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AQUIFER DISPOSAL OF CARBON DIOXIDE: AN EXAMINATION

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SUMMARY

This paper examines the technical feasibility of permanent carbon dioxide (CO₂) disposal and storage in deep aquifers.

Australia does not have a R&D program in place which investigates the technical and economical feasibility of CO₂ sequestering into aquifers, depleted petroleum reservoirs, or other geological structures.

Aquifers at a depth of more than 800 m containing saline or brackish formation water and a sealing barrier on top provide the most promising storage sites. CO₂ storage in deep aquifers is technically feasible, the current knowledge of injection technology being adequate. The deeper the aquifer the better. With increasing pressure with depth, the differences between CO₂ and water become less extreme.

The environmental effects are thought to be minimal, with advanced planning, monitoring and proper material selection. A risk assessment should be undertaken to analyse long-term security with respect to sudden leakages and cap-rock fracturing.

Estimates indicate that in Australia coal and gas-fired power stations generate about 0.25 Gt y⁻¹, and that CO₂ aquifer storage capacity is sufficient for about 20 years.

If CO₂ emission abatement does not become a global effort, the likelihood that any ameliorating activity in Australia will yield a measurable improvement is nominal at best. CO₂ aquifer disposal and sequestering in general will lead to an enormous increase in cost of electricity production. The cost per tonne of disposed CO₂ is estimated at between US\$8 and US\$16 depending upon size and location.

The technology in Australia is available to store CO₂ in deep aquifers. But foremost, a comprehensive feasibility study needs to be carried out to assess if the aquifer storage capacities are available in Australia's coastal regions and if socio-economical impacts are manageable.

BACKGROUND

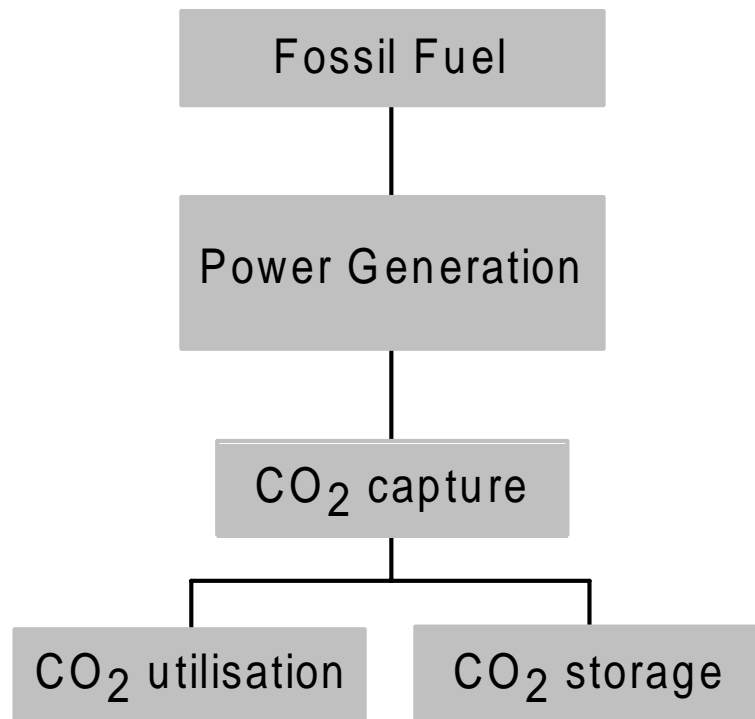
It is questionable whether energy conservation and the application of renewable energy can solve the CO₂ problem fast enough. It is concluded that CO₂ removal can contribute substantially to a reduction of CO₂ emissions, but it is not known yet what technologies are the best to recover, utilise, store and dispose CO₂. In general, the application of pre-combustion techniques to recover CO₂ seems to be more attractive than post-combustion techniques. To make CO₂ removal and disposal a feasible option for substantial CO₂ emission reduction, massive R&D efforts are needed to reduce its costs, to investigate its environmental impact and to understand how it can be applied within the concepts of sustainable development. In several countries, important R&D programs (e.g. the Alberta Energy, TNO Delft) have been initiated, and some feasibility studies (e.g. Stanley Industrial consultants Ltd, 1993, Denmark, UK studies) have been conducted. International cooperation is achieved by the Greenhouse Gas R&D program of the International Energy Agency. As far as I am aware, Australia is not participating in this program nor conducting any research or feasibility studies on CO₂ aquifer disposal, although the Bureau Resources Sciences has expressed an interest (pers. com. D. Rossiter).

INTRODUCTION

In the coming decades, the emission of CO₂ from human activity may increase from about 7 GtC in the year 1990 to above 20 GtC in the year 2100 (Houghton et al., 1990), this may enhance the greenhouse effect. The global anthropogenic CO₂ emission from fuel combustion in 1990 was 12.6 Gt CO₂, Australia contributes about 2.2 % (extracted from the United National Framework Convention on Climate Change, the 3rd UNFCCC Kyoto Conference official website <http://www.unfccc.de/>, Table A2, FCCC/CP/1996/12/Add.2.). About 57.6% of Australia's CO₂ emissions are from energy and transformation industries, 24.6% from transport. To limit the risk of a climate change to sustainable levels, it is proposed we should reduce the emission of CO₂ (to below 3 GtC per year) and other greenhouse gases (IPCC, 1990).

A general reduction in CO₂ emissions can be accomplished by:

- improved or alternate energy uses (improvements likely to be slow, no immediate solutions)
- the capture and utilisation of CO₂ (technical feasible, overall effect is likely to be small, effect is long term)
- the long-term disposal of CO₂.



What is needed is effective permanent disposal.

There are several options for disposal of CO₂: Biological disposal refers to the concept of CO₂ emission uptake by plants, such as algae and forests. This is ecologically attractive, but it is a long-term concept. It does not offer a permanent solution to the problem, because plants remove the CO₂ from the atmosphere in photosynthesis to form starches, sugars and other organic compound. Bacterial degradation releases CO₂ back into the atmosphere.

Disposal into the deep ocean may seem attractive for coastal CO₂ emitters. Storage is possible below 3000 m water depth, which would delay equilibration with the atmosphere for several hundred years. The dynamic of the processes are not well understood, also the impact of CO₂ disposal on the environment and on ocean ecosystems is not known (Turkenburg, 1992).

Depleted oil and gas reservoirs have limited capacity to store CO₂ and are often not located near the CO₂ emitters as is the case in Australia (Koide et al., 1992). Underground storage of CO₂ in depleted oil and gas reservoirs will not be examined in this paper.

That leaves disposal of CO₂ into deep aquifers. CO₂ is an ideal gas for aquifer disposal because of its high density and high solubility in water at the relatively high pressures which may be imposed in aquifers. There are two types of trapping mechanisms of CO₂ in aquifers: Hydrodynamic trapping mechanisms occur when CO₂ is injected into the aquifer and the gas does not react with the minerals of the aquifer matrix (inert gas). In the second type, the CO₂ reacts with the minerals, is converted to carbonate minerals and thus is rendered immobile (mineral trapping; Gunter et al., 1993).

To be able to determine the role aquifer storage of CO₂ may have in greenhouse gas emission reduction strategies, the following questions should be addressed:

- is aquifer storage technically feasible?
- how much CO₂ can be stored?
- what are the environmental side-effects?
- what are the economical costs of CO₂ storage?

No technical and economic feasibility study on underground storage of CO₂ in Australia has been conducted to date (pers. com. AGSO, BRS, CSIRO).

TERMINOLOGY

It is important to understand what certain hydrogeological and geochemical terms in this paper mean. Suitable sites for injection and storage of CO₂ gas are located within sedimentary basins, which are accumulations of sedimentary rocks deposited over long geological periods. Tectonic forces have acted to create their basin-like structure. All sedimentary rocks (except for salt formations) contain spaces between their mineral grains that are filled with fluids or gases, water being the most common fluid. The sedimentary formations are hydrogeologically classified into three types: aquifers, such as sandstones and limestones, from which groundwater can be pumped or injected; aquitards, such as shales and siltstones, from which groundwater cannot be pumped, but through which movement of water still occurs over geological periods of time; and aquicludes, such as evaporites, that are barriers to fluid flow. Permeability is a term used to describe the ability of the porous medium to allow flow of fluids. In sedimentary basins, deep groundwater moves cross-formationally on the order of less than one centimetre to one metre a year.

The groundwater in these basins is typically a few thousand years old. The groundwaters range in chemical composition from freshwater to brines. When CO₂ is injected into a deep aquifer in a sedimentary basin, the CO₂ will react with the chemical constituents of the groundwater or with the minerals that comprise the aquifer rocks. To understand the principles of aquifer injection of CO₂ it is essential to understand the hydrodynamics (flows) of groundwater in sedimentary basins and the various chemical reactions that may take place between the injected gas, the groundwater, and the minerals of the aquifer matrix.

BEHAVIOR OF CARBON DIOXIDE IN DEEP AQUIFERS

Pressure–temperature considerations

For disposal underground, the CO₂ will need to be removed from the power station flue gases by compressing it to a pressure of about 60 bars at ambient temperature (15°C). Under these conditions the CO₂ will be a relatively pure liquid, small quantities of SO₂ and NO_x may be present. In coal gasification power plants which are common in Australia, the CO₂ may contain potential impurities such as HCl and H₂S.

Supercritical CO₂ is considered as a necessary attribute in any significant CO₂ disposal system due to its high density. Supercritical here is defined as any pressure above 7400 kPa when handling pure CO₂. Supercritical CO₂ acts much like a gas, with much greater changes in density than with liquids as pressure and temperature are varied. The critical temperature at which CO₂ will be in a supercritical stage is 31.1°C. Above this temperature CO₂ cannot exist as a liquid. Supercritical CO₂ is non-polar, is immiscible in water, and is a very good solvent for organic compounds, one reason why it has been used in enhanced oil recovery (EOR) operations. As dry CO₂ passes through the aquifer, there will be appreciable water evaporation into the CO₂ rich phase – up to 0.25% of the dry CO₂ weight.

The average geothermal gradient in the onshore sedimentary basins of Australia is about 25–26°C km⁻¹. Assuming that the surface temperature is about 15°C, at depths of more than 800 m the CO₂ will be in a supercritical stage. At temperatures below 31.1°C, at a depth less than 800 m below the surface, CO₂ would exist as a compressed gas.

Solubility in groundwater

In most water-rock systems, CO₂ is the most abundant gas, but rarely exceeds 2 mol % in solution. CO₂ solubility in water decreases sharply from 25°C to 250°C and with increasing salinity CO₂ solubility decreases by a factor of 4 for a 6 molal solution

(Holloway et al., 1993). This means that CO₂ disposal in saline aquifers in sedimentary basins is less efficient and implies that low saline aquifers are better sites for CO₂ disposal.

Reaction with the host rock

Formation damage may occur as a result of the removal of carbonate cements from the aquifer sandstones due to the increase P_{CO_2} in pore fluids. Since supercritical CO₂ is non-polar and water immiscible, it is unlikely that it will cause appreciable reaction with the host rock. A small amount of injected CO₂ will dissolve in the formation water as bicarbonate which will dissolve carbonate minerals present in the host rock. An increase in P_{CO_2} will increase the bicarbonate concentration of groundwater and hence calcite dissolution. Porosity will be produced in the aquifer, depending on P_{CO_2} , salinity and temperature of the groundwater.

The reaction of feldspars, micas and clays in the aquifer with carbonic acid will result in the production of kaolinite, and/or silica. The volume change involved in these reactions are small, however, the production of kaolinite could constrict pore throats in the aquifer and thus reduce permeability.

Groundwater pollution

The contamination of potable groundwater would occur if CO₂ escaped as a result of a seal failure to the host formation, a leak in the injection system, or if unidentified pathways such as faults or fractures existed. The effect of CO₂ on groundwater quality depends on the buffering capacity of the aquifer system. If the aquifer matrix is carbonate-rich, then dissolution of the rock and an increase in bicarbonate concentration of the groundwater would result. Groundwater may become acidic, if the buffering capacity is depleted or poor. Consequently, oxygen may be depleted, and iron, manganese and heavy metals which are more soluble in lower pH or Eh may enter solution.

Injecting CO₂ into a formation will displace other fluids such as saline groundwater which may migrate to and contaminate other groundwater resources at shallow depths.

Geotechnical problems

The stability of the ground may be affected if minerals are dissolved, or if pressures greater than geostatic are applied. Overpressuring may result in formation fracturing and absidence. Fracturing will increase permeability and porosity but may also damage the integrity of the sealing barrier. Overpressures may raise the level of the ground surface;

mineral dissolution may allow the surface to subside. The greater the depth of the CO₂ storage, the less the effects may on the surface. The release of tectonic stresses and micro-earthquakes may be a problem in certain sedimentary basins which needs consideration.

GEOLOGICAL CONSIDERATIONS

Underground structures for CO₂ storage

The basic idea of aquifer storage is that CO₂ be stored in a geological structure in such a way that it can not escape in the short-term into the atmosphere. The structure must therefore contain a barrier to CO₂ of impermeable or low-permeable strata. Such a strata may consist of clay or salt. In principal, CO₂ can be stored in any gastight underground structures which is not completely filled. Or which is occupied by a fluid that can be removed, e.g. water.

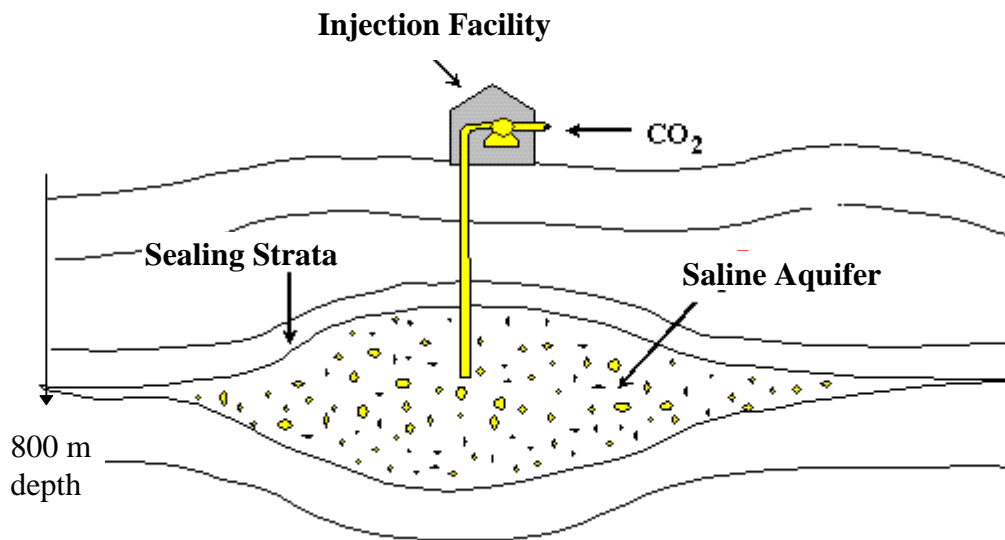
Underground structures which potentially offer the largest storage capacity are aquifers. The structure and the interconnection of the pores gives the bed the property of permeability, i.e. gases and fluids can flow through the aquifer. The porosity, permeability and a sealing caprock (which seals the top of an aquifer) can make an aquifer suitable of CO₂ storage. Aquifers can be found all over Australia, this is relevant in connection with the transport distance from the CO₂ recovery unit to the storage site. The real problem is to find an aquifer system which has the correct hydraulic properties and sealing strata. Basically, we need to find an aquifer compartment, or as it is called in the petroleum industry a reservoir which has the ability to trap hydrocarbons. That is why depleted oil or gas fields are ideal sites for CO₂ storage. The problem in Australia is that these depleted reservoirs are too far away and mostly offshore from the major coastal cities, which makes CO₂ storage in depleted reservoirs in Australia most likely uneconomical. We have the techniques and knowledge in Australia to find these underground structures for CO₂ disposal near CO₂ generating power plants or industry. A geological and hydrogeological reservoir study needs to be carried out to investigate the potential of aquifer storage in Australia. Institutions in Australia who can jointly conduct such a study are AGSO, CSIRO, universities and a consortium of the petroleum and mining industry.

The following constraints define a suitable aquifer for CO₂ storage (van der Meer, 1992):

1. it should possess intergranular pore space within the rock (porosity)
2. its constituent rock must be permeable to a fluid
3. the top of the aquifer must be located at a depth of more than 800 m

4. a cap-rock seal should directly overlie the aquifer
5. the aquifer should be part of a geological trap structure.

These criteria can be used to select appropriate aquifers that are suitable for long-term CO₂ storage provided they contain a geological trap or trapping mechanism (e.g. mineral trapping)



Schematic illustration of CO₂ injection into a deep isolated aquifer
(source: <http://www.ieagreen.org.uk/>)

TECHNICAL CONSIDERATIONS FOR CO₂ INJECTION IN AN AQUIFER

Injection of fluids or gases into deep aquifers or reservoirs is not often practised, although in the last few decades, technical advances in injection and storage of liquid petroleum in salt mines, re-injection of natural gas in gas fields, injection of water in aquifers, and the storage of compressed air in aquifers has been made. CO₂ injection has only been used for EOR in oil fields. Plans to store CO₂ have been developed in Norway (Kaarstad, 1992), Denmark (Krom et al., 1993) and Canada (Hitchon, 1996).

The CO₂ is injected into the geological structure through one or more wells. These wells have to be drilled, using techniques that are applied in petroleum production. In some instances, CO₂ must be compressed at the well site under higher pressure in order to meet

the required well-bottom pressure. Sufficient security measures must be taken to avoid blow-out of the CO₂.

Experiences in fluid injection for EOR operations yield two possible limiting aspects in respect to CO₂ storage in aquifer: well/formation damage and injection pressure (van der Meer, 1993). All problems associated with well clogging or well damage are understood and technically solvable, the additional cost of limiting these problems may exceed the economical efficiency of a CO₂ aquifer storage project.

The injection of the CO₂ into an aquifer will result in an increase of the fluid pressure of the aquifer, which causes a decrease in effective stress (the grain pressure reduces). It is expected that a formation pressure increase, to a level equal to the grain pressure or to the overburden pressure, will have no adverse effects on the hydraulic properties of the aquifer formation or on the properties of the surrounding formation. This would need to be investigated for each individual site. If the fluid pressure in the aquifer exceeds the overburden pressure, there is risk of fracturing and absidence. For example, if the aquifer is at about 800 m depth the hydrostatic gradient is about 10.5 kPa m⁻¹ and the geostatic gradient about 22.6 kPa m⁻¹, the mean pressure for injection can be 9680 kPa. The hydrostatic gradient is dependent on the salinity of the groundwater, the more saline the water the steeper the gradient and the lower the allowable injection pressure. In parts of sedimentary basins, aquifers or reservoirs can be overpressured due to compartmentalisation of the strata or due to ascending groundwater flow systems. In these regions the formation pressure gradient is above the hydrostatic pressure gradient reducing the injection pressure even further.

HYDRODYNAMIC TRAPPING

From a hydrodynamics point of view, an additional selection criteria for a suitable site for CO₂ storage, is to identify regions in an sedimentary basin which have a hydrostatic or subhydrostatic pressure regime. Regions of descending groundwater flow are preferable over regions where groundwater is ascending cross-formationally to shallow depth. In regions where groundwater is flowing downward and downgradient the residence time of the groundwater is much larger, enhancing the effects of CO₂ hydrodynamic and mineral trapping. This additional constraint has not been applied in previous and current CO₂ aquifer storage studies. Hydrodynamic methods and techniques are available to identify these regions (Otto et al., 1997). The geological time-scale trapping of CO₂ in deep regional aquifers is called hydrodynamic trapping because it depends on the groundwater flow systems of a sedimentary basin.

MINERAL TRAPPING

Reactive CO₂ sinks are the most effective for permanent long-term disposal. Therefore, the chemistry of formation water and the rock mineralogy play an important role in determining the potential for CO₂ capture through geochemical reactions. The reactions sequester the CO₂ in immobile form as carbonate minerals. This mineral trapping mechanism has been studied theoretically and by modelling by (Gunter et al., 1993; Hitchon, 1996).

Gases such as CO₂ when injected into an aquifer dissolve in the aqueous phase and alter the pH through reactions coupled to the dissociation of water. Some of the CO₂ dissolves as bicarbonate in water. Only minor amounts of bicarbonate (and a proton) will be produced. The amount of dissolved carbonates is nearly independent of depth and temperature from a depth of 750 m on (van der Meer, 1992). Gunter et al., 1993 concluded that brackish and dilute formation water can take up more CO₂ than brine water. The maximum solubility of CO₂ is limited in brines due to the salting-out effect at higher ionic strengths. This is another constraint that brines alone are not acceptable sinks for CO₂. However, because the CO₂ dissolution also results in a lower pH and acid conditions in the water, silicate minerals (feldspars and clays) present in the aquifer are attacked. Free ions such as Ca, Mg and Fe are released. The free calcium ion reacts with the bicarbonate to precipitate calcite. This reaction forms the basis for sequestering CO₂ as the mineral calcite. Similar reactions occur for the formation of dolomite and siderite. Mineral traps of CO₂ are most effective when the aquifer matrix contains minerals that absorb the protons such as the basic silicate and clay minerals. Consequently, mineral trapping of CO₂ is favoured in sandstone aquifers over carbonate aquifers containing brackish formation water.

AQUIFER STORAGE CAPACITY

It is necessary to adequately estimate the potential aquifer storage capacity at a local scale, but also at regional, national scale. This has not been done for Australia and is beyond the scope of this examination. (Koide et al., 1993) estimates that the potential for CO₂ storage in Australia and Oceania is about 10.1 Gt C. It is most likely an overestimate since no economic and geographical considerations were included.

The capacity of an aquifer to store CO₂ will be determined by the size of the aquifer system, the effective porosity, and the density of the CO₂. The storage capacity of an aquifer will greatly depend on the local geothermal gradient and pressure gradient, the groundwater salinity and to what extent the groundwater can be displaced.

To get an idea about the capacity of CO₂ aquifer storage, I have reviewed previous studies from other countries using the following parameters modified after (Hendriks et al., 1993): specific aquifer volume, percentage of the reservoir to be filled, the density of CO₂ under aquifer pressure and the area with aquifers suitable for CO₂ storage. A similar approach should be undertaken for Australian conditions.

The specific aquifer volume is the volume available for CO₂ storage for a region and is determined by the total aquifer volume, the average porosity and the percentage of the aquifer that is not suitable for CO₂ storage based on the selection criteria described above. Engelenburg et al., 1992 assume an aquifer thickness of 200 m for the Netherlands with a porosity of 20%. Koide et al., 1992 assume a worldwide average thickness of 300 m with a porosity of 20%. Huurdeman, 1992, and Van der Meer et al., 1992, took aquifer depths, structural traps into consideration, which meant a reduction of the volume to 5–20% (Table 1). The amount of CO₂ in the aquifer depends on the part of the aquifer that can be filled, called the sweep efficiency. Various authors have assumed different percentages (Table 1).

Table 1. Factors that determine the storage potential for CO₂ in aquifers, from different publications (modified after Hendriks and Blok, 1992)

Region	Netherlands ¹	Netherlands ¹	Netherlands ²	World ³	World ⁴
specific aquifer (m ³ m ⁻²)	40	40	0.1–0.4	1.6	60
sweep efficiency	9	100	100	2	20
CO ₂ density in aquifer (kg m ⁻³)	150/650 (displacement)	50/55 (solution)	714	900	41 (solution)
storage capacity per unit area (kt km ⁻²)	900	2050	80-300	30	492
fraction of area suitable	100	100	80	10	0.4
total storage capacity (Gt)	220	460	2.5–10	425	320

¹ Van Engelburg and Blok, 1992; ² Huurdeman, 1992; ³ Van der Meer et al., 1992;

⁴ Koide et al., 1992.

The figures used for the CO₂ density varied from 150 to 900 kg m⁻³ due to differences in depth and temperature or pressure gradients. In the studies in the Netherlands, it is assumed that all of the area contains suitable aquifers. For the world Koide et al, (1992)

and Van der Meer et al. (1992) assume 44% and 10%, respectively. Koide et al, (1992) also included economic and other limitations and assumed that only 1% of the remaining area is suitable. All publications state that the areas are possibly underestimated because of limited knowledge.

If the conservative approach by Van der Meer et al., (1992) is followed, the global storage capacity is about 425 Gt CO₂. Possibly, the area containing aquifers is much higher than assumed. If a non-conservative approach is followed the specific aquifer volume will be at least an order of magnitude higher which would lead to an estimate of the global storage capacity exceeding 10 000 Gt CO₂ (excluding socio-economic and geographical constraint).

If we assume that for Australia only about 2% of its area is appropriate for CO₂ storage, because of the proximity of the power plant, I estimate using the conservative approach less than 5 Gt of storage capacity is available for CO₂. Australia generates about 1.6 Gt CO₂ per year from the energy and transformation industries (statistic from UNFCCC website). Table 3 shows estimated CO₂ emission values from coal and gas-fired power stations for the States and Territory. It was assumed that the power station operates 24 hours. For 1 MW it was assumed that a coal-fired power station emits 1 t of CO₂ per hour, and 0.6 t CO₂ per hour for gas-fired power stations (pers. com., Western Power).

This indicates that in Australia coal and gas-fired power stations generate about 0.25 Gt y⁻¹, and that CO₂ aquifer storage capacity is sufficient for about 20 years. These estimates are very crude and indicative only. It is interesting to note that the main CO₂ emitters are located on the east coast of Australia. A proper investigation is required to determine the aquifer storage capacity in Australia. Local circumstances will generally determine the usefulness of aquifer storage, but CO₂ disposal credits may well extend across state boundaries, encouraging large scale disposal at one site than needed for local CO₂ emission reduction commitments.

Table 3. Estimated CO₂ emission from coal and gas-fired power stations in Australia (source: Electricity Australia 1996)

State and Territory	power station	number	capacity (MW)	CO ₂ emissions (t/day)	CO ₂ emissions (Mt/yr)
NSW	coal-fired	9	11641	279384	100
	gas-fired	5	307.5	4428	1.6
Vic	coal-fired	7	6870	164880	60
	gas-fired	2	498	71712	2.6
QL	coal-fired	5	4886	117264	42.8
	gas-fired	4	1530	22032	8
SA	coal-fired	5	2080	49920	18
	gas-fired	4	295.5	4255.2	1.5
WA	coal-fired	3	1280	30720	11.2
	gas-fired	6	1496	21542.4	7.8
TAS	coal-fired	1	240	57460	2.1
	gas-fired	1	10	144	0.05
NT	coal-fired				
	gas-fired	4	127.9	1841.8	0.6
Total					256

SOCIO-ECONOMICAL CONSIDERATIONS

The implementation and operation of a facility which can sequester CO₂ in a deep aquifer will be expensive. In the published cost estimates, it was assumed that the power station is within a 30–50 km radius, if not the disposal cost in US\$/tonne CO₂ is estimated to increase by about 30%. The accuracy of the cost is in the order of 30%.

The cost per tonne of CO₂ disposed of ranges from US\$8.6 to \$16 per tonne and about 85% of these costs are associated with the purification and pressurising stages (Stanley, 1993). Cost estimates for Denmark are about US\$14.5 per tonne when sequestering 1.3 Mt CO₂ per year using a 35 km pipeline, 10% discount rate and including operational costs (Krom et al., 1993). Koide et al., 1992 estimate that CO₂-emission-free electricity in Japan may become possible with a cost increase of 35% for a natural-gas fired power station and of 60% for a coal-fired power station. No figures are available for Australia.

Sociological aspects with disposal of CO₂ must be addressed. It is not the risk question, but a question of public willingness to pay for a benefit they will probably not realise within their lifetime. If CO₂ emission abatement does not become a global endeavour, the

likelihood that any ameliorating activity in Australia will yield a measurable improvement is nominal at best. CO₂ aquifer disposal and sequestering in general will lead to an enormous increase in cost of electricity production.

STATE OF READINESS

From the literature review I conclude that a minimum of 10 years will be required to establish a disposal facility and to gain political approval. A status evaluation for Australia can be conducted in three technical areas using the selection criteria discussed previously for reservoir identification and characterisation, risk evaluation and waste availability. The transport of gases at the proposed pressures is technically well developed.

Foremost, it is necessary to conduct a comprehensive technical and economical feasibility study on CO₂ disposal in deep aquifers in Australia.

CONCLUSIONS

Australia does not have a R&D program in place which investigates the technical and economical feasibility of CO₂ sequestering into aquifers, depleted petroleum reservoirs, or other geological structures.

Aquifers at a depth of more than 800 m containing saline or brackish formation water and a sealing barrier on top provide the most promising storage sites. CO₂ storage in deep aquifers is technically feasible, the current knowledge of injection technology being adequate. The deeper the aquifer the better. With increasing pressure with depth, the differences between CO₂ and water become less extreme.

Hydrodynamic and mineral trapping are promising mechanisms to store CO₂ in deep aquifers depending on the aquifer mineralogy and formation water chemistry as well as the hydrodynamic regime in a sedimentary basin.

Once a site is selected formation waters should be rigorously tested for short-term and long-term chemical changes.

The environmental effects are thought to be minimal, with advanced planning, monitoring, and proper material selection. A risk assessment should be undertaken to analyse long-term security with respect to sudden leakages and cap-rock fracturing.

The cost per tonne of disposed CO₂ is estimated to be between US\$8 and \$16 depending upon size and location.

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