CSIRO

Geosequestration technology

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Introduction

This submission is structured under numbered headings corresponding to the terms of reference of the inquiry. There is a growing literature on geosequestration that is becoming quite substantial. This submission concentrates on both a broad description of geosequestration and CSIRO's particular areas of experience and expertise. Conclusions and recommendations are listed after the discussion.

Terms of Reference

1. The science underpinning geosequestration technology.
2. The potential environmental and economic benefits and risks of such technology.
3. The skill base in Australia to advance the science of geosequestration technology.
4. Regulatory and approval issues governing geosequestration technology and trials.
5. How to best position Australian industry to capture possible market applications.

1. The science underpinning geosequestration technology

Geosequestration technology is already available. About a million tonnes of carbon dioxide has been injected annually since 1996 at Sleipner in the North Sea and for the last two years, about a million tonnes per year has also been injected at In Salah in Algeria. There are also more than 144 sites in the USA where carbon dioxide has been injected into the ground to enhance recovery from oil reservoirs [1]. This industry experience, for the period less than 25 years, provides considerable knowledge. Beyond this, for periods greater than 25 years up to thousands of years, greater unknowns exist and hence the need for scientific understanding of geological containment. Natural accumulations of carbon dioxide have existed underground for very long time periods, and through studying these, confidence in the viability of geosequestration has increased.

In looking at strategies available to reduce the global carbon emission rate in 2054 by one billion tonnes of carbon a year (1 GtC/year), Pacala and Socolow [2] have estimated that 3500 projects of the scale of Sleipner are required in addition to the equivalent quantity of power plants that capture carbon dioxide (one tonne of carbon is equivalent to 3.67 tonnes of carbon dioxide). Existing technologies already exist for a range of other solutions; the difficulty is one of scale and cost (refer to *Table 1* below). Stabilisation of atmospheric carbon dioxide will require a reduction of several billion tonnes of carbon emission per year.

Table 1. Selected strategies available to reduce the global carbon emission rate in 2054 by one billion tonnes of carbon a year, extracted from Pacala and Socolow [2]. Refer to Table 1 in their paper for a complete list.

Options	**Effort by 2054 to reduce emissions by 1 GtC/year**
Efficient vehicles	Double fuel economy for 2 billion cars
Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30 million hectares
Photovoltaic power for coal power	Add 2000 GW-peak photovoltaic (700 times the current capacity) occupying two million hectares
Biomass fuel for fossil fuel	Add 100 times the current Brazil or US ethanol production, with the use of one-sixth of world cropland
Geological storage	Create 3500 Sleipners

The main public sources of information on the current status of the science of geosequestration are the Greenhouse Gas Technology Conferences that are held every two years. The most recent, GHGT-8, was held in Norway in June 2006. Presentations at this conference are available on the web (http://www.ghgt8.no/). Technical journals and other meetings also provide a steady stream of information available to the research community and the public. Also of note is the Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage released in 2005 and available online (http://www.ipcc.ch/).

CSIRO has been actively involved in the science of geosequestration since 1999. Initially this was mainly as a partner to the GEODISC program of the Australian Petroleum Cooperative Research Centre. This program was superseded and expanded by the formation of the Cooperative Research Centre for Greenhouse Gas Technologies in which CSIRO has been a core participant since its inception in 2003. CSIRO has also been a partner in other ventures, including the European “Reduction of carbon dioxide emission by means of carbon dioxide storage in coal seams in the Silesian Coal Basin of Poland” (RECOPOL) pilot project for injection into coal seams and a consortium organised by the Alberta Research Council in Canada.

Three broad goals can be identified for further development of the science of geosequestration:

- the reduction of costs;
- scaling up the scope of sites where the technology can be applied; and
- ensuring that the long-term confinement is effective in terms of atmospheric carbon dioxide reduction, safety and security.

Sequestration technology can be discussed under the components that make up geosequestration: capture, transport and storage. Storage can be further divided into different geological environments.

Capture

For most potential geosequestration applications, the cost of capturing carbon dioxide is the greatest component of the total cost. Existing sequestration projects like Sleipner and In Salah and the proposed Gorgon project are all run by the natural gas industry. These are projects where the discovered natural gas contains large amounts of carbon dioxide, which has to be separated to bring the gas to market, hence capture of the carbon dioxide does not present an additional cost. The real impact of geosequestration, however, requires the capture from coal-fired power generation and it is here that cost reduction is highly desirable.

Carbon dioxide can be captured from the gases leaving the power station after the fuel has been combusted. This option, known as Post Combustion Capture, is the one that can be most easily applied to Australia’s existing coal and gas-fired power station. This process, which involves dissolving the carbon dioxide in a solvent, is a well established technology that has been used for many years in the gas industry. Unfortunately, regeneration of the solvent to produce a concentrated carbon dioxide stream for disposal requires considerable energy and can reduce the electricity output from a power station by up to 30%. Current research by CSIRO is directed at developing new solvents that will have much lower energy penalties, as well as looking at ways to integrate the process with renewable systems such as solar power to minimise efficiency losses from power stations even further.

The other option, known as Pre Combustion Capture, is to remove the carbon from the fuel before it is burnt. This requires a new generation of power stations in which the fuel is firstly gasified. The separation of carbon dioxide is facilitated by the high pressures at which the system is operated, leaving a stream of hydrogen that can then be burnt in a high efficiency gas turbine to generate electricity. CSIRO is actively involved in the development of this technology through its work within the Centre for Coal in Sustainable Development (CCSD) and the Centre for Low Emission Technology (cLET). Much of this work is directed at developing new membrane separating systems that will avoid the need for solvents and avoid their associated energy penalties.

Transport

Transport of carbon dioxide over distances of more than a hundred kilometres can become prohibitively expensive. Pipelines need to be constructed from special steels because any water present will combine with carbon dioxide to form corrosive carbonic acid. Unless the cost can be significantly reduced, it will not be feasible to pipe carbon dioxide long distance, for example from large sources in New South Wales to large storage reservoirs in other states. Materials research may show how costs can be reduced, but at the moment transport is receiving little attention in Australia or overseas compared to other aspects of geosequestration.

Storage

(a) Saline formations

The main targets for underground storage of carbon dioxide are porous sandstone rocks. The pore spaces in these rocks are normally filled with salty water, and hence are known as saline formations. The sandstone rocks are formed from sand in beaches, lakes, rivers and the ocean floor that become buried, compressed and heated over geological time so that the sand grains often become cemented together. It is the void space between the grains, perhaps 30% of the total volume, that is available to be occupied by fluids, normally water, but it can be oil, natural gas or carbon dioxide. In geosequestration, carbon dioxide is injected at considerable depth (one kilometre or more below the ground surface) into these porous rocks to push out the water. This is the opposite process to oil and gas extraction, where water comes in to replace the fluids that are extracted. Australia is well endowed with large sedimentary basins and the sorts of sandstones suitable for geosequestration, except in New South Wales where the sandstones generally have little space between the cemented grains (low porosity). Rocks other than sandstones are also potential storage media. Much of the world's oil and gas is found in limestone (carbonate) rocks, but porous limestones are rare in Australia. Eastern Australia does have extensive coal and the potential for this rock to store carbon dioxide is discussed in more detail below.

Containment of carbon dioxide in sandstone rocks is achieved by selecting sites with overlying sealing rocks; normally shales with fine grains that are strongly compressed and cemented together. These overlying shales are the same types of rocks that have held natural gas, oil and natural carbon dioxide accumulations underground for millions of years.

Injected carbon dioxide is initially buoyant; at depths below 800 metres the density is generally between 0.6 and 0.8 times the density of the surrounding water contained in the rock. Over time, however, the carbon dioxide slowly dissolves into the underlying water, making that water about 1% more dense (carbon dioxide is one of the few gases that makes water more dense when dissolved). When dissolved, the carbon dioxide is no longer buoyant and sinks to greater depths, meaning that seal rocks are no longer required. A portion of the carbon dioxide can also combine with minerals to produce carbonate solids.

CSIRO, through the Cooperative Research Centre for Greenhouse Gas Technologies, has been performing world-leading science on the process of carbon dioxide dissolution leading to permanent sequestration [3]. This science opens up the opportunity for a greater number of sites to be considered, in turn leading to potential cost reduction through reduced transportation requirements.

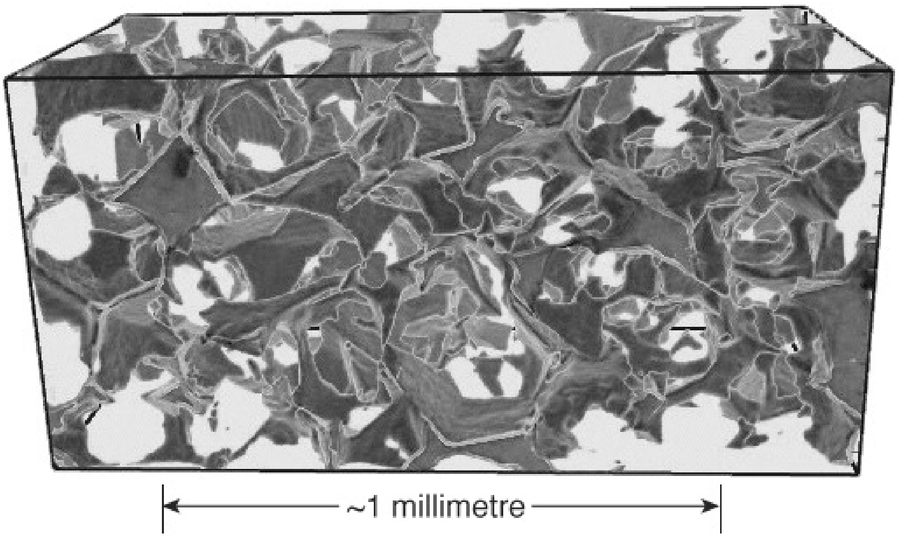

Figure 1. A microscopic image of the space between the grains in a sandstone rock. It is this space that stored carbon dioxide occupies after injection. Saline water, oil or natural gas would otherwise fill this space. This image was obtained using x-ray microtomography. Image supplied by Professor Mark Knackstedt, Australian National University.

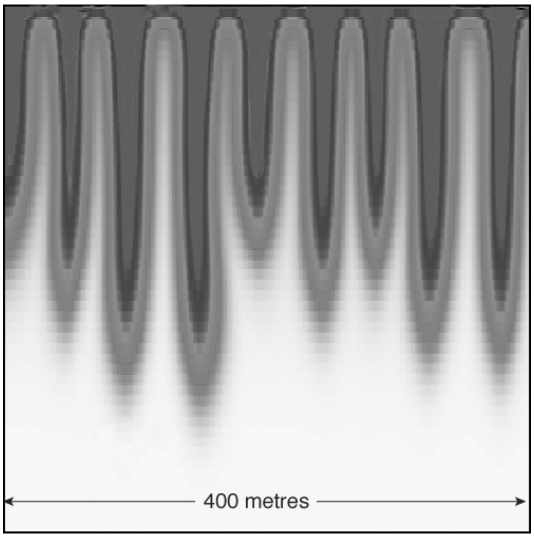

Figure 2. A vertical section trough a carbon dioxide storage reservoir. Free carbon dioxide, shown as the dark area, initially rises to the top under buoyancy. Over time the carbon dioxide dissolves in the surrounding water making it more dense, so that plumes of carbon dioxide descend downwards. CSIRO, through the Cooperative Research Centre for Greenhouse Gas Technologies, has performed leading research on this process.

(b) Depleted oil and gas reservoirs

Although carbon dioxide injection has been used for enhanced oil recovery in more than 144 sites in North America, to date this has not happened in Australia. Historically most of Australia's oil has come from Bass Strait where primary oil recovery percentages have been much higher than almost anywhere else in the world, so there is comparatively little benefit from enhanced recovery. Western Australia has a reservoir with a large fraction of unrecovered oil, but the shallow depth of the reservoir makes it unsuitable for carbon dioxide enhanced recovery as carbon dioxide and oil do not mix well at low pressure. Nevertheless, there are some locations (predominantly in central Australia) where carbon dioxide flooding should work, although the economic conditions have not existed to make it an attractive option. Restructuring taxes associated with the process could make it more economically viable.

Enhanced gas recovery is also possible by injecting carbon dioxide into the edges of natural gas reservoirs. Gas is less valuable than oil, so the economic incentive to do this has not existed.

(c) Coal seams

Coal is unusual in that some gases, including carbon dioxide, adhere to the extensive internal surfaces. This means that at depths between 400 metres and 800 metres carbon dioxide can be stored at liquid-like density that would require depths of over 800 metres in sandstones. This offers the opportunity for shorter wells and significant savings in drilling costs. Against this, however, is the general problem that the capacity of coal to flow fluids, in the case of sequestration, to accept large volumes of carbon dioxide, is much reduced in comparison to porous sandstones. This reduced capacity to flow means that more wells are needed, offsetting the cost advantage of shallower wells.

Many coal seams already contain natural gas (methane) and this opens up the possibility of injecting carbon dioxide to displace methane that then goes to production. This is known as enhanced coal bed methane. Methane production provides a revenue source to offset the cost of carbon dioxide injection, potentially lowering the cost of sequestration. This is possible because carbon dioxide adheres to coal more strongly than methane, and about two molecules of carbon dioxide take the space of only one molecule of methane. Hence about two carbon atoms are sequestered for every carbon atom released.

(d) Monitoring and verification

Monitoring of geosequestration can be used to verify containment for the purposes of regulation, carbon accounting and public safety. It has been argued that small amounts of leakage could be tolerated without compromising the goals of atmospheric carbon dioxide reduction and safety. Risked leakage rates of one percent in 1000 years have been suggested as a benchmark, but detecting leakage this small is difficult against a background of natural carbon dioxide generated in the soil. Theoretical limits for seismic detection of small accumulations of carbon dioxide in the subsurface have been determined to be no better than 1000 tonnes of carbon dioxide at depths greater than 800 metres, even in favourable geological environments [4]. Hence a 10 million tonne storage site leaking at one percent in 100 years would not be detectable until the carbon dioxide had risen to 800 metres or shallower. Either regulation would need to be framed around allowing this level of leakage, or deeply buried monitoring technologies would need to be developed and implemented. CSIRO, through the Cooperative Research Centre for Greenhouse Gas Technologies, is actively involved in developing and testing monitoring technologies that include instrumentation deep underground.

CSIRO has been active in measuring carbon dioxide in the atmosphere. The sophisticated atmospheric monitoring technology and dispersion modelling that CSIRO has developed may be used to verify that geosequestration storage sites are not leaking to the surface through the soil or from wells. With a combination of atmospheric measurement and modelling techniques the detection of ground-released carbon dioxide may be 1000 tonnes per year or better of suitable tracers are used [5].

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2. The potential environmental and economic benefits and risks of such technology

(a) Environmental benefits

Geosequestration offers the opportunity for deep cuts in carbon dioxide emissions, not just for Australia but also globally. Geosequestration offers the potential for zero emission electricity at prices that at many locations are potentially competitive with renewables and without the base-load problems. There is some uncertainty about the final cost of geosequestration as it depends very much on location. The Latrobe Valley coal power generation is relatively close to large potential storage in the offshore Bass Strait oil and gas field region. However, the Hunter Valley in New South Wales does not have comparable storage sites of similar capacity within proximity; hence geosequestration in the Hunter Valley will be more expensive than the Latrobe Valley.

(b) Economic benefits

The cost of delivering low-emission electricity from renewables remains very high with difficulties surrounding base load power demands. Reliable, low-cost energy has many benefits, and geosequestration may enable coal to continue to provide comparatively low-cost base load power in many locations.

(c) Risks

Geosequestration suffers from the perceived risk of catastrophic release of carbon dioxide. Close examination and experience however shows that this risk is not real and that public education is an important step towards implementation. There are many natural leaks of carbon dioxide from the earth in countries like Italy and New Zealand that exceed potential leaks from a site with a failure. Nevertheless, proper regulation is essential to ensure that operators are competent, sites are appropriately chosen, and that wells are properly cemented. This is no different to other professional industries.

Other risks include leakage that could compromise the intention of geosequestration, ownership of future risks to the land owner, and risks to the industry posed by public unacceptance.

Any consideration of risks also has to include the possible consequences of inactivity and the effect on climate change.

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3. The skill base in Australia to advance the science of geosequestration technology

(a) Capture

There is a significant skill base both within universities and CSIRO that is being deployed into the development of capture technologies. This covers the full range of options including solvent scrubbing, various membrane separators, solid adsorbents and cryogenic separations. The work of the universities (Melbourne, Monash, Curtin, Adelaide, New South Wales and Queensland Universities) is being largely carried out within the capture program of the Cooperative Research Centre for Greenhouse Gas Technologies, while the CSIRO work is being performed within the Energy Transformed National Research Flagship program. The focus of the CSIRO work is the application of capture to power generation systems, both the existing pulverised fuel fired plants and the high pressure gasification plants that might be built in the future. To this end CSIRO has developed its National Post Combustion Capture Facility that includes a large pilot plant which can capture up to 1000 tonnes per year of carbon dioxide. The plant is designed to be relocatable so capture studies can be performed on various power station sites around Australia.

(b) Storage

The skill base for advancing the science of underground storage largely exists in the parties to the Cooperative Research Centre for Greenhouse Gas Technologies. This includes the universities with petroleum schools (Curtin, Adelaide and New South Wales), plus the agencies (CSIRO and Geoscience Australia). Because of the overlap with petroleum technology, the effort in geosequestration could be increased through greater entrainment of petroleum activity. At the moment the petroleum industry is experiencing an acute skills shortage, but over time, if the predictions are true for falls in domestic oil production, this skill base could be directed more strongly toward geosequestration.

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4. Regulatory and approval issues governing geosequestration technology and trials

Geosequestration trials and commercial projects could be greatly assisted by the development of state and federal government legislation. At present geosequestration is not adequately covered by petroleum or environmental acts. The technical capability that is required to assess proposed storage sites overlaps strongly with current petroleum regulation, so amendments to current federal and state petroleum legislation may be the most appropriate way to proceed. Amendments to petroleum legislation could simplify applications involving enhanced oil recovery or enhanced gas recovery.

A central issue is the long term liability for a geosequestration site. Current thinking is that this liability will have to be assumed by governments, given the unknown lifetimes of specific companies. Within this context, however, it would be possible to devise schemes where geosequestration operators make financial provision or equivalently insure for future remediation in a trust held with government.

Periodic verification of the storage (of the amount stored and that no leaks to atmosphere are occurring) is likely to be required if carbon credits and carbon trading eventuates.

5. How to best position Australian industry to capture possible market applications

The existing petroleum industry has most of the skills required to build and operate carbon dioxide storage sites. The Australian domestic industry consists of a number of domestic companies and overseas-based companies. Many of these companies operate with both a domestic and international workforce.

Geosequestration technology is actively being developed by the large overseas-based multinational companies. Service providers to the petroleum industry are to looking at creating carbon divisions building business in activities like geosequestration. Examples of technologies that are being developed include carbon dioxide-resistant cements for use in sealing wells and tools for detecting and measuring carbon dioxide from within wells.

To position Australian industry to capture market applications, a first step is to undertake pilot or commercial geosequestration projects. This would be facilitated by partnerships between government, industry and innovators. Pilot and commercial geosequestration projects will more clearly identify the key technical challenges, and provide the environment where solutions can be developed and put into practice.

Countries that are among the first to introduce a carbon price signal are likely to be the first to have industry respond to building a business around carbon.

If geosequestration is to contribute significantly to global reductions in atmospheric carbon dioxide, it will need to be applied extensively outside Australia, especially in developing countries such as China and India. There is a potential role for developed countries like Australia to provide technical capability to assist developing countries, through research collaboration, bilateral agreements and technology transfer. International relationships can help position Australian industry to capture market applications overseas.

Potentially thousands of sites will be required if geosequestration is to be used to significantly reduce carbon emissions on a global scale. This means that the scale of the potential industry and market is very large.

Conclusions and Recommendations

- In developing solutions, it is important to recognise the magnitude of the problem of reducing atmospheric carbon dioxide.
- Continuing and increased support for research and development will help reduce costs and improve technology.
- International collaboration in industrial deployment, especially with the developing world, is needed if atmospheric carbon dioxide is to be reduced.
- Public education and consultation will assist implementation of technology.
- Government support for large-scale demonstration projects will help Australian industry develop capability in geosequestration.
- Geosequestration is part of a potential solution that will also need to include other technologies and improvements to energy end-use efficiency.

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