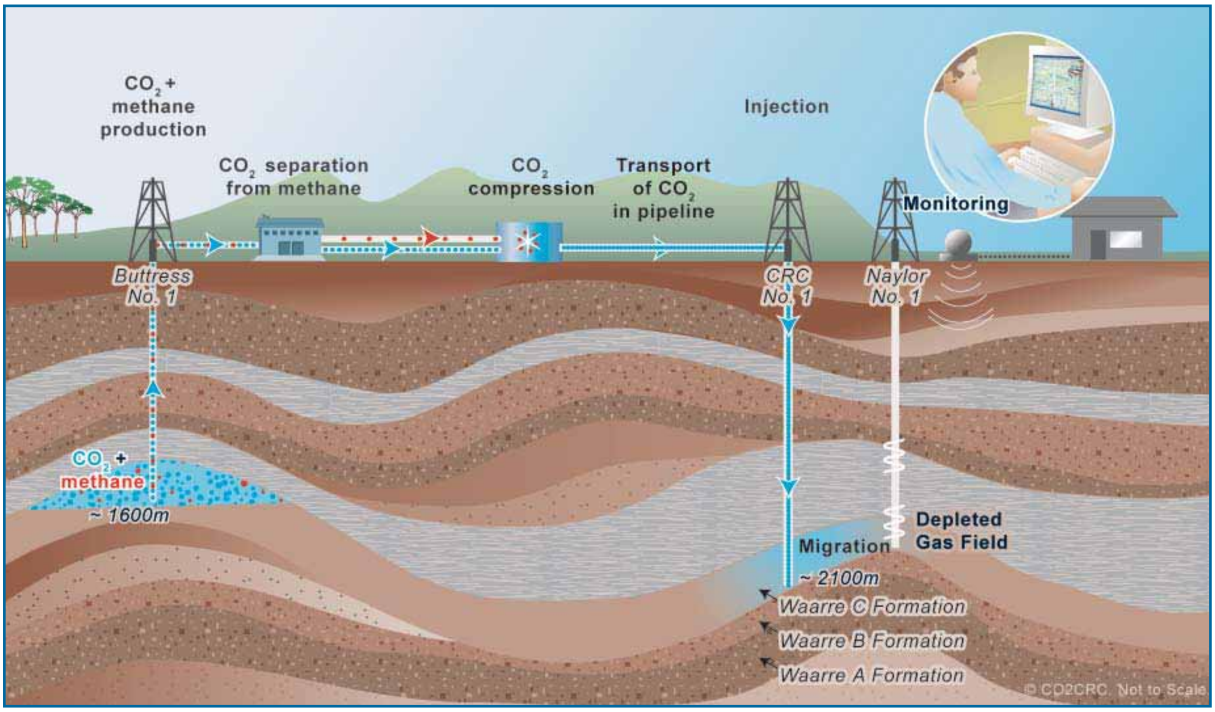

Figure 8. Schematic representation of the Otway Basin Project of CO2CRC.

5. Australia's Skill Base for Geosequestration

5.1 Education and training

There is a limited skill base worldwide capable of addressing geosequestration from a scientific and technology based perspective. Such technical input is critical to industry to enable capability of ongoing research, development and deployment of geosequestration projects and for techno-economic project planning. It is required by government for informed legislative/regulatory decision-making capability. Largely through CO2CRC, Australia has built up a significant geosequestration skill base in the universities, CSIRO, Geoscience Australia and in industry.

The skill base required for geosequestration falls into two broad categories, namely the earth sciences and engineering (largely chemical engineering). Burgeoning activity in the minerals and petroleum sectors provides supply/demand pressures for these skills. However, many other skills need to be brought to bear and a characteristic of geosequestration is its multidisciplinary nature.

A robust education and training program must be part of any geosequestration strategy. The aim of such a program must be to produce quality graduates able to develop and implement geosequestration technologies in Australia and contribute this expertise globally.

To help meet this objective, CO2CRC has developed and implemented a strong education and training program that focuses on four major strategies: 1) Undergraduate Education; 2) Postgraduate Training; 3) Professional Skills Development, and 4) Continuing Education. CO2CRC addresses these through its university partners. It provides grants, scholarships and other forms of student support through a defined student program, encourages and supports industry-specific short courses for students and industry partners and engages in continuing education programs.

At present there are 32 enrolled post-graduate students in the CO2CRC universities, but more are needed. The students (and postdocs) emerging from CO2CRC have participated in a distinctive educational experience and have developed unique insights into geosequestration technology which will be at the core of Australia's enviro-economic future. They represent a new generation of skilled professionals capable of leading us forward into a new age of efficient and environmentally sustainable technologies for greenhouse gas mitigation. However, additional resources are requited if Australia is to meet its future needs for experts skilled in geosequestration. Additionally, Australia has an important future role to play in providing geosequestration education and training to developing countries, especially China and India. This will contribute directly to the Government's international objectives through CSLF and AP6.

5.2 "Team Australia"

Geosequestration is a technology that will be developed further and more widely deployed as greenhouse gas mitigation options are embraced by industry and government, and as regulatory bodies seek to enact informed legislation in Australia. There is a skills shortage of quality graduates able to develop and implement such greenhouse gas technologies. The CO2CRC is addressing this through undergraduate and postgraduate education and training, professional skills development and continuing education in connection with industry. Through the coordination provided by CO2CRC it has been possible to develop a significant body of geosequestration expertise in Australia in a relatively short period of time. CO2CRC is the premier geosequestration research body in Australia and one of the top programs in the world. This in turn has allowed Australia to punch "above its weight" not only in research but also in a range of geosequestration activities. It is crucial that this "Team Australia" approach is retained. Having a range of separate organisations in Australia all aspiring to develop their own expertise in geosequestration research and education would lead to loss of criticial research mass and diminish Australia's standing in this crucial topic. It is also essential that a coordinated approach is taken to university education and training in the evolving area of geosequestration. The development of individual geosequestration courses in a dozen different (and separate universities) would not be sensible from a national perspective, nor would it be cost effective from the perspective of DEST. Training in geosequestration is to be encouraged and supported, but it must be coordinated through a body such as CO2CRC, to ensure quality, leading edge, user-focussed education and training, not only for the benefit of Australia, but also for the benefit of other countries such as India and China, which face major challenges in addressing future energy and greenhouse gas issues.

Similarly in geosequestration research, if Australia is to maintain its world standing, it makes no sense to develop numbers of small, potentially non-viable geosequestration research groups. In many ways, geosequestration science is "big science" that requires large numbers of researchers and a few well-funded very major facilities and projects. Australia's science base can only afford one major program focussed on geosequestration. CO2CRC and its Core Participants, working in collaboration with organizations such as the Centre for Low Emission Technology and with international partners, can meet national and industry CO_2 mitigation needs as well as make a major contribution to resolution of international greenhouse gas issues.

6. Regulatory and Approvals Issues Relating to Geosequestration

There are a number of regulatory and approval issues relating to geosequestration. Some of these issues have an international dimension, particularly if geological storage occurs offshore. Bodies such as the International Energy Agency (IEA) and the Carbon Sequestration Leadership Forum (CSLF) have taken a lead role in considering these issues. Australia, through the Department of Industry, Tourism and Resources (DITR) and the Australian Greenhouse Office (AGO) has played a very positive and leading role in considering international regulatory, licencing and environmental issues in the IEA, the CSLF and the London Convention. Whilst the Kyoto Protocol does not deal with geosequestration specifically, there is increasing interest by a number of developing countries in taking geosequestration forward under the Clean Development Mechanism.

In many ways Australia is less likely to be affected by international regulations than countries of the European Union, which are directly affected by the OSPAR Convention. Nonetheless, it is important that Australia continues to engage in international fora to ensure that future international rules, under for example the London Convention, do not inhibit Australia's future options for implementation of offshore geosequestration.

In the case of offshore Australia, most of the storage potential lies within the Continental Shelf or Extended Continental Shelf and therefore largely under Federal jurisdiction. DITR in conjunction with other Federal Departments and State bodies is actively looking at the relevant issues, including those posed by CO_2 moving across jurisdictions e.g. CO_2 emissions that are generated onshore (under State legislation) being geologically stored offshore (under Federal legislation).

The current approach proposed by DITR is to use the offshore petroleum legislation as a basis for geosequestration licensing and regulation. This is a sensible and practical approach. There will be issues relating to overlap of petroleum tenements and CO_2 storage tenements, but there should be no insurmountable barriers to resolving such issues, provided the approach taken is transparent, a "level playing field" is maintained between various proponents (and interests), and the national interest can be fully taken into account. The consultative approach taken by DITR to these issues should help to ensure that an appropriate approach will be developed.

The deployment of geosequestration onshore will be largely a state issue although obviously Federal environmental or other issues may also impact on occasions. It is unrealistic to aim for uniform geosequestration legislation in all States, but it is highly desirable to have consistent legislation, given that some sedimentary basins likely to be suitable for geosequestration cross state boundaries. Additionally in some cases, CO_2 produced in one state may be stored in a second state. Under the Ministerial Council, Federal and State Departments have come together to produce a framework for regulation which in many ways provides a world lead for geosequestration. This initiative and the MCMPR document are to be applauded. The framework for environmental regulation requires further consideration in areas such as impact, monitoring and liability. As pointed out elsewhere, no natural geological system is risk free but the risk of leakage during geosequestration is very low. However it is important to note that there is no such thing as the perfect site for geological storage and it is important that the bar is not set too high for storage sites. In other words the possibility of some (minor) CO_2 leakage must be acknowledged, but this must be set against the risks arising to the environment of doing nothing about emissions. Similarly, it would be prohibitively costly to require that any leakage, no matter how small, must be remediated. If a small leak occurs and it poses no problem to the environment or life, then it would be foolish to require an operator to spend vast sums of money to fix a leak which is no more than an "accounting issue" requiring that say only 99% of the injected CO_2 will be deemed stored for 1,000 years rather than the full 100%.

Similar issues arise with the nature of the injected gas; it would be unrealistic to expect that only 100% pure CO_2 will be injected and stored; there may be minor impurities such as methane, or nitrogen oxides which will have little if any impact in the subsurface, but which could be prohibitively expensive to completely remove prior to injection. A much more selective approach must be taken to impurities, to severely limit concentrations of undesirable elements such as mercury, but accept "benign" impurities.

The issue of how much monitoring is required needs further consideration to the extent that the development and optimisation of monitoring technologies is still underway. Any attempt to place a heavy monitoring burden on projects could place an undue financial impost on projects and endanger their variability. There are also practical considerations such as the length of time required for monitoring: obviously this must be carried out whilst injection is underway and for some years after that – preferably until the site (and the CO_2) is behaving as expected in terms of migration within the storage formation and lack of leakage. But to insist that monitoring should continue after closure for many decades (or even centuries) is not necessary and is unrealistic in terms of the organisational structures available to handle ongoing monitoring activities for such long periods of time. Only Governments have the capacity to undertake such long term activities and it is Governments that should take on this monitoring role if society requires that monitoring should continue for such extended periods.

A related issue is that of long term liability. There is general acceptance that the company (or operator) using the storage site will carry liability during the operational phase. However following closure and confirmation of the stability of the system, there is no obvious holder of long term liability other than Government. Given that there is long term community benefit in mitigating CO_2 emissions through geosequestration, it is entirely appropriate for Government to take on the associated long term liability. Indeed there is no other option. It is significant that the State of Texas has recently announced that if FutureGen (a major geosequestration project) is sited in Texas, the state will take on long term liability. There is no other example of this known to CO2CRC but it may provide an important precedent which Australia may choose to follow in order to accelerate the rate of deployment of geosequestration.

The final point which must be made in considering regulatory and approval issues is that the science of geosequestration is relatively new. Therefore it is important at this stage that any legal framework has sufficient flexibility to allow for improvements in our understanding of geosequestration and for technological developments. As an example of this, it has for the most part been considered that the deep ocean (which is mostly beyond the Territorial Seas and the Extended Continental Shelf) is not relevant to the storage of CO_2

and therefore of little legislative interest at this time. However the suggestion has recently been made that CO_2 could be stored in deep sea sediments in the form of CO_2 hydrates. This is scientifically feasible, but does face significant technical challenges. Nonetheless it highlights the fact that should this turn out to be a feasible mitigation option at some time in the future then it is likely to require extensive reconsideration of international legal considerations including potentially the regulatory regime under the London Dumping Convention and Protocol.

7. Positioning Australian Industry to Capture the Benefits of Geosequestration

7.1 Attracting industry

Australia is extraordinarily well positioned to capture the benefits of geosequestration because of its large storage capacity "resource" and its abundance of coal and natural gas. Application of the concept of low-emission hubs in which the issue of CO_2 mitigation is addressed through a coordinated regional mitigation approach could provide a powerful impetus to Australian industry, and a magnet to international industry and industrial development generally.

7.2 Providing Australia with a cost-effective mitigation option

Australian industry is energy intensive and also internationally competitive because of its access to low cost electricity. A requirement to adopt costly mitigation measures could jeopardize that competitiveness. It is therefore very important that Australian industry maintain a lead in the adoption of the most cost effective mitigation options including geosequestration. One way that Australian industry seeks to maintain this position is by supporting and participating in CO2CRC, one of the largest geosequestration programs in the world and a technology leader. It is crucial that Australia maintains CO2CRC, its successor, beyond 2010 (the current date for the termination of CO2CRC) as the issue of greenhouse gases will not be resolved over the next 3-4 years. The long term maintenance of Australia's geosequestration R&D capacity is crucial to ensuring that Australian industry can capture the benefits of the technology.

7.3 Maintaining Australia's exports

Australia is a major exporter of energy (coal, LNG) and energy intensive (aluminium) exports, worth a total of $45 billion in 2005. The imposition by an importing country of any form of tariff on such exports, because Australia was considered to not be taking adequate steps to address its CO_2 emissions, could have a very detrimental effect on those exports. A decrease of 1% in these exports because of tariffs (or other imposts) would cost the Australian economy almost half a billion dollars a year. The application of geosequestration could provide some insurance to Australian industry that such inhibitions on exports would not be contemplated.

7.4 Development of a geosequestration industry

A geosequestration industry is emerging in Australia. Already CO2CRC, through its commercial arm (Innovative Carbon Technologies Pty Ltd) is providing consultancy services to industry and governments in Australia and internationally. The demand for geosequestration services is rapidly expanding, with a skill shortage inhibiting that growth to some extent. Nonetheless the business opportunity is expected to continue to grow for CO2CRC and its member companies and other companies. This Australian-based international business opportunity could be worth $100 million within 10-15 years. What is needed to support this opportunity? The presence of a strong research and development base is undoubtedly one of the best ways of developing this business in Australia. In addition early implementation of geosequestration by Australia would provide considerable stimulus to this nascent industry. What form would the industry take? Obviously the provision of technical advice and consultancy services would provide a starting point. However, the role of project development and management would offer future opportunities and the development and deployment of monitoring technologies will be a future prospect. The role of "auditor" (for the purpose of carbon credits) is likely to become an increasingly important role for geosequestration "specialists" with the Otway Basin Project offering an outstanding opportunity to develop and validate carbon dioxide audit methodologies. However some of the most rewarding commercial geosequestration opportunities may be in the CO_2 capture and separation area. The development of a more cost effective separation technology could offer a particular benefit to industry in Australia and a major export opportunity. CO2CRC recently lodged its first international patent for a new CO_2 separation technology. A further opportunity lies in the provision of capture "systems" which bring together existing technologies in a cost (and energy) effective manner. Again there is scope for Australian-based enterprises to offer this service globally.

8. Concluding Statement

Geosequestration has the potential to be one of the most important technologies available to us for decreasing CO_2 emissions to the atmosphere whilst continuing to access the benefits of fossil-fuel-based energy systems. But it is not a "silver bullet" and other mitigation steps will be required, including greater energy efficiency, more use of renewable energy and perhaps nuclear power. A target of 550 parts per million atmospheric CO_2 by 2100 will be difficult to achieve, which is why we need to start the implementation of geosequestration and other measures as soon as is practicable. It is judged that this should be no later than 2015 – nine years' time. But if this is to be implemented there needs to be a clear message to industry and the public so that geosequestration development and demonstration can get underway on a sufficient scale to enable all new power generation facilities to be "low-emission", including geosequestration-enabled, commencing 2015.

There are some opportunities for early use of geosequestration provided by industrial and combustion processes that produce a fairly pure pressurised stream of CO_2 and such opportunities should be taken by Australia wherever it is environmentally and economically feasible. The proposed Gorgon Project is potentially an excellent example of this approach.

There is a need for more research into geosequestration and this should be supported, but it needs to be backed up by demonstrating geosequestration in Australia at a commercially significant scale. Geosequestration is not something for the distant future; it is happening now in various parts of the world. Australia is in the fortunate position of having outstanding researchers and technologists, an extensive knowledge base and in many parts of the country the right geology. It is likely to gain greater benefit from the application of geosequestration technologies than almost any other country. In the editorial for the 10th August edition of *Nature* entitled *Capturing Carbon* it is stated "carbon sequestration is the only credible option that would allow the continued use of fossil energy without dangerously altering the Earth's climate system. Speeding up its development must therefore become a priority on the global energy agenda." Australia has the opportunity to demonstrate how technology can lead to real and sustainable decreases in greenhouse gas emissions to the atmosphere.

an emission free vision for the future

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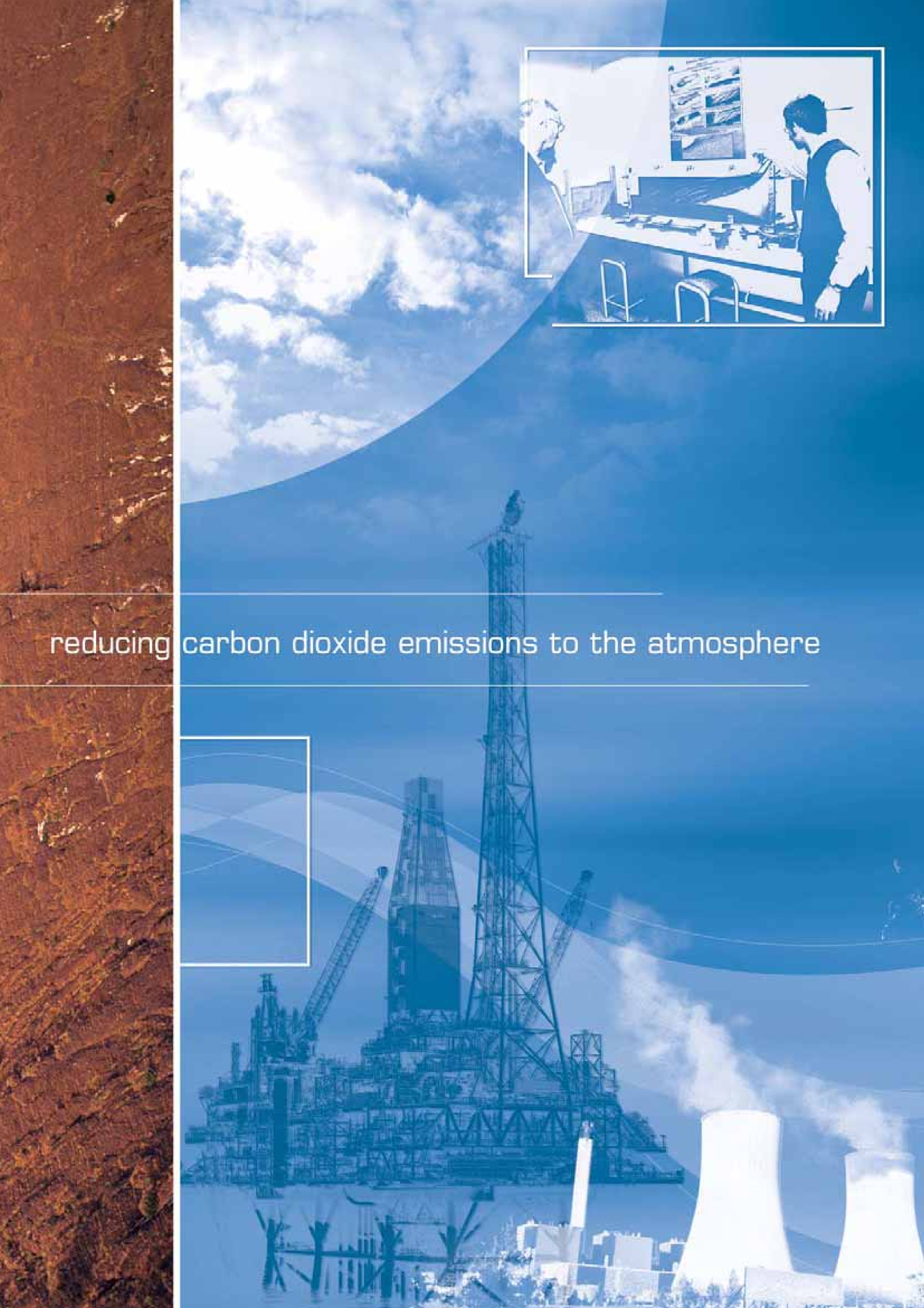
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