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Why Brown Coal Should Stay in the Ground

Greenhouse implications of the proposed expansion of brown coal exploration and mining in Victoria

Prepared by:

Institute for Sustainable Futures, UTS

UTS
University of Technology, Sydney

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Greenhouse implications of the proposed expansion of brown coal exploration and mining in Victoria

Final Report

Author:
Keith Tarlo

Institute for Sustainable Futures

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EXECUTIVE SUMMARY

On 3 October 2001, the Victorian Minister for Energy and Resources, The Hon. Candy Broad, called for exploration tenders for large tracts of the State's vast brown coal reserves.

In greenhouse terms, the resources up for tender are equivalent to one half of the entire amount of fossil fuel burnt globally in one year. At the national level, this expansion has the potential to single-handedly wipe out the modest gains from the 2 per cent Commonwealth Mandatory Renewable Energy Target, the Greenhouse Gas Abatement Programme and State sustainable energy initiatives like those of the Sustainable Energy Authority of Victoria.

The statement by the Minister creates the reasonable expectation that any successful tenderer could eventually proceed to exploiting the resource. The tender is taking place in a policy vacuum as if action on climate change were not foreseeable and as if successful tenderers will not have to pay for their carbon dioxide production within the lifetime of their projects. Forward-looking companies think otherwise:

> BP's business judgment is that the inevitable outcome is a higher price on burning carbon.[1]

Can the expansion of brown coal mining be reconciled with meeting the Government's stated objectives of "reduced greenhouse gas emissions" and "maximising the uptake of renewable energy and the implementation of energy efficiency programs"? This briefing paper demonstrates clearly that:

- no brown coal based technology is likely to deliver "reduced greenhouse gas emissions";
- some new brown coal based technologies would make the situation worse, especially coal-to-gas and coal-to-oil processes; and
- investment in brown coal projects would defer "the uptake of renewable energy and the implementation of energy efficiency programs" for several decades, because of the long life of brown coal projects. As the Federal Treasurer, Mr Peter Costello, recently stated in relation to intergenerational issues, deferral of action will make adjustment more and more difficult in the future.

The coal industry claims it can solve these problems with "clean coal". In the greenhouse context, "clean coal" is a contradiction in terms. "Clean coal" is a marketing term invented in the 1970s and 1980s in an attempt to counter the linkage between coal and acid rain caused by coal's sulphur content. The term covers a number of technologies and processes, some of which are not relevant to brown coal and many of which are of little or no relevance to reducing greenhouse gas emissions.

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[1] Bourne, Greg, 2002, "Changing course: A sustainable energy future for Australia", speech to *Towards Opportunity and Prosperity Conference* by CEO, BP Australia, Melbourne University, April 4-5, p.2.

Pursuing brown coal as the major source of power for Victoria is likely to impose an additional cost on electricity consumers of about 3.1 cents per kilowatt-hour for electricity using current technology, or 1.9 cents per kilowatt-hour using the hypothetically best achievable brown coal power station, if the price of carbon dioxide emissions were A$25 per tonne. For comparison, the average pool price in the Victorian region of the National Electricity Market in 2001–2 has been about 3 cents per kilowatt-hour. Most of this additional cost can be avoided if sustainable energy sources or natural gas are used for new and replacement power stations instead of brown coal.[2]

Turning brown coal into synthetic gas and oil makes the carbon dioxide problem worse, not better. An integrated coal-to-oil plant and power station, like the one proposed by Australian Power and Energy Ltd (APEL), would produce 67 per cent more carbon dioxide than making the same amount of liquid fuels from conventional oil and power from conventional brown coal power stations, that is, 5.5 million tonnes more carbon dioxide. The reason is simple: in manufacturing liquid fuels, the coal-to-oil process would create eight times the amount of carbon dioxide per unit of fuel output, compared to the amount created in making liquid fuels from conventional oil.

Capturing the carbon dioxide and injecting it into long-term storage deep underground ("geo-sequestration") does not solve the problem. Large-scale geo-sequestration is a speculative technology which faces a number of risks. Estimated by the Petroleum Cooperative Research Centre to cost at least A$46 per tonne of carbon dioxide, geo-sequestration would be more expensive than the likely carbon price of A$25 per tonne.

In this situation, a company would choose to emit the carbon dioxide and pay A$25 per tonne, rather than using geo-sequestration at A$46 per tonne, unless they were required to use geo-sequestration by regulation.

Indicative scenarios developed in this paper for greenhouse emissions in 2040 show that:

- the hypothetically best achievable brown coal technology would increase emissions by 10 per cent relative to current emissions and hence cannot deliver any emission reduction; and

- one coal-to-oil plant like the APEL proposal would increase Victoria's power and brown coal project emissions by a further 20 percentage points (or 10.5 million tonnes), if geo-sequestration, an unproven option, is not viable.

The only scenarios that would reduce emissions in *absolute* terms in 2040 are:

- natural gas combined-cycle turbines for all new and replacement plant, which can deliver an 11 per cent reduction; and

- a mix of natural gas technologies, renewable energy and end-use energy efficiency, which can deliver a 30 per cent reduction.

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[2] See Fig 2 in Section 3.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

GLOSSARY AND ABBREVIATIONS

APEL	Australian Power and Energy Ltd
APFBC	Advanced pressurised fluidised bed combustion, a power station technology for coal.
CCGT	Combined-cycle gas turbine, a power station technology for natural gas.
CFBC	Circulating fluidised bed combustion, a power station technology for coal.
CO_2	Carbon dioxide, the main human-induced greenhouse gas emission.
CO_2-e	Carbon dioxide equivalent, used where lifecycle emissions of carbon dioxide, methane and other greenhouse gases have been converted into a common unit, using the global warming potential of each gas.
Contingent carbon liability	The future cost of paying for greenhouse gas emissions. The size of this cost is contingent on the future price of emitting a tonne of carbon dioxide.
CRC	Co-operative Research Centre
Geo-sequestration	Geological sequestration. Injection of carbon dioxide into long-term storage deep underground. Requires capture and separation of carbon dioxide beforehand.
GW	Gigawatt, a million kilowatts.
GWh	Gigawatt-hour, a million kilowatt-hours.
IGCC	Integrated gasification combined-cycle, a power station technology for coal.
KW	Kilowatt, a unit of measurement of instantaneous power generation or usage.
KWh	Kilowatt-hour, the standard unit for measurement of electrical energy generation or consumption. Literally, a kilowatt generated or used for one hour.
Lignite	Brown coal. Coal with low energy content and high moisture content.
MW	Megawatt, one thousand kilowatts. Usual unit for measuring capacity (maximum power output) of power stations.
MWh	Megawatt-hour, one thousand kilowatt-hours.
PC	Pulverised coal, a power station technology for coal.
PFBC	Pressurised fluidised bed combustion, a power station technology for coal.
Synthetic gas	Gas synthesised from coal by chemical processes. Consists mainly of carbon monoxide and hydrogen.
TW	Terawatt, a billion kilowatts
TWh	Terawatt-hours, a billion kilowatt-hours

1 INTRODUCTION

On 3 October 2001, the Victorian Minister for Energy and Resources, The Hon. Candy Broad, called for exploration tenders for large tracts of the State's vast brown coal reserves. Up to 5 billion (dry) tonnes[3] of brown coal are at stake. By any measure, this is a large resource. It constitutes most of the economically winnable resources in the Latrobe Valley that are not already covered by mining licences.[4] Five billion (dry) tonnes would be sufficient to run the largest power station in Victoria, Loy Yang A, for over 600 years.[5]

In greenhouse terms, the reserves up for tender are equivalent to one half of the entire amount of fossil fuel burnt globally in one year.[6] The reserves are large enough to have a material impact on atmospheric concentrations (cumulative emissions) of greenhouse gases.[7] At the national level, this expansion has the potential to single-handedly wipe out the modest gains from the 2 per cent Commonwealth Mandatory Renewable Energy Target, the Greenhouse Gas Abatement Programme and State sustainable energy initiatives like those of the Sustainable Energy Authority of Victoria.[8]

At the time the Minister called for tenders, the Government also stated that:

> There is a clear expectation that any successful proposal will include processes and/or technologies that will deliver reduced greenhouse gas emissions consistent with

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[3] *Release of Brown Coal Resources in the Latrobe Valley, Victoria, Australia.* Address by The Hon. Candy Broad, MLC, Minister for Energy and Resources, 2 October 2001. http://www.nre.vic.gov.au

[4] Economically recoverable resources in Latrobe Valley = 35 billion tonnes. Resources already covered by mining licences = 20 billion tonnes. Resources covered by tender = 5 billion (dry) tonnes = 13 billion tonnes of brown coal (at 62 per cent moisture). Source: Victorian Department of Natural Resources and Environment, *Victorian Mineral Projects Register*, February 2001. http://www.nre.vic.gov.au

[5] Loy Yang A uses about 20 million tonnes of coal per year = 7.6 million (dry) tonnes at 62 per cent moisture content. Source: Victorian Department of Natural Resources and Environment, 2001, as above.

[6] Five billion (dry) tonnes of brown coal are equivalent to 3.3 billion tonnes of carbon (67% carbon). Annual global carbon emissions from fossil fuels = 6.6 billion tonnes. Source: Marland, G., T.A. Boden, and R. J. Andres, 2001, "Global, Regional, and National CO_2 Emissions". In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A, at http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm

[7] Total quantity of carbon in the atmosphere = 750 billion tonnes. Source: Socolow, Robert (ed), *Fuels Decarbonization and Carbon Sequestration: Report of a Workshop*, Princeton University, September 1997, p.46, http://www.princeton.edu/~ceesdoe/.

[8] Statement based on one brown coal-to-oil and power plant = 14 million tonnes per year (see Appendix 3) and 2000 Megawatts of new base-load power station capacity, using world best practice technology in commercial use (supercritical steam with coal drying, producing 0.9 tonnes CO_2/ MWh) = 14 million tonnes/ year. Total = 28 million tonnes/ year. Emission reductions (in 2010) from Mandatory Renewable Energy Target = 7.3 million tonnes/ year, from Greenhouse Gas Abatement Programme = 10.8 million tonnes/ year, from State and Territory action = 2.5 million tonnes/ year. Total = 20.6 million tonnes per year. Source: Australian Greenhouse Office, 2001, *Draft of Australia's Third National Communication under the UN Framework Convention on Climate Change*, September.

> Victoria's need to be an active and effective participant in meeting the challenge of global warming,[9] [and]
>
> The Government is strongly committed to maximizing the uptake of renewable energy and the implementation of energy efficiency programs. This tender process offers the potential to develop brown coal as a transition fuel to a fully sustainable future.[10]

Can the expansion of brown coal mining be reconciled with meeting these objectives? This briefing paper demonstrates clearly that:

- No brown coal based technology is likely to deliver "reduced greenhouse gas emissions consistent with Victoria's need to be an active and effective participant in meeting the challenge of global warming"; and
- Some new brown coal based technologies would make the situation worse, especially coal-to-gas and coal-to-oil processes.

By focusing on the brown coal resource, the tender diverts investment attention from where it is most needed— sustainable energy. Far from being "a transition fuel to a fully sustainable future," investment in brown coal projects would defer "the uptake of renewable energy and the implementation of energy efficiency programs" for several decades, because of the long life of brown coal projects. As the Federal Treasurer, Mr Peter Costello, recently stated in relation to intergenerational issues, "…if we don't have the courage to make small adjustments now, we will just have to make greater and greater and more and more difficult adjustments in the future".[11]

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[9] Victorian Department of Natural Resources and Environment (2001). *Brown Coal Tender: Fact Sheet 1: An Overview.* http://www.nre.vic.gov.au

[10] Victorian Department of Natural Resources and Environment (2001). *Working with Industry in the development of the State's Energy Infrastructure.* http://www.nre.vic.gov.au

[11] Federal Treasurer, Mr Peter Costello, interviewed on ABC Radio, AM, 16 May 2002. Mr Costello was speaking in relation to the Government's Intergenerational Report tabled with the 2002/3 Federal Budget. http://www.abc.net.au/am/s556744.htm

2 RISK OF PAYING FOR GREENHOUSE EMISSIONS

Brown coal projects face the likelihood that the right to emit carbon dioxide into the atmosphere will come at a cost well within the lifetime of the projects being proposed in response to the tender. This cost will arise as the world moves to bigger reductions in greenhouse gas emissions beyond the timeframe of the Kyoto Protocol (2012) in order to achieve the objective of the Framework Convention on Climate Change[12]. Victorian brown coal projects face the likelihood of large payments for their carbon dioxide emissions, with the consequence that these costs will lead to the premature closure of plants.[13]

Forward-looking energy companies and investment advisors are already factoring in the likelihood that this will happen, for example:

> BP's business judgment is that the inevitable outcome is a higher price on burning carbon. The price may be set by market-driven emission trading, by regulatory-driven taxes, by other measures, or by a hybrid set of the available options. *But come it will*.[14]
>
> The chairman of the Australian Stock Exchange, Maurice Newman, warned that for a company to assume there will be no action on climate change – whether or not the Kyoto Protocol is ratified – "is an act of faith which could prove very expensive". Directors of companies that didn't take action could also be putting themselves at risk of action by shareholders, he said.[15]
>
> Climate change, and governmental policy responses to tackle it, represents a genuine business risk for companies in resource intensive industries, particularly those engaged in fossil fuel extraction …The cost of offsets required by Suncor to reduce its [greenhouse] emissions [from the proposed Stuart shale oil project in Queensland] should be of concern to investors because in such a carbon-intensive process it could add significantly to operating costs, thereby reducing cash flows and earnings.[16] [In 2001, Suncor pulled out of the Stuart shale oil project.]

The consequences of this risk are very serious. While a brown coal project may appear profitable in the short-term of five to ten years, the added cost of paying for

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[12] "The ultimate objective of this Convention…is to achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." United Nations, *Framework Convention on Climate Change*, Article 2, Objective. Because of the long lifetime of carbon dioxide in the atmosphere, stabilisation of concentrations requires deep cuts in annual emissions.

[13] This cost is often referred to as a "contingent liability" because its size is dependent on the future price of emitting a tonne of carbon dioxide. In economic terms, "failure to pay for the costs of the [greenhouse gas] pollution for which [an industry] is responsible amounts to an additional subsidy…" Hamilton, Clive, 2001, *Running from the Storm: The development of climate change policy in Australia*, UNSW Press, Sydney, pp. 65-6.

[14] Bourne, Greg, 2002, "Changing course: A sustainable energy future for Australia", speech to *Towards Opportunity and Prosperity Conference* by CEO, BP Australia, Melbourne University, April 4-5, p.2. Emphasis is in original.

[15] "Don't bleat, don't lunge, forum told", *Environmental Manager*, 295, May 16, 2000.

[16] Innovest Strategic Value Advisors, 2001, "The Stuart Oil Shale Project: Implications of Carbon Emissions Constraints for Suncor Shareholders", Investment Research for Greenpeace, April 2001, p.2.

carbon dioxide emissions could make it unprofitable for the rest of its intended life (up to fifty years).[17]

The scale of these additional costs is large. For example, if the price of carbon dioxide emissions were A$25 per tonne,[18] current total Victorian brown coal use would incur an additional cost of A$1.5 billion. Later in this report, it is estimated that:

- electricity generated from brown coal would incur an extra cost of about 3.1 cents per kilowatt-hour using current technology, or 1.9 cents per kilowatt-hour using the hypothetically best achievable brown coal power station. For comparison, the average pool price in the Victorian region of the National Electricity Market in 2001/2 has been about 3 cents per kilowatt-hour;[19] and

- one coal-to-oil and power project would face an added cost of A$345 million, assuming that capture and geological storage of carbon dioxide is not feasible. This would take about one third of the project's estimated gross revenue of about A$1 billion. [20]

The only way to avoid stranding investments—apart from Victorian taxpayers providing an open-ended guarantee to pay the carbon dioxide emission costs of private brown coal project investors—is to invest in sustainable energy instead.

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[17] Fifty years is the proposed life of one project being proposed by Australian Power and Energy Ltd in response to the brown coal exploration tender. Australian Power and Energy Ltd, 2002, *Offer Information Statement*, 21 February 2002, p.5, http://www.apel.com.au.

[18] Hamilton, C. and Turton, H. 1999, *Business tax and the environment: emissions trading as a tax reform option*, Discussion Paper no. 22, The Australia Institute, August, pp.36-8. Hamilton and Turton review Australian and overseas market prices and modelling estimates. They conclude that A$20 is quite reasonable, although $15 is possible, at the then prevailing exchange rate of A$1 = US$0.67. At the exchange rate as at 1st May 2002 of US$0.54, A$20 is equivalent to A$25. A$25 per tonne of carbon dioxide = A$92 per tonne of carbon (used in some studies).

[19] National Electricity Market Management Company, 2002, *Average monthly prices 2001-2002*, http://www.nemmco.com.au/data/tables.htm (at 14 May 2002).

[20] Estimate of A$1 billion revenue based on: (a) 52,600 barrels per day output of liquid fuels, 158.99 litres per barrel, 30 cents per litre ex-refinery price, 340 production days per year = A$853 million; and (b) 5,413,680 Megawatt-hours output of electricity, A$30 per Megawatt-hour = A$162 million. Total = A$1,015 million. Sources: See Section 4 and Appendix 3.

3 BROWN COAL POWER STATIONS

The current Latrobe Valley power stations produce very high levels of greenhouse gas pollution. A typical power station using Victorian brown coal emits 37 per cent more carbon dioxide per unit of power output than a power station using black coal and more than three times the emissions of a co-generation plant using natural gas.[21]

The main reason for brown coal greenhouse gas emissions being even higher than black coal is its high water content. Water has to be either heated and evaporated or extracted before the coal will burn properly. This process wastes much of the energy in the coal.

> The major issue in the efficient use of Victorian and South Australian lignites in existing or advanced power generation technologies is the drying or dewatering of the coal prior to gasification and/or combustion. In conventional lignite-based pulverised fuel boiler plants, the high moisture content of low-rank coals (up to 2 kg of water per kg of dry coal) leads to low energy efficiency, high carbon dioxide emissions and high capital costs.[22]

As a result, even the best Latrobe Valley power stations have efficiencies of only about 29 per cent.[23] In other words, to get one unit of electrical energy, the power stations have to burn over three units of energy from brown coal.

The major long-term hope held out by the Victorian brown coal industry for reduced emissions from new power stations is an advanced power station technology, called Advanced Pressurised Fluidised Bed Combustion.

This technology is a complex, hybrid type power station, requiring integration of a number of technological processes, including coal drying, partial gasification, fluidised bed combustion, gas clean-up, gas turbines and steam turbines.[24] This technology is not yet demonstrated at a commercial scale anywhere in the world (for more detail, see Background on Technology Status at Appendix 1). A planned demonstration plant in the USA will use black coal.[25] As black coal has very different characteristics to wet Victorian brown coal, the technology and its emission levels when using brown coal can only be regarded as hypothetical.

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[21] See Appendix 2.

[22] CRC for Clean Power from Lignite, 2002, Centre Programs, Research Activities, Program area 1: Coal Drying, Dewatering and Characterisation, from http://www.cleanpower.com.au/, 3 May 2002. Lignite is a term for brown coal.

[23] Figure for Loy Yang Power Station, from Brockway, David, undated, *Potential Greenhouse Gas Emission Reductions from Future Lignite-Fired Power Generators in Victoria and South Australia*, Submission by Cooperative Research Centre for Clean Power from Lignite to the Senate Environment, Communications, Information Technology and the Arts Reference Committee Inquiry into Global Warming, p.4.

[24] Brockway, as above; and Longwell, J.P., E.S. Rubin and J. Wilson, 1995, "Coal: Energy for the Future," *Progress in Energy Combustion Science*, 21, pp. 316-7.

[25] Brockway, as above, p.5; and Longwell et al, 1995, as above, p.316-7.

3.1 Emissions

Industry figures for emissions from advanced power station technologies clearly demonstrate that even the hypothetically best technology for brown coal yields very limited emission reductions compared to other fuels and technologies (see Figure 1 below and Appendix 2).

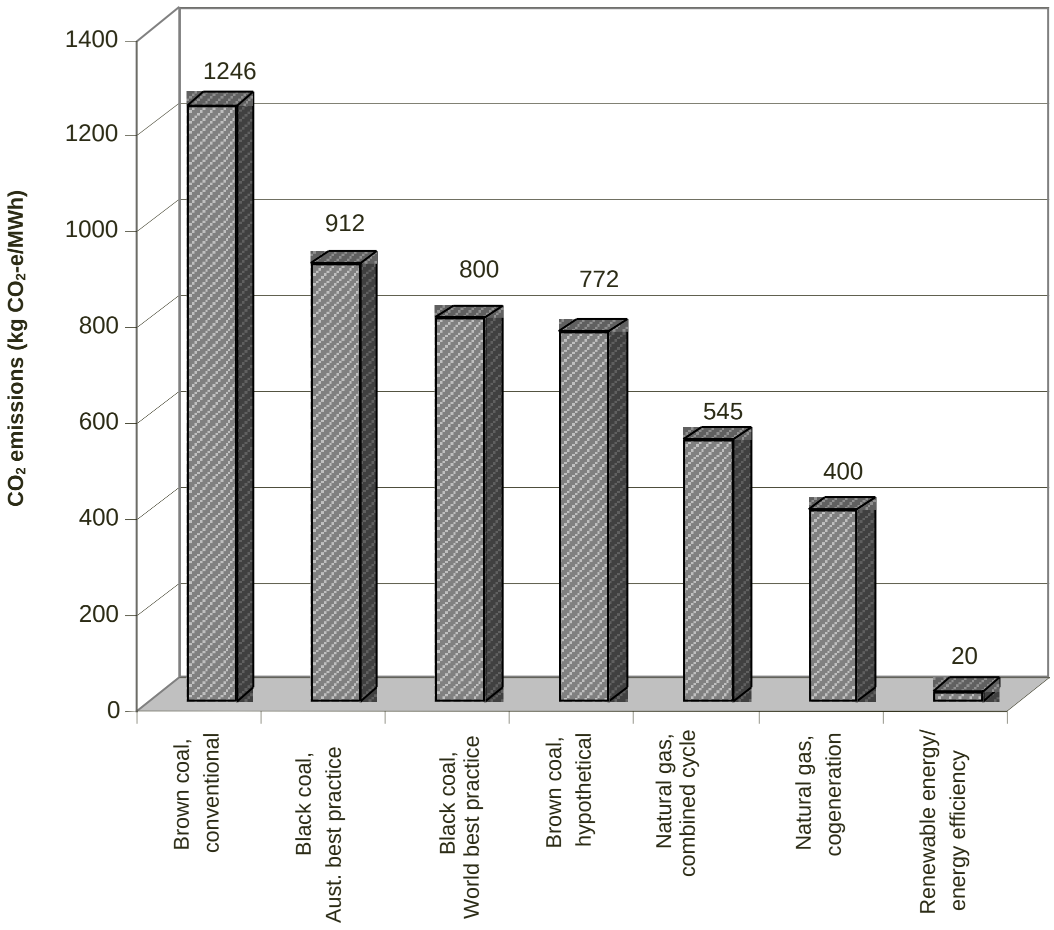

Figure 1: Emissions from power generation

Compared with the hypothetically lowest achievable emissions from brown coal:

- renewable energy and end-use energy efficiency avoid 97 per cent of the emissions;
- fully commercially available natural gas technologies yield emissions that are 29 to 48 per cent lower;
- fully commercialised world best practice black coal (using supercritical steam) yields similar emission levels; and
- conventional black coal power stations (Australian best practice for pulverized coal with sub-critical steam) have slightly higher emissions (by about 18 per cent)[26].

Put another way, readily available natural gas technologies will provide emissions today of only half to two-thirds of the emissions from the hypothetically best possible performance from brown coal. Sustainable energy performs even better than natural gas.

3.2 Cost if paying for greenhouse emissions

As discussed in Section 2 above, a major commercial risk facing brown coal project proponents is the likelihood of paying for carbon dioxide emissions well within the lifetime of the project, with the consequence that these added costs may lead to the premature closure of brown coal based projects.

Figure 2 compares the extra costs that would be faced by electricity generators using different types of power stations, if the price of carbon were to be A$25 per tonne of carbon dioxide.

- Conventional brown coal power stations would face added costs of 3.1 cents per kilowatt-hour;
- The hypothetically lowest emission brown coal power station[27] would incur extra costs of 1.9 cents per kilowatt-hour;
- Natural gas power stations would have additional costs of 1.0 to 1.4 cents per kilowatt-hour, depending on the technology; and
- Renewable energy and energy efficiency would face minimal added costs.

For comparison, the average pool price in the Victorian region of the National Electricity Market in 2001–2 has been about 3 cents per kilowatt-hour[28] and the average retail price of power in Victoria was 12 cents per kilowatt-hour in 2001–2.[29]

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[26] A black coal power station using supercritical steam recently started operation at Milmerran in Queensland but emissions data are not yet available. "Callide C comes online", *Australian Energy News*, 21, Sept 2001, p.21.

[27] Using advanced pressurised fluidised bed combustion.

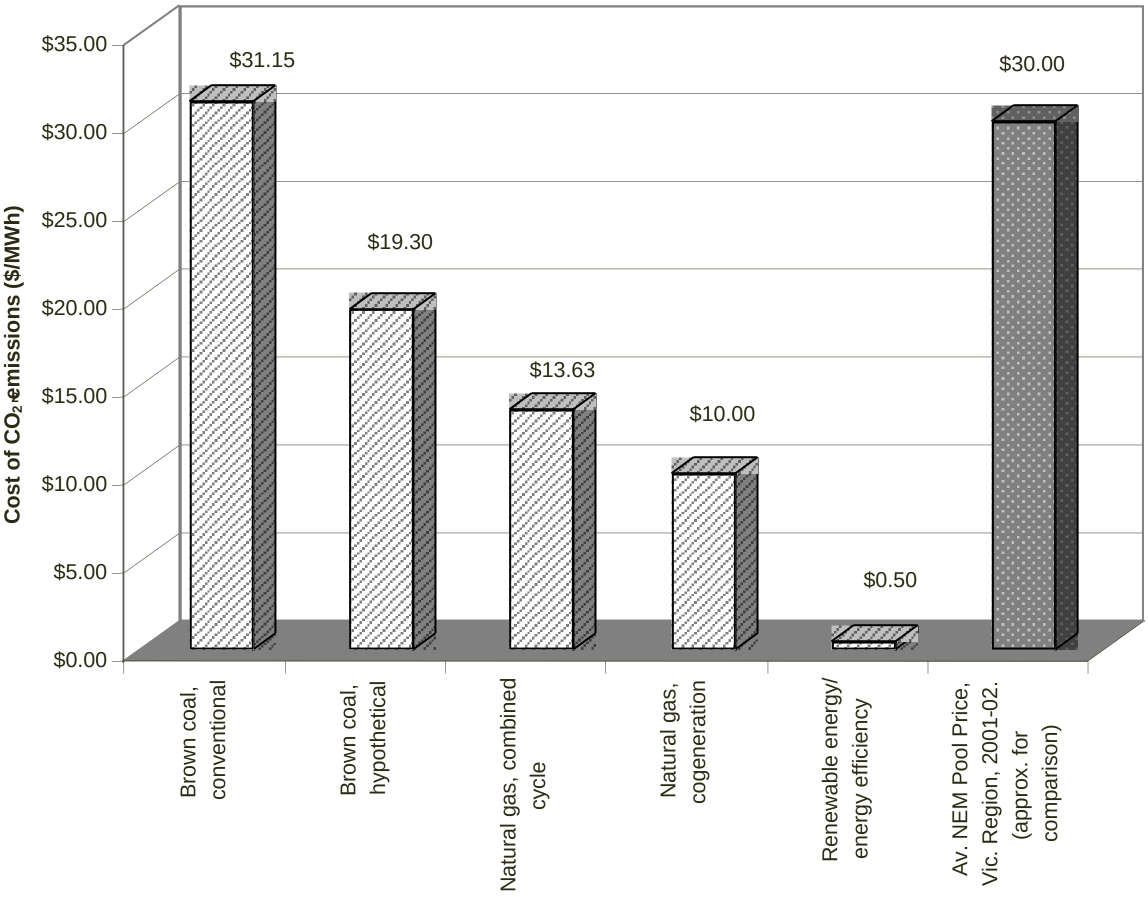

Figure 2: Paying for CO_2 emissions: added costs of power generation

If brown coal-fired power stations had to pay for their carbon dioxide emissions, it is highly likely that they would no longer be the cheapest power stations in the National Electricity Market. They would have difficulty competing with other power stations fuelled by natural gas and renewable sources of energy during periods of low pool prices, unless subsidised by Victorian taxpayers.

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[28] National Electricity Market Management Company, 2002, *Average monthly prices 2001-2002*, http://www.nemmco.com.au/data/tables.htm, as at 14 May 2002.
[29] Electricity Supply Association of Australia, 2002, Industry Data on website, http://www.esaa.com.au/store/page.pl?id=1281, as at 13 May 2002.

4 MAKING GAS AND OIL FROM BROWN COAL

One of the hopes held out in the brown coal tender is that greenhouse emissions from brown coal can be reduced by first converting it into synthetic gas.[30] This is an illusion.

In fact, turning brown coal into synthetic gas makes the greenhouse gas problem worse, not better. One of the tenderers for the brown coal exploration licences, Australian Power and Energy Ltd (APEL), has provided figures for an integrated coal gasification, coal-to-oil and power generation plant.[31] The proposed APEL project is used in this paper to provide a case study. As the tender process is behind closed doors, it is not possible to analyse all proposals. However, it is likely that the findings on emissions and on the cost of paying for emissions would be broadly similar for any proposal to convert brown coal into oil, because of the chemical composition of coal and the technical limits to the conversion processes available.[32]

4.1 Carbon dioxide production

Figure 3 illustrates the main reason for the very high greenhouse gas production from a coal-to-oil plant such as the one proposed by APEL—the very high production of carbon dioxide from the brown coal to oil process. In manufacturing liquid fuels, a project like the APEL one would create eight times the amount of carbon dioxide per unit of fuel output, compared to the amount created in the production of transport fuels from conventional oil[33].

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[30] Victorian Department of Natural Resources and Environment, 2001, *Frequently Asked Questions – Brown Coal.* http://www.nre.vic.gov.au

[31] Australian Power and Energy Ltd, 2002, *Offer Information Statement*, 21 February 2002, http://www.apel.com.au.

[32] The Institute attempted to verify how the emissions from the plant proposed by APEL would compare with emissions from other coal-to-oil plants internationally. The only comparison available is limited to the theoretical (laboratory) efficiency of the gasification step in the process and therefore does not include the energy used and emissions from coal drying, air separation, gas clean up, the shift reactor and gas-to-oil liquefaction. At the theoretically best efficiency, emissions from production and end-use combustion of gas from coal are about 110 grams of carbon dioxide per Megajoule. This is about 31 per cent higher than conventional oil (about 84 g CO_2/ MJ). Consistent with the uncounted processes listed above, the emissions from the coal-to-oil plant proposed by APEL (182 g/ MJ including combustion emissions) are higher than the theoretical gasification emissions alone. Source: Inaba, A. and Okada. K, 1995, “Coal utilization technology for reducing carbon dioxide emission”, *Coal Science and Technology*, 24, 2, pp.1919-1922. In source, shown as 0.13 grams of carbon per kilocalorie = 110 g CO_2/ MJ.

[33] Australian Power and Energy Ltd (APEL) actually claim that they will store the majority of this carbon dioxide underground (called “geo-sequestration”). As this is speculative, the Institute has separated the analysis of carbon dioxide production (this section) from comments on the status of geo-sequestration (next section).

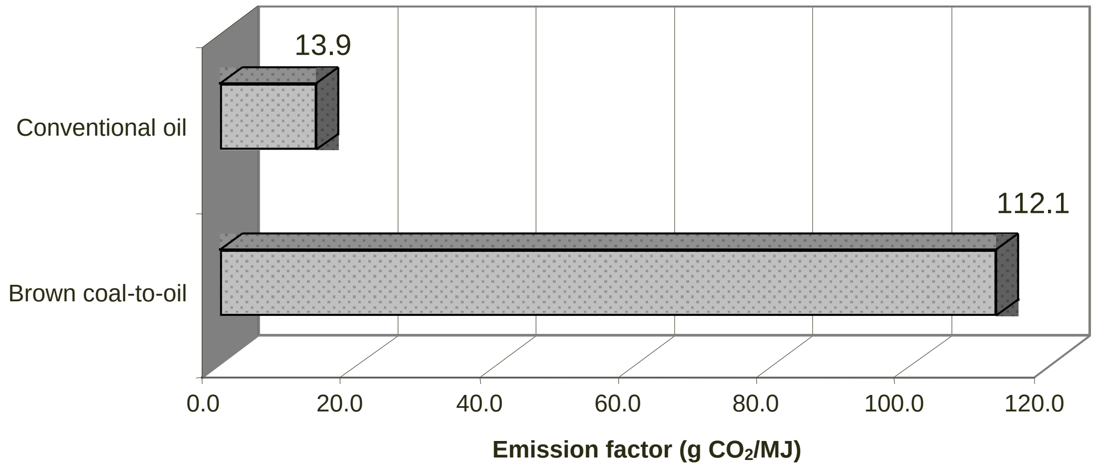

Figure 3: CO_2 production per unit of output: brown coal-to-oil vs. conventional oil

As a result of this high level of greenhouse gas production from the coal-to-oil process, the plant as a whole would produce nearly 14 million tonnes of carbon dioxide per year. This would be a 26 per cent increase in greenhouse gas production, compared to 2002 emissions from Victorian brown coal power and energy projects.[34] If the emissions from the end use combustion of the transport fuels were included, total carbon dioxide production from a plant like the one proposed by APEL would be over 21 million tonnes.[35]

An integrated brown coal-to-oil plant and power station, like the one proposed by APEL, would produce 52,600 barrels[36] of diesel and other liquid fuels and 5,414 Gigawatt-hours of electricity.[37] The best way to compare such a plant with conventional fossil and/or sustainable sources is to compare carbon dioxide production from the same output of liquid fuels and electricity from conventional fossil and/or sustainable sources.

Figure 4 and Appendix 3 show that an integrated coal-to-oil plant and power station, like the one proposed by APEL, would be even worse than conventional oil and conventional power stations using brown coal. It would produce 67 per cent more carbon dioxide than from the production of the same amounts of diesel and other fuels from conventional oil and of power from conventional brown coal power stations—or 5.5 million tonnes more.[38]

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[34] 2002 emissions: 53.35 million tonnes. Brockway, as above, Figure 4, p.11.

[35] Calculation assumes that naphtha, a minor output, is combusted.

[36] 1 barrel of oil = 159 litres.

[37] Australian Power and Energy Ltd, 2002, as above, pp.10-11. APEL give exact figures for daily output of diesel and “high value specialty products”, but only base and peak load power generating capacity. The Institute for Sustainable Futures has estimated the electricity output based on the base-load and peak-load power generating capacity given in the Offer Information Statement – see Appendix 2 for more details. APEL did not respond to a request from the Institute for a more precise figure for electricity output. 1 Gigawatt-hour = 1 million kilowatt-hours.

[38] Not including end use combustion of transport fuels.

The wastefulness of an integrated coal-to-oil plant and power station is even more striking when compared with cleaner sources of energy. Such a plant would produce:

- three times as much carbon dioxide as from the production of the same amounts of diesel and other fuels from conventional oil and of power from conventional natural gas combined-cycle power stations—or 9.3 million tonnes more;
- over eight times as much carbon dioxide as from the production of the same amounts of diesel and other fuels from conventional oil and of power from renewable energy power stations—or 12.2 million tonnes more; and
- 53 times as much carbon dioxide as from the production of the same amounts of diesel and other fuels from renewable energy sources and of power from renewable energy power stations—or 13.5 million tonnes more.

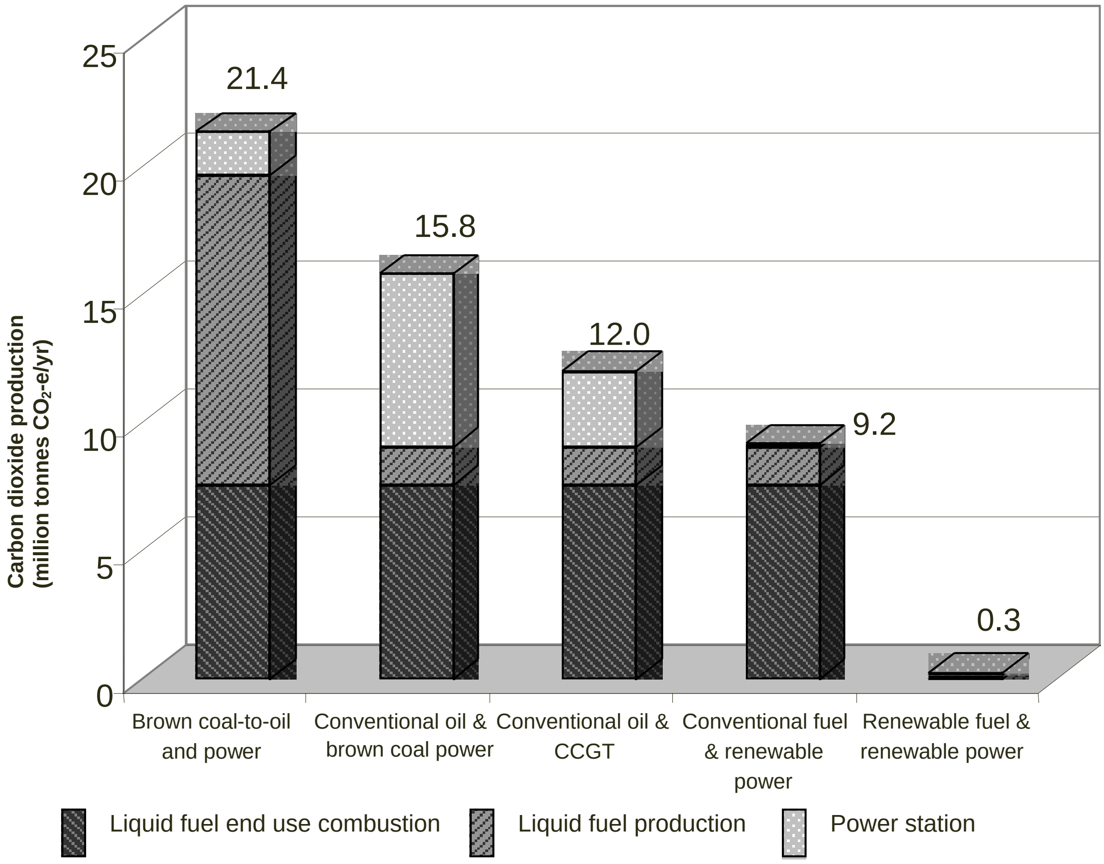

Figure 4: Total CO_2 production: brown coal-to-oil vs. other fuels

4.2 Cost if paying for greenhouse emissions

Because of the inherent greenhouse intensity of the brown coal-to-oil process, a plant like the one proposed by APEL could face particularly high additional costs if it had to pay for its carbon dioxide emissions. If geo-sequestration were not viable and the price of carbon were to be A$25 per tonne of carbon dioxide emitted, an integrated coal-to-oil plant and power station would face extra costs of A$345 million per year or about one third of the project's estimated gross revenue of about A$1 billion (see Appendix 3 and page 4 in Section 2). For the coal-to-oil part of the process, this extra cost would add about 11 cents to the production cost of a litre of liquid fuel.[39]

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[39] Figures based on APEL column in Appendix 3.

5 GEO-SEQUESTRATION

The coal-to-oil project proposed by Australian Power and Energy Ltd and possibly other tenderers for the brown coal exploration licences are relying on geological sequestration (geo-sequestration) to reduce their very high levels of carbon dioxide emissions.[40] Geo-sequestration involves capturing the carbon dioxide and injecting it into long-term storage deep underground.

Although there is some experience with injection of carbon dioxide into oil and natural gas wells to enhance the recovery of oil and gas, the biggest capacity and the greatest interest is in deep saline aquifers (deeper than 800 metres). Australian Power and Energy Ltd appear to be considering deep saline aquifers when they refer to “the large Gippsland sedimentary basin which is geologically suited to geo-sequestration”, partly because the deep aquifers are closer to the project site than depleted oil and gas wells in Bass Strait.[41] The question that needs to be asked is whether this is realistic?

A power station or liquid fuel project with geological sequestration would cost more than an equivalent project without sequestration. Hence, there is no reason why a company would use geo-sequestration unless forced to, either by a regulatory requirement or if the price of carbon dioxide emissions exceeded the cost of geo-sequestration.

The cost of geological sequestration is made up of two major components:

- separating and capturing the carbon dioxide from other gases; and
- the costs of compression, pipeline transport, drilling injection wells and (for off-shore injection) installing platforms.

Cost estimates for these processes are available although they are subject to large uncertainties (see Table 1 on next page).

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[40] Victorian Department of Natural Resources and Environment, 2001, *Frequently Asked Questions – Brown Coal*, Q. 23, http://www.nre.vic.gov.au

[41] Australian Power and Energy Ltd, 2002, as above, p.16; also Allan Blood, Director of APEL, personal communication, 15 April 2002.

Table 1: Estimates of costs for geological sequestration

Cost type	Technology type	Source	Cost A$/ tonne CO_2
Separation, capture	After combustion (flue gases)	Herzog, 1999[42]	\$37 - \$130
	After combustion (flue gases)	IEA, 2002[43]	\$74
	Before combustion (gasification)	-	Not available
Compression, transport, injection	Oil and gas wells	Australian Petroleum CRC, 2001[44]	\$46
Total	After combustion		\$83–\$156
	Before combustion (gasification)		See text below

Australian Power and Energy Ltd claim that the cost of capturing and separating carbon dioxide does not apply to their project as the carbon dioxide is already in a separate concentrated pure stream. If this is correct, then the estimated total cost of geo-sequestration may be comparable to the estimate of A$46 per tonne by the Australian Petroleum CRC. However, this estimate was prepared by the Australian Petroleum CRC for oil and gas projects which already have an infrastructure for compression, pipeline transport and drilling.

A coal-to-oil project such as the one proposed by APEL would have to build special infrastructure for these tasks dedicated to geo-sequestration. Even assuming no additional cost above the oil and gas industry's estimated costs, at $46 per tonne of carbon dioxide, geo-sequestration would be more expensive than the likely carbon price of A$25 used elsewhere in this paper. In this situation, a company would choose to emit the carbon dioxide and pay A$25 per tonne, rather than using geo-sequestration at A$46 per tonne (unless they were required to use geo-sequestration by regulation).

Large scale geo-sequestration is a speculative technology which faces a number of risks. Even if the Government imposed a requirement now to resolve these risks and to use geo-sequestration, there is a high likelihood that a company relying on geo-sequestration may subsequently decide that it is too costly or not technically viable.

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[42] Herzog, H., 1999, "The economics of CO_2 capture", *Greenhouse gas control technologies*, Elsevier Science Ltd. Cited in Rigg, A.J., G. Allinson, J. Bradshaw, J. Ennis-King, C.M. Gibson-Poole, R.R. Hillis, S.C. Lang, and J.E. Streit, 2001, "The Search for Sites for Geological Sequestration of CO_2 in Australia: A Progress Report on GEODISC", *Australian Petroleum Production and Exploration Association Journal* 2001, pp. 711 – 725.

[43] International Energy Agency Greenhouse Gas Research and Development Programme, *Capture and Storage of CO_2*, at http://www.ieagreen.org.uk/removal.htm.

[44] Rigg, A.J. et al, 2001, as above.

Once a project has been approved or has started, it may be hard to stop it because of the political and economic expectations already built up.

Some of the risks faced by geological sequestration are set out below with a qualitative comparison with the risks faced by mature sustainable energy technologies such as many energy efficiency technologies (e.g. efficient buildings and equipment such as motors) and some renewable energy technologies such as wind power.[45]

Table 2: Comparison of risks faced by geo-sequestration and sustainable energy

Type of risk (mostly site specific)	Geo-sequestration	Mature sustainable energy
Insufficient storage capacity at site	Early stage of investigation	No risk (except for hydro-electricity)
Technical viability	Early stage of investigation	Low risk for mature technologies
Cost/economic viability	Highly uncertain	Commercial experience available for mature technologies
Long term release to atmosphere of CO_2	Early stage of investigation	No risk
Catastrophic release of CO_2[46]	Early stage of investigation	No risk
Compromise of other natural resources	Early stage of investigation	Known and manageable risks e.g. for wind power.
Faulting/seismic activity	Early stage of investigation	No risk

There are only two precedents for pumping carbon dioxide into deep aquifers, the largest option for geo-sequestration, one in Norway and one in Indonesia. Both involve carbon dioxide extracted from natural gas at the wellhead.[47] The only research and development to date into geo-sequestration in Australia is focused on the needs of the oil and natural gas industries.[48] Neither the overseas precedents nor the Australian research are necessarily applicable to a Victorian brown coal plant.

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[45] Sources for geo-sequestration risk include: Rigg et al, as above, p.715; and Socolow, Robert, editor, 1997, *Fuels Decarbonization and Carbon Sequestration: Report of a Workshop*, Princeton University, PU/CEES Report No.302, p.25, http://www.princeton.edu/~ceesdoe/.

[46] "The integrity of carbon dioxide sequestration is important not only to prevent the adverse climate impacts of carbon dioxide leaking too rapidly into the atmosphere, but also to prevent catastrophic releases, both from reservoirs and pipelines. Air with only 25% carbon dioxide is lethal. Because carbon dioxide is heavier than air, a large release at ground level could displace air locally in valleys and home basements and cause asphyxiation." Source: Socolow, Robert, editor, 1997, as above, p.25, http://www.princeton.edu/~ceesdoe/.

[47] Socolow, Robert, editor, 1997, as above, p.23, http://www.princeton.edu/~ceesdoe/.

[48] The Australian Greenhouse Office, CSIRO, the Australian Petroleum Cooperative Research Centre and six oil and gas companies are collaborating in a project called Geodisc (Geological Disposal of Carbon dioxide), Http://www.greenhouse.gov.au/media/media_releases/1999/geodisc.html.

6 EMISSION SCENARIOS

The Co-operative Research Centre for Clean Coal from Lignite has developed scenarios in an attempt to show that advanced brown coal power station technologies have greenhouse benefits.[49] These fail to deliver the *absolute* emission reductions that will be required over coming decades as the Kyoto Protocol targets for 2012 are replaced by deeper reductions aimed at achieving the objective of the Framework Convention on Climate Change. This objective is aimed at stabilising concentrations of greenhouse gases in the atmosphere (see Section 2 above). Because of the long lifetime of carbon dioxide in the atmosphere, stabilisation of concentrations requires deep reductions in annual emissions.

The Co-operative Research Centre's (CRC's) scenarios are specific to the emissions from brown coal based projects in Victoria and from the electricity power-generating sector in Victoria. They do not include emissions from other sectors (such as transport, or residential, commercial and industrial use of natural gas) and are based on growth in electricity use of 1.5 per cent per year (or 73 per cent between 2002 and 2040).[50]

Figure 5 and Appendix 4 show projected emissions in 2040 from the two main scenarios in the CRC's paper, compared to current emissions:

- conventional brown coal plant for all new and replacement power stations, plus the Commonwealth Government's mandated renewable energy target (2 per cent target); and

- hypothetically best achievable brown coal technology for all new and replacement power stations, plus the 2 per cent renewable energy target.

Figure 5 compares these with four indicative alternative scenarios (all scenarios include the 2 per cent renewable energy target and assume 1.5 per cent per year growth in electricity use):

- one coal-to-oil plant, based on the Australian Power and Energy Ltd proposal discussed above, in addition to hypothetically best achievable brown coal technology for all new and replacement power stations. This scenario assumes that geological sequestration is not used and that there is no improvement in the efficiency of the coal-to-oil technology over time;

- one coal-to-oil plant, as in the previous scenario, but with geological sequestration;

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[49] Brockway, undated, as above, pp.9-11.

[50] The Institute does not endorse the validity of this projected level of growth, but uses it to enable comparison with the CRC for Clean Power from Lignite's scenarios. Nor does the Institute endorse any of the CRC's scenarios. For example, even the Australian Bureau of Agricultural and Resource Economics does not forecast any increase in brown coal consumption over the next 15 years. Source: A Dickson, S Thorpe, J Harman, K Donaldson & L Tedesco, 2001, *Australian Energy: Projections to 2019-2020*, ABARE, Canberra.

- natural gas combined-cycle turbine for all new and replacement plant, also assuming no improvement in the efficiency of the technology over time; and
- sustainable energy sources for all new and replacement power stations.

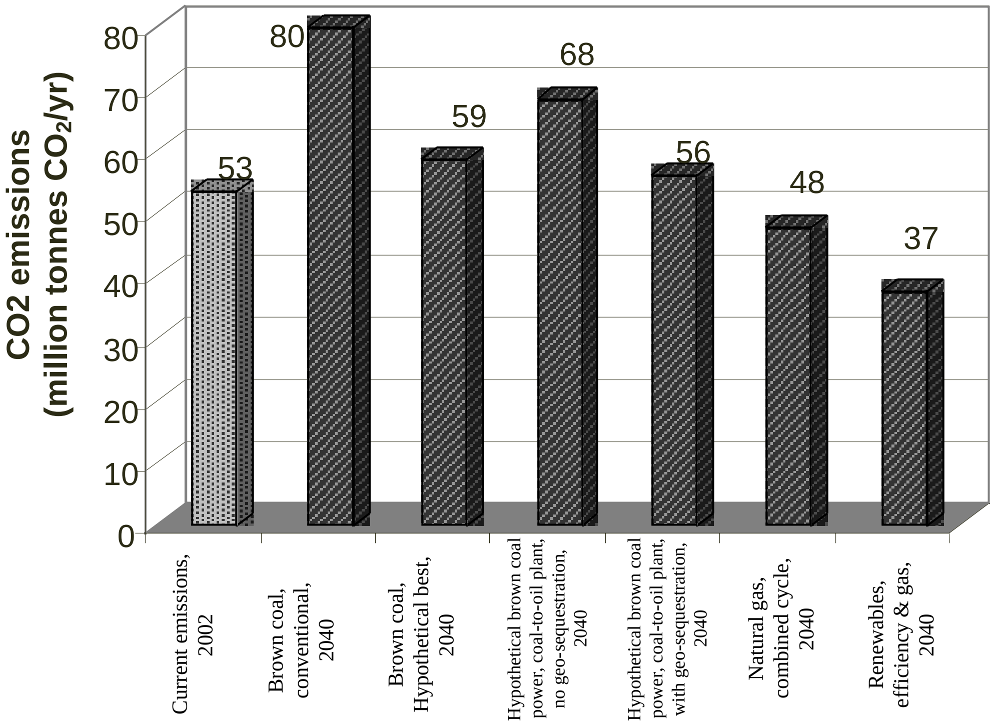

Figure 5: Indicative scenarios: emissions from Victorian power and energy projects in 2040

These show clearly that:

- the hypothetically best achievable brown coal technology would not deliver any emission reduction from current emissions, but rather an increase of 10 per cent;
- one coal-to-oil plant like the APEL proposal would increase Victoria’s power and brown coal project emissions by a further 20 percentage points (or 10.5 million tonnes of carbon dioxide), if geo-sequestration were not viable; and
- even with geo-sequestration, a coal-to-oil plant like the one proposed by APEL would increase Victoria’s power and brown coal project emissions by 5 per cent (or 3 million tonnes) over current levels (with hypothetically best achievable brown coal power stations for all other new and replacement plant).

The only scenarios that reduce emissions in absolute terms in 2040 are:

- an 11 per cent reduction if natural gas combined-cycle turbines were used for all new and replacement plant; and

- a 30 per cent reduction if a mix of natural gas technologies, renewable energy and end-use energy efficiency were used.

None of the scenarios presume premature retirement of any existing power stations. However, if brown coal based projects proceed and then have to pay for greenhouse gas emissions, there may well be forced retirements. Hence, it is essential that the right policy settings be put in place now to ensure an investment pathway towards sustainable energy is being followed. Conversion of the exploration tender for brown coal resources into a tender for the exploration and commercial use of some of Victoria’s renewable energy resources would be an important first step.

APPENDIX 1: BACKGROUND ON TECHNOLOGY STATUS

1. Advanced Pressurised Fluidised Bed Combustion

The technology being promoted by the CRC for Clean Power from Lignite, for new and replacement power stations is called "advanced pressurised fluidised bed combustion". First generation pressurised fluidised bed combustion technology (PFBC) is just beginning to be commercially demonstrated in North America and Europe. Advanced pressurised fluidised bed combustion (APFBC) will not reach this stage for several more years, with a demonstration only, planned in the USA using black, not brown coal.[51]

According the International Energy Agency, "PFBC has been widely tested, but reliable operation at acceptable levels of availability has not yet been achieved…it remains to be seen as to whether they will be able to achieve the performance which would make the technology competitive for use with low value coals."[52] Hence, it is unlikely to be used on a purely commercial basis unless forced by regulation or by a high enough price on carbon dioxide emissions (see sections 2 and 3 of this paper).

Advanced pressurised fluidised bed combustion faces a number of technical challenges, especially the development of hot gas particulate clean up before the gasified coal can be used in a gas turbine.[53] More significantly for Victoria, most of the pilot and commercial-scale demonstration plants in the world for both first generation and advanced pressurised fluidised bed combustion use black coal. The International Energy Agency warns: "Care must be taken…in extrapolating the results and experience obtained with a high quality fuel; it is not always correct to assume that low value coals will behave in the same way."[54] Hence the application of advanced pressurised fluidised bed combustion to wet Victorian brown coal is problematic. Nevertheless, the Co-operative Research Centre for Clean Power from Lignite is pursuing this option.[55]

2. Can Brown Coal be Clean?[56]

The former Co-operative Research Centre for New Technologies for Power Generation from Low-Rank Coal renamed itself as the Co-operative Research Centre for Clean Power from Lignite. But can lignite (brown coal) ever be clean?

In the greenhouse context, "clean coal" is a contradiction in terms. "Clean coal" is a marketing term invented in the 1970s and 1980s in an attempt to counter the linkage between coal and acid rain caused by coal's sulphur content. The term covers a number of technologies and processes which can be used before, during and after

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[51] Brockway, as above, p.5; and Longwell et al, 1995, as above, p.316-7.

[52] Katerina Rousaki and Gordon Couch, 2000, *Advanced clean coal technologies and low value coals*, International Energy Agency Coal Research Report CCC/39, IEA, London, pp. 48 and 69.

[53] Longwell et al, 1995, as above, p. 317.

[54] Rousaki, K and Couch, G, 2000, as above, p. 5.

[55] Brockway, as above, p.5.

[56] This heading is inspired by a report with a similar title about black coal technologies: Ellis, Mark, 1997, *Can coal be clean: 'Clean Coal' technologies and their potential impact on global warming*, Report for Aid/Watch and Greenpeace Australia.

combustion (outlined in the following three sections). Some of these are not relevant to brown coal and most of them are of little or no relevance to greenhouse gas emissions.

Coal preparation[57]

Most Australian research, development, demonstration and commercial activity in "clean coal" has gone into coal washing to reduce its ash content. This is of no relevance to Victorian brown coal, which has a low ash and high water content. With black coal, coal washing can reduce the efficiency of combustion and increase emissions because it increases the water content of the coal. This effect is partially offset by the reduced ash content in washed coal.[58]

The main coal preparation process relevant to brown coal is coal drying. This is needed to make power stations using brown coal more efficient. The Co-operative Research Centre for Clean Power from Lignite is now building a pilot-scale plant for a particular coal drying process called Mechanical Thermal Expression, for use with existing as well as new power stations. If added to existing power stations, coal drying would reduce greenhouse gas emissions slightly, though emissions would still be higher than the hypothetically best type of new brown coal power station described above (advanced pressurised fluidised bed combustion). The Commonwealth and Victorian Governments are subsidising the development of this process by $11.13 million and $680,000 respectively.[59]

Advanced coal combustion

A variety of technologies is under development to improve power station efficiency and to reduce acid rain emissions. These include the advanced pressurised fluidised bed combustion technology discussed above. Some of these technologies offer small reductions in emissions. Most research, development, demonstration and commercialisation of advanced coal combustion technologies have taken place in North America and Europe and mostly for black coal.

According to the CRC for Clean Power from Lignite, the emission reductions possible from the main technologies using brown coal (all with coal drying and no sulphur removal after combustion), are:

- 11 per cent from circulating fluidised bed combustion;
- 24 per cent from pulverised coal with supercritical steam;
- 25 per cent from first generation pressurised fluidised bed combustion;

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[57] The material in this and the following two sections is drawn from Longwell et al, 1995, as above; Ellis, 1997, as above; and Rousaki, K and Couch, G, 2000, as above.

[58] Hugh Saddler, Energy Strategies Ltd, personal communication, April 2002.

[59] "Government funds clean power development", Media Release, CRC for Clean Power from Lignite, 18 July 2001; and "Brown coal technology development aid welcomed", News Release, Latrobe Valley Generators, 19 October 2001, both on http://www.cleanpower.com.au.

- 20 per cent from integrated gasification combined-cycle; and
- 34 per cent from advanced pressurised fluidised bed combustion[60].

Of these, the only ones in commercial use are:

- circulating fluidised bed combustion, which is mainly used for high sulphur coals, coal wastes and other types of waste, rather than brown coals; and
- pulverised coal with supercritical steam, which has been used for new brown coal fired power stations in Germany and for a power station in Queensland using high ash black coal[61].

After combustion

Most research, development, demonstration and commercialisation of post-combustion technologies has gone into removing sulphur, the cause of acid rain. Sulphur removal is of no relevance to Victorian brown coal with its low sulphur content. With black coal, removal of sulphur increases gas emissions because of the energy required to run the sulphur removal process. Most work on sulphur removal processes has taken place in North America and Europe, driven by legislation like the US Clean Air Act.

Removal of carbon dioxide from flue gases, after combustion, is technically possible though expensive in both energy and dollar terms.[62] Capture of carbon dioxide is more feasible if the coal is gasified first, yielding a stream of gases rich in carbon dioxide.[63] This process would occur with integrated gasification combined-cycle power stations or with an integrated coal-to-oil and power station project like that proposed by Australian Power and Energy Ltd (see section 5 on geo-sequestration and below).

3. *Integrated coal-to-oil and power projects*

Projects like the one proposed by APEL involve the integration of three processes:

- conversion of coal into synthetic gas;
- conversion of the synthetic gas into liquid fuels; and
- an advanced power station technology called “integrated gasification combined-cycle”.

Making synthetic gas: There are many coal-to-gas technologies. Although some technologies were formerly used to make “town gas” before natural gas became

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[60] Brockway, undated, as above, p.7, Fig. 3.
[61] Rousaki, K and Couch, G, 2000, as above, pp. 54-6.
[62] International Energy Agency Greenhouse Gas Research and Development Programme, *Capture and Storage of* CO_2, at http://www.ieagreen.org.uk/removal.htm.
[63] “Governments urged to embrace clean coal technology as greenhouse solution”, Media Release, Australian Coal Association, 30 April, 2002.

commonplace, this does not mean that they can easily be applied to an integrated plant like the one proposed by APEL:

> No single gasification process is likely to be optimal for all applications: the wide range of coal properties will, in itself, affect the choice…Solid reaction systems are notoriously difficult to extrapolate, making development of any system to commercial scale a costly operation (about [US]$0.5 billion for each process).[64]

Making oil: The largest example of converting coal into synthetic gas and then into liquid fuels is the South African Coal, Oil and Gas Corporation (Sasol).[65] This was driven by trade embargoes imposed on the former apartheid regime. There are some other gas-to-oil projects using natural gas as the raw material. In the late 1980s, there was a Japanese operated brown coal-to-oil pilot-scale plant in Victoria, but it used a different technology (direct liquefaction), which does not allow integration with power generation.[66]

Integrated gasification combined-cycle power generation (IGCC) is at the commercial-scale demonstration stage in the USA and Europe, mostly using black coal. However, “the technology is not yet fully mature…currently, capital costs are high and operationally the plants do not match the availability or flexibility of conventional units…IGCC will require time before it is commercialised for use with coal, even with high value coals.”[67]

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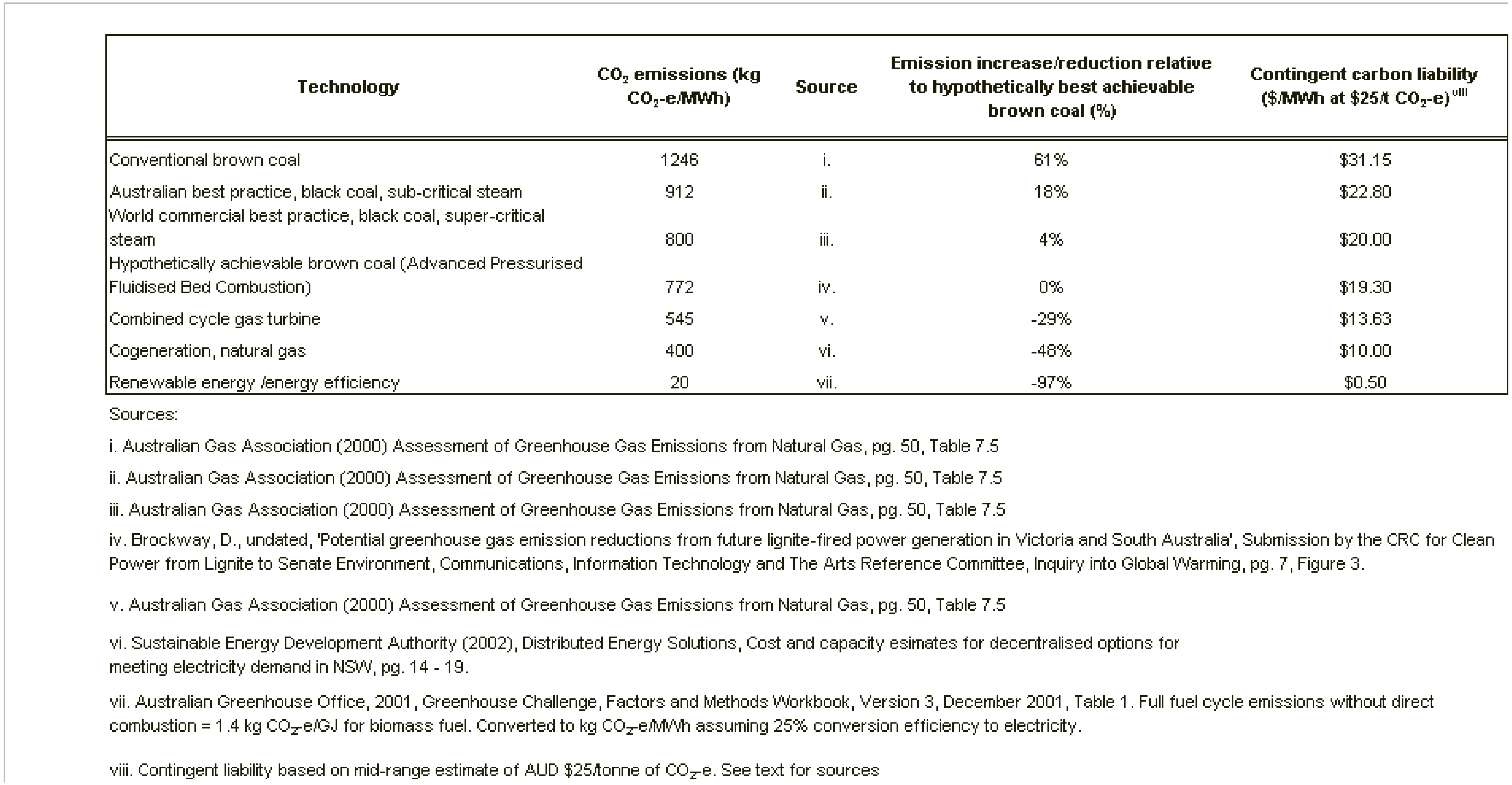
[64] Longwell et al, as above, p.302.
[65] Longwell et al, as above, p.306.
[66] Longwell et al, as above, pp.307, 311.
[67] Rousaki, K and Couch, G, 2000, as above, pp. 30, 69.

APPENDIX 2: POWER GENERATION: EMISSIONS AND COSTS OF EMISSIONS



Technology	CO_2 emissions (kg CO_2-e/MWh)	Source	Emission increase/reduction relative to hypothetically best achievable brown coal (%)	Contingent carbon liability ($/MWh at $25/t CO_2-e)[viii]
Conventional brown coal	1246	i.	61%	$31.15
Australian best practice, black coal, sub-critical steam	912	ii.	18%	$22.80
World commercial best practice, black coal, super-critical steam	800	iii.	4%	$20.00
Hypothetically achievable brown coal (Advanced Pressurised Fluidised Bed Combustion)	772	iv.	0%	$19.30
Combined cycle gas turbine	545	v.	-29%	$13.63
Cogeneration, natural gas	400	vi.	-48%	$10.00
Renewable energy /energy efficiency	20	vii.	-97%	$0.50

Sources:

i. Australian Gas Association (2000) Assessment of Greenhouse Gas Emissions from Natural Gas, pg. 50, Table 7.5

ii. Australian Gas Association (2000) Assessment of Greenhouse Gas Emissions from Natural Gas, pg. 50, Table 7.5

iii. Australian Gas Association (2000) Assessment of Greenhouse Gas Emissions from Natural Gas, pg. 50, Table 7.5

iv. Brockway, D., undated, 'Potential greenhouse gas emission reductions from future lignite-fired power generation in Victoria and South Australia', Submission by the CRC for Clean Power from Lignite to Senate Environment, Communications, Information Technology and The Arts Reference Committee, Inquiry into Global Warming, pg. 7, Figure 3.

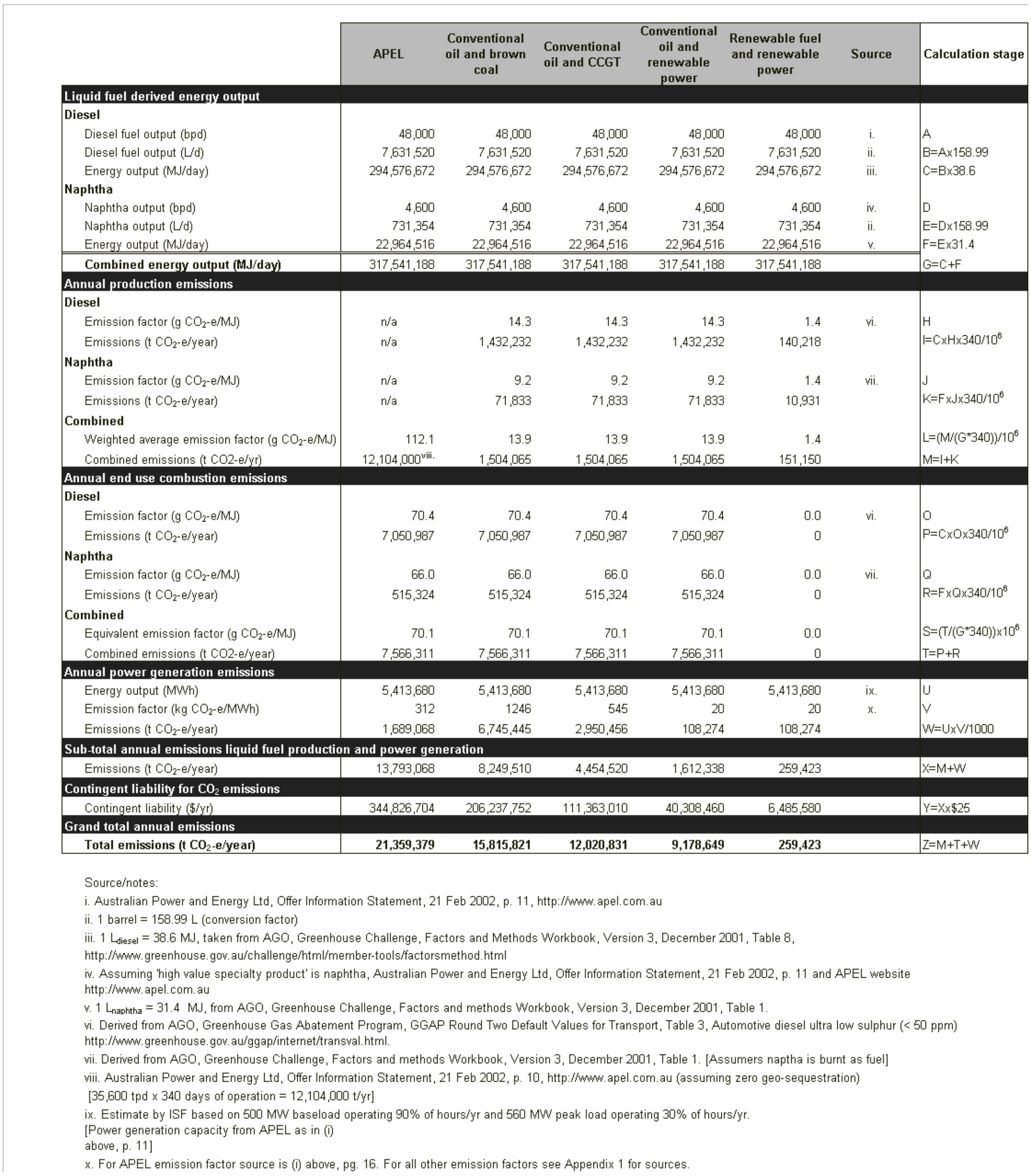
v. Australian Gas Association (2000) Assessment of Greenhouse Gas Emissions from Natural Gas, pg. 50, Table 7.5

vi. Sustainable Energy Development Authority (2002), Distributed Energy Solutions, Cost and capacity esimates for decentralised options for meeting electricity demand in NSW, pg. 14 - 19.

vii. Australian Greenhouse Office, 2001, Greenhouse Challenge, Factors and Methods Workbook, Version 3, December 2001, Table 1. Full fuel cycle emissions without direct combustion = 1.4 kg CO_2-e/GJ for biomass fuel. Converted to kg CO_2-e/MWh assuming 25% conversion efficiency to electricity.

viii. Contingent liability based on mid-range estimate of AUD $25/tonne of CO_2-e. See text for sources

APPENDIX 3: COAL-TO-OIL: EMISSIONS & CO_2 COSTS



	APEL	Conventional oil and brown coal	Conventional oil and CCGT	Conventional oil and renewable power	Renewable fuel and renewable power	Source	Calculation stage
Liquid fuel derived energy output							
Diesel							
Diesel fuel output (bpd)	48,000	48,000	48,000	48,000	48,000	i.	A
Diesel fuel output (L/d)	7,631,520	7,631,520	7,631,520	7,631,520	7,631,520	ii.	B=Ax158.99
Energy output (MJ/day)	294,576,672	294,576,672	294,576,672	294,576,672	294,576,672	iii.	C=Bx38.6
Naphtha							
Naphtha output (bpd)	4,600	4,600	4,600	4,600	4,600	iv.	D
Naphtha output (L/d)	731,354	731,354	731,354	731,354	731,354	ii.	E=Dx158.99
Energy output (MJ/day)	22,964,516	22,964,516	22,964,516	22,964,516	22,964,516	v.	F=Ex31.4
Combined energy output (MJ/day)	317,541,188	317,541,188	317,541,188	317,541,188	317,541,188		G=C+F
Annual production emissions							
Diesel							
Emission factor (g CO_2-e/MJ)	n/a	14.3	14.3	14.3	1.4	vi.	H
Emissions (t CO_2-e/year)	n/a	1,432,232	1,432,232	1,432,232	140,218		I=CxHx340/10^6
Naphtha							
Emission factor (g CO_2-e/MJ)	n/a	9.2	9.2	9.2	1.4	vii.	J
Emissions (t CO_2-e/year)	n/a	71,833	71,833	71,833	10,931		K=FxJx340/10^6
Combined							
Weighted average emission factor (g CO_2-e/MJ)	112.1	13.9	13.9	13.9	1.4		L=(M/(G*340))/10^6
Combined emissions (t CO2-e/yr)	12,104,000[viii.]	1,504,065	1,504,065	1,504,065	151,150		M=I+K
Annual end use combustion emissions							
Diesel							
Emission factor (g CO_2-e/MJ)	70.4	70.4	70.4	70.4	0.0	vi.	O
Emissions (t CO_2-e/year)	7,050,987	7,050,987	7,050,987	7,050,987	0		P=CxOx340/10^6
Naphtha							
Emission factor (g CO_2-e/MJ)	66.0	66.0	66.0	66.0	0.0	vii.	Q
Emissions (t CO_2-e/year)	515,324	515,324	515,324	515,324	0		R=FxQx340/10^6
Combined							
Equivalent emission factor (g CO_2-e/MJ)	70.1	70.1	70.1	70.1	0.0		S=(T/(G*340))x10^6
Combined emissions (t CO2-e/year)	7,566,311	7,566,311	7,566,311	7,566,311	0		T=P+R
Annual power generation emissions							
Energy output (MWh)	5,413,680	5,413,680	5,413,680	5,413,680	5,413,680	ix.	U
Emission factor (kg CO_2-e/MWh)	312	1246	545	20	20	x.	V
Emissions (t CO_2-e/year)	1,689,068	6,745,445	2,950,456	108,274	108,274		W=UxV/1000
Sub-total annual emissions liquid fuel production and power generation							
Emissions (t CO_2-e/year)	13,793,068	8,249,510	4,454,520	1,612,338	259,423		X=M+W
Contingent liability for CO_2 emissions							
Contingent liability ($/yr)	344,826,704	206,237,752	111,363,010	40,308,460	6,485,580		Y=Xx$25
Grand total annual emissions							
Total emissions (t CO_2-e/year)	**21,359,379**	**15,815,821**	**12,020,831**	**9,178,649**	**259,423**		Z=M+T+W

Source/notes:

i. Australian Power and Energy Ltd, Offer Information Statement, 21 Feb 2002, p. 11, http://www.apel.com.au

ii. 1 barrel = 158.99 L (conversion factor)

iii. 1 L_{diesel} = 38.6 MJ, taken from AGO, Greenhouse Challenge, Factors and Methods Workbook, Version 3, December 2001, Table 8, http://www.greenhouse.gov.au/challenge/html/member-tools/factorsmethod.html

iv. Assuming 'high value specialty product' is naphtha, Australian Power and Energy Ltd, Offer Information Statement, 21 Feb 2002, p. 11 and APEL website http://www.apel.com.au

v. 1 $L_{naphtha}$ = 31.4 MJ, from AGO, Greenhouse Challenge, Factors and methods Workbook, Version 3, December 2001, Table 1.

vi. Derived from AGO, Greenhouse Gas Abatement Program, GGAP Round Two Default Values for Transport, Table 3, Automotive diesel ultra low sulphur (< 50 ppm) http://www.greenhouse.gov.au/ggap/internet/transval.html.

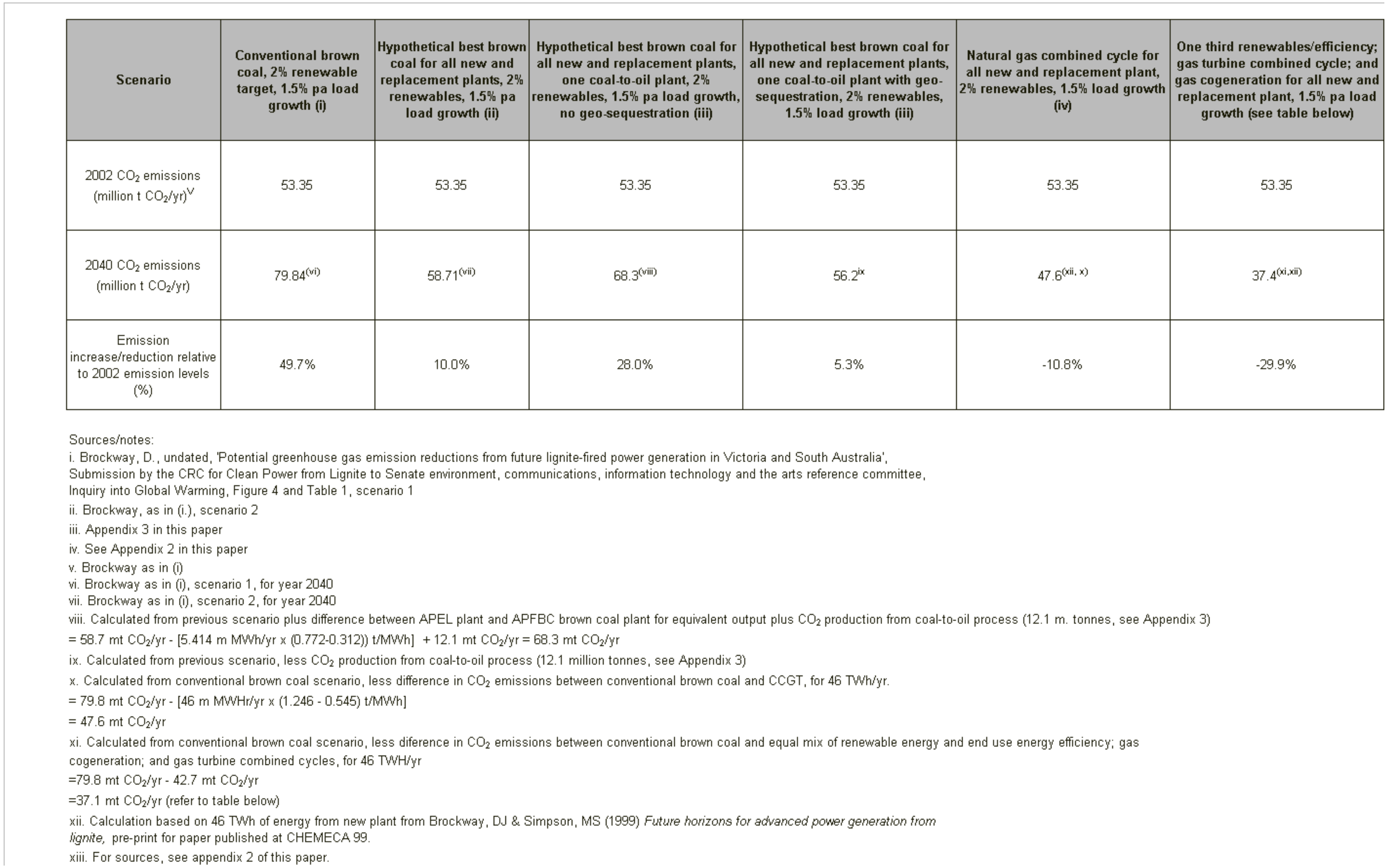
vii. Derived from AGO, Greenhouse Challenge, Factors and methods Workbook, Version 3, December 2001, Table 1. [Assumers naptha is burnt as fuel]

viii. Australian Power and Energy Ltd, Offer Information Statement, 21 Feb 2002, p. 10, http://www.apel.com.au (assuming zero geo-sequestration) [35,600 tpd x 340 days of operation = 12,104,000 t/yr]

ix. Estimate by ISF based on 500 MW baseload operating 90% of hours/yr and 560 MW peak load operating 30% of hours/yr. [Power generation capacity from APEL as in (i) above, p. 11]

x. For APEL emission factor source is (i) above, pg. 16. For all other emission factors see Appendix 1 for sources.

APPENDIX 4: INDICATIVE SCENARIOS: VIC. POWER AND ENERGY PROJECT EMISSIONS, 2040



Scenario	**Conventional brown coal, 2% renewable target, 1.5% pa load growth (i)**	**Hypothetical best brown coal for all new and replacement plants, 2% renewables, 1.5% pa load growth (ii)**	**Hypothetical best brown coal for all new and replacement plants, one coal-to-oil plant, 2% renewables, 1.5% pa load growth, no geo-sequestration (iii)**	**Hypothetical best brown coal for all new and replacement plants, one coal-to-oil plant with geo-sequestration, 2% renewables, 1.5% load growth (iii)**	**Natural gas combined cycle for all new and replacement plant, 2% renewables, 1.5% load growth (iv)**	**One third renewables/efficiency; gas turbine combined cycle; and gas cogeneration for all new and replacement plant, 1.5% pa load growth (see table below)**
2002 CO_2 emissions (million t CO_2/yr)[V]	53.35	53.35	53.35	53.35	53.35	53.35
2040 CO_2 emissions (million t CO_2/yr)	79.84(vi)	58.71(vii)	68.3(viii)	56.2[ix]	47.6(xii, x)	37.4(xi,xii)
Emission increase/reduction relative to 2002 emission levels (%)	49.7%	10.0%	28.0%	5.3%	-10.8%	-29.9%

Sources/notes:

i. Brockway, D., undated, 'Potential greenhouse gas emission reductions from future lignite-fired power generation in Victoria and South Australia', Submission by the CRC for Clean Power from Lignite to Senate environment, communications, information technology and the arts reference committee, Inquiry into Global Warming, Figure 4 and Table 1, scenario 1

ii. Brockway, as in (i.), scenario 2

iii. Appendix 3 in this paper

iv. See Appendix 2 in this paper

v. Brockway as in (i)

vi. Brockway as in (i), scenario 1, for year 2040

vii. Brockway as in (i), scenario 2, for year 2040

viii. Calculated from previous scenario plus difference between APEL plant and APFBC brown coal plant for equivalent output plus CO_2 production from coal-to-oil process (12.1 m. tonnes, see Appendix 3)

= 58.7 mt CO_2/yr - [5.414 m MWh/yr x (0.772-0.312)) t/MWh] + 12.1 mt CO_2/yr = 68.3 mt CO_2/yr

ix. Calculated from previous scenario, less CO_2 production from coal-to-oil process (12.1 million tonnes, see Appendix 3)

x. Calculated from conventional brown coal scenario, less difference in CO_2 emissions between conventional brown coal and CCGT, for 46 TWh/yr.

= 79.8 mt CO_2/yr - [46 m MWHr/yr x (1.246 - 0.545) t/MWh]

= 47.6 mt CO_2/yr

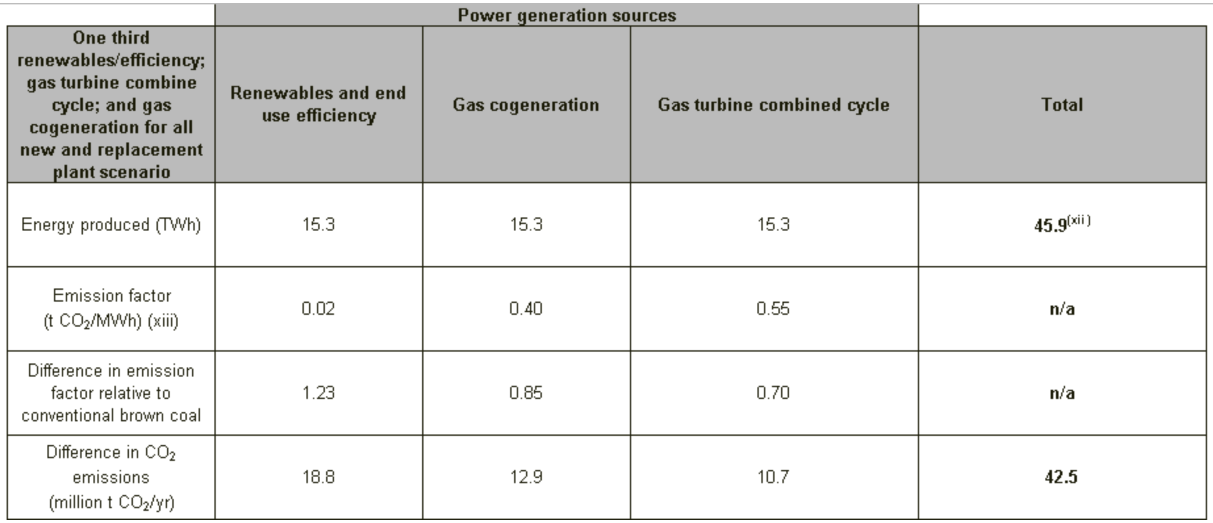
xi. Calculated from conventional brown coal scenario, less diference in CO_2 emissions between conventional brown coal and equal mix of renewable energy and end use energy efficiency; gas cogeneration; and gas turbine combined cycles, for 46 TWH/yr

=79.8 mt CO_2/yr - 42.7 mt CO_2/yr

=37.1 mt CO_2/yr (refer to table below)

xii. Calculation based on 46 TWh of energy from new plant from Brockway, DJ & Simpson, MS (1999) *Future horizons for advanced power generation from lignite,* pre-print for paper published at CHEMECA 99.

xiii. For sources, see appendix 2 of this paper.



	Power generation sources			
One third renewables/efficiency; gas turbine combine cycle; and gas cogeneration for all new and replacement plant scenario	**Renewables and end use efficiency**	**Gas cogeneration**	**Gas turbine combined cycle**	**Total**
Energy produced (TWh)	15.3	15.3	15.3	**45.9**(xii)
Emission factor (t CO_2/MWh) (xiii)	0.02	0.40	0.55	**n/a**
Difference in emission factor relative to conventional brown coal	1.23	0.85	0.70	**n/a**
Difference in CO_2 emissions (million t CO_2/yr)	18.8	12.9	10.7	**42.5**