The Australian Electricity Industry and Geosequestration – Some Abatement Scenarios

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Abstract

Geosequestration is currently promoted by some in industry and government as the only realistic option to achieve major reductions in the Australian electricity sector's greenhouse gas emissions. However its technical feasibility, cost effectiveness, theoretical abatement potential and possible environmental risks are not yet known. While there is clearly value in supporting development of this technology, such support needs to be directed by risk-based technical assessments of this, and other possible abatement options.

In this paper we explore one aspect of such a technical assessment – the theoretical abatement potential and timing of geosequestration of coal-fired electricity emissions. This is done using scenario analysis drawing on Australian geosequestration data provided by the GEODISC program of the Australian Petroleum Cooperative Research Centre. For this study we assume the technology is proven to be feasible, cost effective and environmentally safe. Nevertheless, our scenarios suggest that geosequestration may have only limited ability to reduce coal-fired emissions below the present in the absence of wider abatement action. This is mainly because of the gradual rate at which it is likely to be introduced and poor source to sink matching for some major emission regions. These findings certainly support the view that geosequestration does not permit 'business-as-usual' growth in electricity supply and demand. In our scenarios emissions fell below 1999 levels only when coal-fired electricity generation grew at much lower annual rates than are currently projected. Thus even assuming the current technical, safety and cost problems with geosequestration can be solved, longer-term reductions in electricity-related emissions below present levels are still likely to require significant contributions from other abatement technologies, such as energy efficiency, efficient gas-fired CCGT and renewable generation.

1. INTRODUCTION

The Australian Government's stated climate change objectives are to meet our Kyoto target and prepare Australia for the large-scale emissions reductions required over the coming century (Australian Government, 2002). A combination of legislative measures, general programs and funding support for research, development and commercialisation are currently being pursued.

These measures seem unlikely to significantly reduce the electricity industry's GHG emissions, which are projected to continue growing annually up to and beyond 2020 (ABARE, 2003). This is in stark contrast to the estimated 60% reduction in world emissions required to stabilise greenhouse gas concentrations (WMO/UNEP, 1990). The CSIRO has equated this to an Australian reduction of 60% to 85% (Wright and Mitchell, 2000).

In order to reduce Australia's energy-related GHG emissions over the long term, both government and the electricity industry are placing considerable emphasis on geosequestration as the key emission reduction strategy. This involves capturing fossil fuel emissions either before or after combustion, and transporting them to be stored underground in geological formations. The Prime Minister's Science, Engineering and Innovation Council (PMSEIC) report on abatement options for stationary energy, *Beyond Kyoto – Innovation and Adaptation*, claimed that "A comparison of the abatement potential of the various technology options …. indicates that within the foreseeable future only carbon capture and geosequestration has the potential to radically reduce Australia's greenhouse signature" (PMSEIC, 2002). They therefore recommended that the Australian Government "establish a national program to scope, develop, demonstrate and implement near zero emissions coal based electricity generation" (PMSEIC, 2002).

However, geosequestration is an immature and unproven technology that is unlikely to be operational on a commercial scale in Australia for a decade or more. Its technical feasibility and commercial viability are unknown, as is the ability of underground sinks to store CO_2 for long periods of time. Thus a considerable amount of research is required before geosequestration's abatement potential can be determined. However important policy decisions have to be made now despite such uncertainties. A risk-based decision framework is therefore required that supports a portfolio of abatement options including gas-fired generation, renewable energy and demand side management. Scenario analysis can also play a useful role in exploring policy options, and forms the basis of the work presented in this paper.

While scenarios of abatement potential are fraught with uncertainty (see MacGill *et al.*, 2003), they have value in formulating policy if their estimations and assumptions are transparent. Here, in order to estimate geosequestration's 'best case' abatement capacity between 1999 and 2100, we assume that it is technically feasible, capable of long term storage, and commercially viable. We model different emission scenarios ranging from business-as-usual through to significantly lower growth of coal-fired generation, with and without geosequestration. Although knowledge of Australia's geosequestration capacity at this time is limited, risk-based and time-based estimates are available from the GEODISC program of the Australian Petroleum Cooperative Research Centre (CRC).

2. GEOSEQUESTRATION SCENARIO PARAMETERS

The scenarios modelled here were defined by the following parameters - see box. No claim is made that these scenarios cover all possibilities. Their role is to illustrate the impact that physical limits may have on geosequestration's capacity to reduce emissions from coal-fired electricity generation in Australia.

Scenario Parameters

1. Three projected rates of growth in coal-fired generation
2. The lifetime of existing and new plant
3. The efficiencies of existing and new plant
4. Geosequestration's ability to reduce emissions per unit of electrical output
5. The limits imposed by source to sink matching
6. The projected rate of penetration of geosequestration

1. Growth in black and brown coal-fired generation, and in carbon dioxide emissions

ABARE (2001) predicted electricity generation in Australia using black and brown coal to grow on average by 2.1% and 1.0% per annum respectively until 2019-20, and so be 53% and 23% higher than in 1998-99. In 2003, ABARE's annual projections for black and brown coal during the first quarter of this 20 year period were revised down considerably to 1.1% and 0.0% respectively after accounting for the effects of the NSW Greenhouse Gas Abatement Scheme and the QLD 13% Gas Scheme. Their projections then increased for the remaining period bringing the average until 2019-20 to 1.6% and 1.0% respectively (ABARE, 2003). Here for the business-as-usual scenario we have assumed annual growth rates of 2.0% and 1.0% through to 2100. This is because the efficacy of the State schemes is unknown - especially past 2020, and growth rates of 2.0% and 1.0% more accurately test geosequestration's effectiveness to reduce emissions in the absence of alternative types of energy supply and demand side management. As can be seen in Figures 3 and 4, these rates result in growth that is considerably less than that used by PMSEIC (2002) and so would tend to overestimate the effectiveness of geosequestration. Note also that emissions from gas-fired generation are not included in our modelling. This type of generation is predicted to grow by 5.4% per year until 2019-20, and would compete with coal for the geosequestration resource.

In order to estimate the impact of reduced growth in coal-fired generation, two additional rates were modelled after 2020: a 50% reduction in annual growth giving 1% and 0.5% for black and brown coal respectively; and a 75% reduction giving annual rates of 0.5% and 0.25% respectively.

According to the AGO (2002), electricity generation from black and brown coal was responsible for 97,937 kilotonnes (kt) and 61,804 kt of CO_2 emissions in 1999. Here it is assumed that CO_2 emissions from existing plant increase in proportion to the amount of electricity generated, after allowing for increases in efficiency as below.

2. Lifetime of plant

In order to account for the finite lifetime of new and existing plant, it is assumed all are decommissioned or upgraded 45 years after being commissioned.

3. Efficiency of generation

The assumed efficiencies of generation from the present to 2100 are shown in Table 1. These efficiencies are consistent with the 0.45% per annum increase assumed by ABARE (2003).

Table 1 Generation efficiency

	Generation Efficiency	
Year	**Black**	**Brown**
existing-2005	37	29
2006-2010	37	29
2011-2015	39	32
2016-2020	41	34
2021-2025	44	36
2026-2100	47	39

4. Emission reduction per unit of electrical output

Geosequestration is commonly said to confer zero emissions status to coal-fired generation, which can then be referred to as 'zero-emissions coal'. However this is not the case. The US Electric Power Research Institute (EPRI) conducted a technical evaluation of various types of fossil fuel power plant (both natural gas and coal), with and without CO_2 removal. They found that a high efficiency E-Gas IGCC plant with either pre- or post-combustion technologies achieved only 90% CO_2 removal per unit of energy produced (EPRI, 2002). The IEA recently completed a study on the performance and cost of new power stations with collection and storage of CO_2. This study found that the process to collect and store CO_2 emissions reduces them by about 80%, and as a result emissions from IGCC with geosequestration are about 40% of existing combined cycle gas turbines (Davison *et al.*, 2001). Thus while there is some variation in the degree of CO_2 removal, it is clear that geosequestration is not a 'zero-emissions' technology, it is a low emissions technology – see Figure 1.

In our modelling it is assumed that geosequestration can account for 90% of emissions (the upper limit of the 80%-90% range). Although the EPRI figure may be generous because it does not include the energy used in transport and storage, it is likely that technological improvements will increase the efficiency of extraction over time.

Note that this capture rate incorporates the decrease in generation efficiencies due to CO_2 capture, which for post- and pre-combustion systems were reported to be 25% and 20% respectively (Davison *et al.*, 2001).

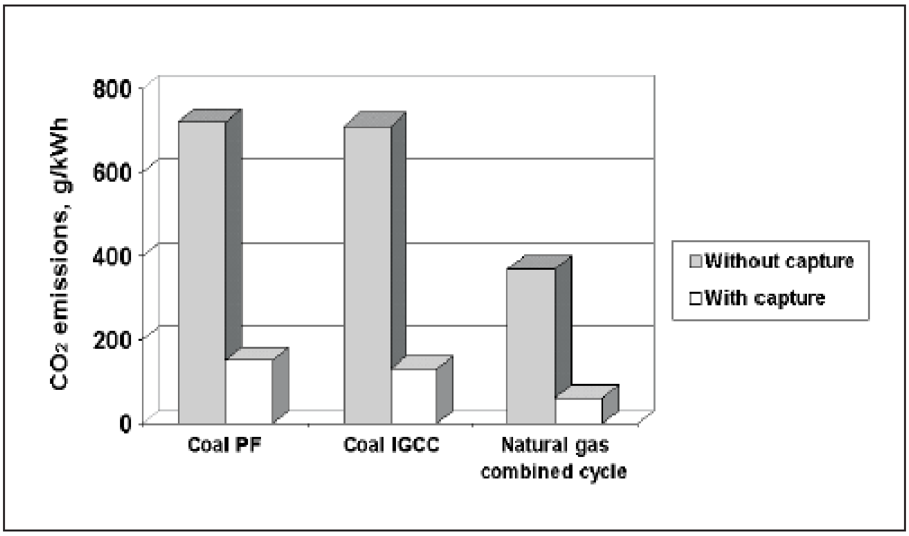


Figure 1 Effect of Geosequestration on CO_2 Emissions from Coal and Gas Generation
From Davison *et al.* (2001)

5. Which sources can be sequestered, and to what extent

Irrespective of its feasibility, geosequestration's capacity to reduce coal-fired electricity CO_2 emissions in Australia is limited. The CO_2 sources and geosequestration sites are often distant to each other, and so not all sources are suitable for geosequestration at reasonable economic cost. As part of the GEODISC program of the Australian Petroleum CRC, Geoscience Australia has analysed Australia's potential to geologically store carbon dioxide. They identified what are termed ESSCIs (Environmentally Sustainable Site for CO_2 Injection) which are sites deeper than 800 metres underground where it is thought that carbon dioxide could be safely injected and stored at temperatures and pressures to keep it in a liquid state. Although the potential for CO_2 storage in deep unminable coal seams and oil and gas fields is limited, CO_2 could be dissolved in deep saline aquifers and may react with unstable minerals to form secure and non-reactive salts. GEODISC has found 65 potential ESSCIs across Australia with sufficient theoretical capacity to store Australia's total emissions for the next 1600 years (Bradshaw *et al*., 2002).

When this geosequestration potential was matched with emission sources and existing gas fields, eight main nodes around Australia were identified. These are the Newcastle-Sydney-Wollongong area in NSW, the Latrobe Valley in Victoria, the Moomba gasfields and the Adelaide-Port Augusta area in South Australia, Perth-Collie and Burrup Peninsula in W.A., and the Gladstone-Rockhampton and Brisbane-Tarong areas in Queensland (Bradshaw *et al*., 2002).

Unfortunately stationary sources are not always located near sinks. Most of the geosequestration potential is located in the North West Shelf region – a considerable distance from the major emission nodes in the eastern seaboard. For example there is no known suitable sink near the emission hot spot spanning the Newcastle-Sydney-Wollongong area – see Figure 2. GEODISC acknowledge that "Broad brush style estimates of CO_2 storage potential at the global and continent scale are probably of limited value for future research programmes, and more sophisticated storage capacity estimates are required that integrate economics, source to sink matching and technical viability" (Bradshaw *et al*., 2002). Such estimates are complicated by the fact that deep saline aquifers, which make up 94% of Australia's geosequestration potential, are the least understood and therefore highest risk type of ESSCI. Although depleted oil and gas fields are known to have contained gases and liquids under high pressure for a considerable time, deep saline aquifers are not (Bradshaw *et al*., 2002).

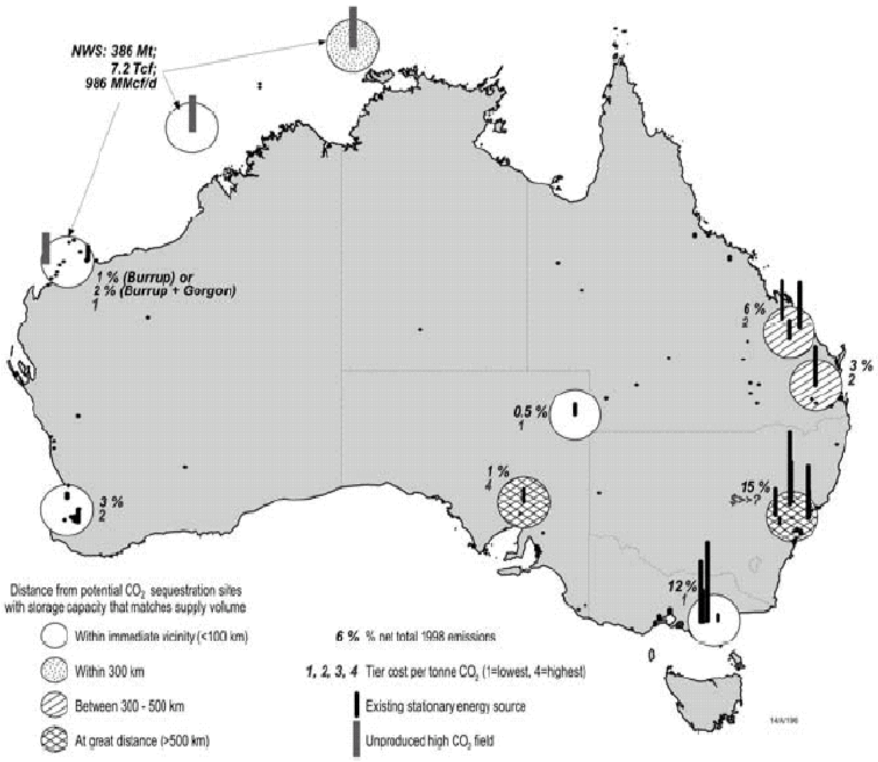


Figure 2 Map of each major emission node, their relative emissions that could be sequestered compared to the net total 1998 CO_2 emissions, the distance to nearest viable geological geosequestration site and an estimate of the cost based on a 4 tiered ranking.
From Bradshaw *et al*. (2002)

Thus according to Bradshaw *et al*. (2002), it is probable that only the sources in bold in Table 2 could be sequestered at reasonable economic cost. In our modelling it is assumed that until 2100, geosequestration of emissions from these sources is unlimited. It is also assumed that new and replacement plant will, in terms of their proximity to sinks, have the same opportunities for geosequestration as existing plant. Although pressure to locate generation plant close to sinks is likely, this would be counter balanced by additional electricity transmission requirements. Thus increased opportunities for geosequestration would come only at considerably increased costs.

Table 2 Emission nodes in Australia: Percentage contributions

	Percentage of 1998 emissions	
	Total[1]	**Black/Brown[2]**
Newcastle – Sydney – Wollongong (black)	15	37.5
Latrobe Valley (brown)	**12**	**30.0**
Brisbane – Tarong (black)	**3**	**7.5**
Gladstone – Rockhampton (black)	**6.4**	**16.0**
Perth – Collie (black)	**2.9**	**7.3**
Burrup Peninsula (gas)	0.9	
Port Augusta (brown) – Adelaide (gas)	1.3[3]	1.6
Moomba (gas)	0.5	
Total	**39.95**	**100**

[1] This value is the percentage that brown or black coal contributed to total Australian emissions in 1998 according to Bradshaw *et al*. (2002)
[2] This value is the percentage that each source contributed to Australian brown or black coal emissions in 1998
[3] This assumes 50% of emissions from this source are from brown coal, 50% are from gas

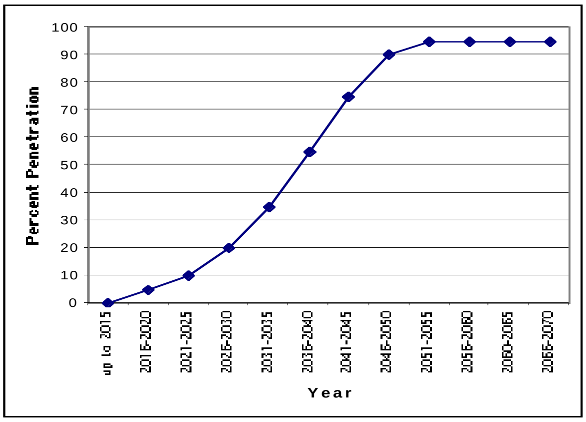
6. Rate of penetration of geoequestration

It is unlikely that geosequestration will be implemented on a commercial scale in Australia before 2016. The first large-scale demonstration plant, FutureGen in the United States, was announced in early 2003 is projected to take place over the next 10 years (DoE, 2003). Thus it was assumed that from 2016 onwards geosequestration is commercially and technically viable, and is applied to both existing and new plant incrementally according to Table 3. This follows a sigmoidal type curve as shown corresponding to: gradual introduction of a novel technology; followed by a phase of rapid growth due to increased familiarity; then a gradual phase as the more difficult and expensive sites are addressed.

Current cost estimates for post-combustion capture are greater than costs for pre-combustion capture, which could lead to slower penetration of the former. However these costs will change over time, and delaying implementation of post-combustion capture by even 10 years had little impact on the outcome in our modelling.

Table 3 Percentage penetration of geosequestration between 2016 and 2100

	Percentage Penetration of Geosequestration	
Year	**Black**	**Brown**
2016-2020	5	5
2021-2025	10	10
2026-2030	20	20
2031-2035	35	35
2036-2040	55	55
2041-2045	75	75
2046-2050	90	90
2051-2100	95	95



3. SCENARIO OUTCOMES

Annual emissions from coal-fired electricity generation between 1999 and 2100 were calculated, both with and without geosequestration, based on a BAU scenario - see Figure 3. The BAU scenario is shown below.

BAU Scenario Parameters

1. Annual growth of black and brown coal generation by 2% and 1% respectively across all major emission regions
2. Generation plant lifetime of 45 years
3. Generation efficiencies according to Table 1
4. Geosequestration achieving on average 90% reduction in CO_2 per kWh
5. Geosequestration in all areas except for NSW and SA
6. The rate of penetration given in Table 3

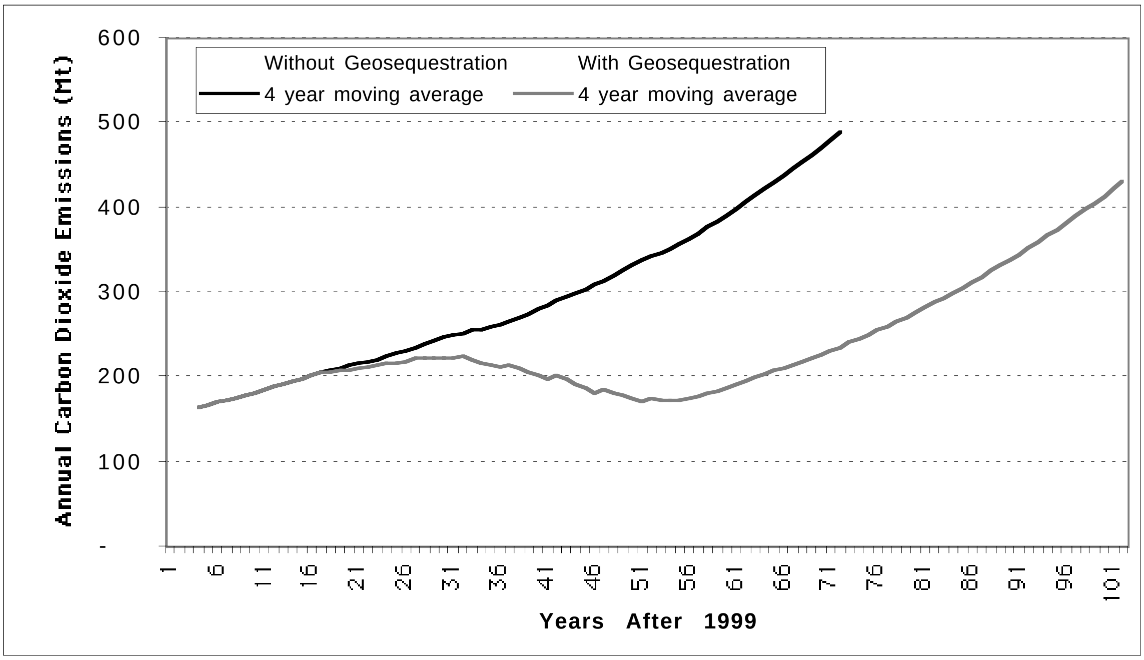
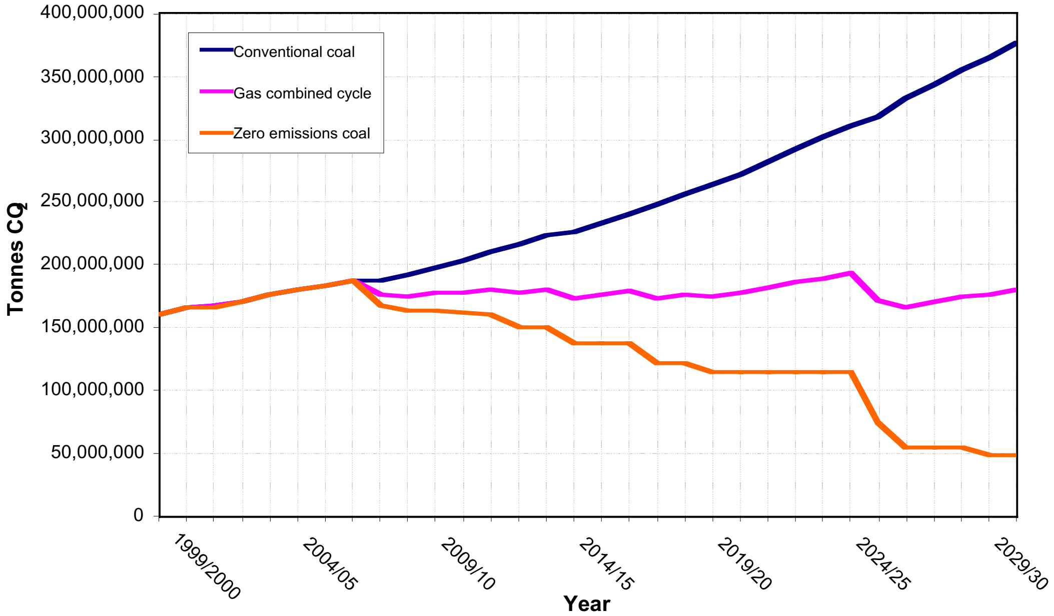


Figure 3 BAU annual carbon dioxide emissions from coal-fired plant in Australia, with and without geosequestration, between 1999 and 2100 – 4 year moving average

It is clear that geosequestration, even with the optimistic and generous assumptions given, does not reduce emissions from coal-fired generation compared to the present day. From 2016 emissions increase at a slower rate as geosequestration is phased in. By the time maximum penetration is achieved in 2051, emissions have dropped to their lowest point which is slightly greater than in 1999. From this point onwards they continue to increase as the lack of geosequestration in NSW and SA becomes evident, finally reaching just under 3 times 1999 levels in 2100. Superimposed on this is the impact of plant becoming more efficient – which can also be seen in the 'Without Geosequestration' scenario.

This is in stark contrast to admittedly 'extreme' scenarios presented by PMSEIC which show 'zero emissions coal' reducing coal-fired emissions from 2006 onwards so that annual emissions are down to 50Mt by 2029-30 – see Figure 4. This PMSEIC reduction is especially remarkable given the considerably higher projected emissions in the absence of geosequestration, reaching 370 Mt by 2030.



(Source: Roam Consulting – unpublished data 2002)

Figure 4 Emissions Projections According to PMSEIC
From Batterham (2003); the x-axis extends from 1999/2000 to 2029/2030.

It is possible that use of coal will not continue to increase beyond 2020 at the rates predicted between the present and 2020. If the rate of growth is halved, annual emissions do in fact drop below 1999 levels before gradually increasing to 25% higher than 1999 levels in 2100 – see Figure 5.

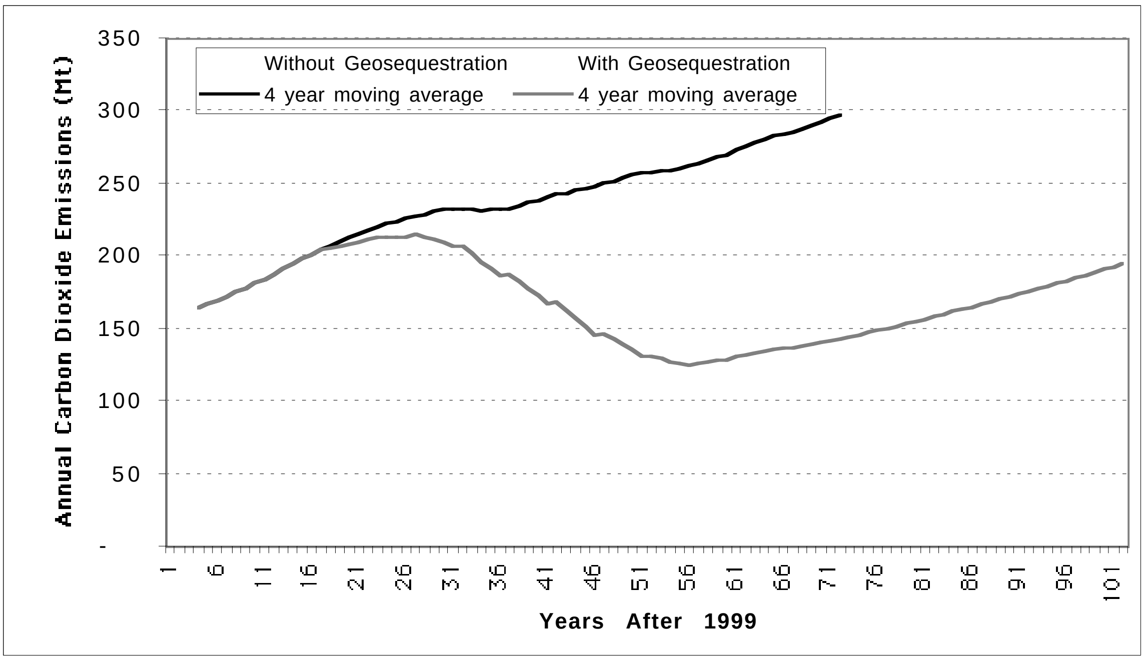


Figure 5 Annual carbon dioxide emissions from coal-fired plant in Australia, with and without geosequestration, between 1999 and 2100, assuming annual growth in electricity generation from black and brown coal of 1.0% and 0.5% respectively – 4 year moving average

When growth in coal-fired generation is further reduced to less than half that predicted to occur between now and 2020, more significant long term reductions in annual emissions are achieved. However, even when growth is reduced by 75%, annual emissions drop no lower than about two thirds of 1999 levels, and in 2100, are just over 80% what they were in 1999, and increasing – see Figure 6.

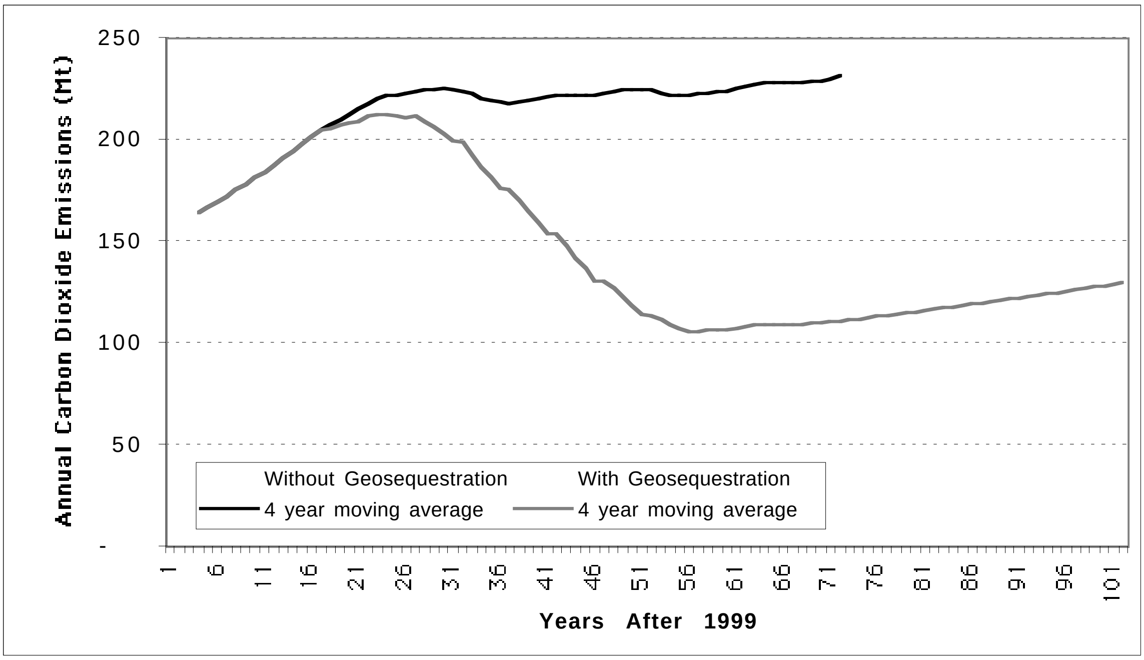


Figure 6 Annual carbon dioxide emissions from coal-fired plant in Australia, with and without geosequestration, between 1999 and 2100, assuming annual growth in black and brown coal use of 0.5% and 0.25% respectively – 4 year moving average

Emissions could certainly be further reduced if any increase in generation capacity over time in SA and NSW was actually constructed in QLD or Vic, and electricity sent to SA and NSW via upgraded transmission lines. If all generation is moved to regions with sequestration options then emissions could be much greater than that modelled here. Alternatively, it may be cheaper to retain new generation in NSW and SA and pipe the carbon dioxide to the nearest sinks in QLD and Vic. However, preliminary GEODISC analysis excluded this option because it would be too expensive (Bradshaw *et al*., 2002).

4. CONCLUSION

Here we have modelled the theoretical physical capacity of geosequestration to reduce emissions from coal-fired electricity generation between 1999 and 2100 in Australia. On the basis that geosequestration is technically feasible, capable of long term storage, and commercially viable, these scenarios suggest that:

- The main limitation for geosequestration in Australia is likely to be poor source to sink matching. This means that despite a very large theoretical national capacity, geosequestration in NSW and SA may not feasible at currently acceptable prices.
- Business-as-usual growth of the electricity industry with 'added-on' geosequestration is not an option if major emissions abatement is to be achieved. Assuming average growth between 2000 and 2100 of 2% and 1% for black and brown coal-fired electricity generation respectively, annual atmospheric emissions would be just under 3 times greater in 2100 than in 1999. Note that emissions due to electricity generation in Australia would be even higher than this because other point sources, such as gas-fired plant, that are predicted to grow by 5.4% per annum until 2019-20, have not been included in this assessment.

- Long term reduction in annual emissions from these sources is achieved through geosequestration only when annual growth in coal-fired generation between now and 2100 is reduced to significantly less than that predicted to occur between the present and 2020.

These findings support the view that while geosequestration may play a very useful role in achieving longer-term emissions abatement within the Australian electricity sector, it is unlikely to be able to deliver this abatement alone. Given the many risks and uncertainties in this technology, a range of abatement options including energy efficiency, gas-fired generation and renewables is almost certain to be required. Australia's national energy policy framework should reflect this likelihood by including this range of abatement options. There are very great risks in attempting to pick a single technology 'winner'.

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