Bureau of Resource Sciences
AUSTRALIA

SCIENTIFIC AND TECHNICAL OPPORTUNITIES TO REDUCE AUSTRALIAN GREENHOUSE GAS EMISSIONS

November 1998

Editors: David Rossiter and Ian B Lambert

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FOREWORD

The Bureau of Resource Sciences* (BRS) provides scientific advice in support of evidence-based Government policy and programs.

Australia has a challenging task to achieve significant reductions in the rates of emission of greenhouse gases. There are hundreds of potential means of reducing emissions, which have a wide range of costs, capabilities and other effects. Evaluating and selecting the best options requires major scientific and technical inputs.

This report summarises work undertaken by the BRS to improve scientific and technical understanding of greenhouse gas emissions and identify the 'best' areas for emissions reduction. It covers emissions from agriculture, land use change, forestry, energy and waste.

The report reviews Australia's greenhouse gas emissions by sector and location and discusses the implications of Australia's reduction target in the Kyoto Protocol. A large number of candidate options for emissions reduction are discussed, covering each of the main emission sectors. Preliminary assessments are made of the individual options, to identify their technical feasibility, relative costs and scales of emission reductions. The preferred options are identified and recommendations made for further work.

Peter O'Brien
Executive Director
Bureau of Resource Sciences

* Since the work reported was conducted, the Bureau of Resource Sciences has been renamed as the Bureau of Rural Sciences within the Department of Agriculture, Fisheries and Forestry. The Mineral Resources and Energy Branch and the Petroleum Resources Branch have moved into the Australian Geological Survey Organisation, within the Department of Industry Science and Resources.

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ACKNOWLEDGEMENTS

The Greenhouse Science Priority Project integrates and coordinates greenhouse/ climate change work across several Branches of the Bureau of Resource Sciences. The staff involved are:

David Rossiter – Project Leader and Energy (fuel combustion)

Ian Lambert – Project co-mentor

Ron Sait – Carbon dioxide abatement technologies

Denis Wright – Energy (fugitive emissions)

Snow Barlow – Project co-mentor

Michele Barson – Land use change

Penny Reyenga – Agriculture

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Robert Smart – Emissions modelling

Richard Lucas — Forestry

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EXECUTIVE SUMMARY

Australia has embarked on a process of potential commitment through the Kyoto Protocol[1] to contain growth in greenhouse gas emissions to 8% between 1990 and the reporting period of 2008 – 2012. The target is well below the estimated growth of about 28% under the 'business as usual'[2] condition. Australia's greenhouse gas inventory estimates that 502 million tonnes of carbon dioxide equivalents were emitted in the base year of 1990.

The Bureau of Resource Sciences (BRS) began work in 1997 to identify how emission reductions might be achieved and to identify where the best options for reductions might lie. This report summarises options for greenhouse gas emission reductions on the basis of assessments of technical, environmental and comparative cost feasibility. The report is intended to:

- improve scientific and technical understanding of emission generation, reduction, sequestration and use;
- identify the 'best' areas for emissions reduction; and
- provide scientific information in support of climate change negotiations.

Though the Kyoto Protocol indicates a potential commitment to limit Australia's annual greenhouse gas emissions to 8% above 1990 levels in the period 2008-2012, a reduction target cannot be quantified exactly at present. Until better information is available, the best estimate is that emissions will need to be reduced by 30-68 million tonnes of carbon dioxide equivalents below the forecast levels for 'business as usual'.

This report examines over 175 candidate options for reducing greenhouse gas emissions to identify their technical feasibility, cost per tonne of carbon dioxide avoided and capability to reduce emissions under Australian conditions. The candidate options were not intended to represent an exhaustive list but they encompass major and some lesser options being canvassed in Australia and overseas.

Preferred options were selected on their performance towards the criteria of technical feasibility, cost and capability.

Many options were identified — often with individually small capability of emission reduction. However, using a cost criterion of 'no regrets' through to low cost (defined here as less than A$15 per tonne of carbon dioxide avoided) the sum of the capability of the preferred options exceeded the target emission reduction range. No single option appears capable of achieving the least cost outcome for emissions reduction.

The preferred options included the following generic groups:

- energy efficiency;
- fuel switching to less carbon intensive or renewable fuels;
- biomass and waste/landfill gas to energy;
- plantation forestry;

[1] The United Nations Framework Convention on Climate Change Conference of Parties Third Session (UNFCCC COP3) held in Kyoto 1-10 December 1997 developed the Kyoto Protocol to the United Nations Framework Convention On Climate Change.

[2] 'Business as usual' is considered to be a condition with all pre-November 1997 greenhouse and energy efficiency policies in place.

- reduced land use change; and
- revised agricultural management methods.

Some other options (such as ocean nourishment and hot dry rocks) where techniques and technologies are not yet mature and cost structures may be less certain, might also prove attractive after more study.

Preferred future options were also identified to meet possible commitments beyond the current Kyoto Protocol, for which the reporting period is 2008-2012.

The policy proposals of the Australian Government (dated 20 November 1997) cover the generic options and also encourage some work on future preferred options. The estimated reduction in emissions (39 million tonnes) from these policy proposals fits neatly within the target emission reduction range.

This analysis identified the need for more work in key areas:

- more detailed study of the implications of Land Use Change and Forestry sectors on the Kyoto target, including reduction of the uncertainty of the 1990 baseline, better estimates of emissions and forecasts of emissions;

- detailed study of the capability for sequestering carbon in forestry and the availability of suitable land;

- study to seek better methods of encouraging reductions in greenhouse gas emissions from motor vehicle use and use of other energy consuming devices, while sustaining Australia's manufacturing capabilities. Such a study would examine behavioural means of moving from a general highlighting and awareness of options to their implementation;

- emission control planning be implemented for all new power generation facilities, particularly for facilities with long lead times and/or long plant life.

1. INTRODUCTION

Australia has embarked on a process of potential commitment through the Kyoto Protocol[1] to contain growth in greenhouse gas emissions to 8% between 1990 and the reporting period of 2008 – 2012. The target is well below the estimated growth of about 28% under the business as usual condition. Australia's greenhouse gas inventory estimates that 502 million tonnes of carbon dioxide equivalents were emitted in the base year of 1990.

The Bureau of Resource Science (BRS) developed a multidisciplinary Greenhouse Science Project in 1997/98 to integrate and focus the range of greenhouse-related projects across the organisation. It did so in anticipation of the need to identify how emission reductions might be achieved and to identify where the best options for reductions might lie.

This first summary report of the Greenhouse Science Project summarises the current knowledge of Australia's greenhouse gas emissions and the issues relevant to meeting targets arising from the Kyoto Protocol. Options for greenhouse gas emission reductions are presented on the basis of assessments of technical, environmental and comparative cost feasibility. Policy and social acceptability of options have only been highlighted and considered generally.

[1] The United Nations Framework Convention on Climate Change Conference of Parties Third Session (UNFCCC COP3) held in Kyoto 1-10 December 1997 developed the Kyoto Protocol to the United Nations Framework Convention On Climate Change.

2. AUSTRALIA'S GREENHOUSE GAS EMISSIONS

2.1 Emissions by Sector

The Intergovernmental Panel on Climate Change (IPCC) considers six modules (or sectors) for greenhouse gas emissions: Energy; Industrial Processes; Solvents; Agriculture; Land Use Change (LUC) & Forestry; and Waste.

Table 1 shows the emissions in carbon dioxide equivalents for the six sectors. It shows the dominance of energy in historic emissions and in the forecasts. In general terms for 1990, for every five units of emissions, three came from Energy and one from each of Agriculture and LUC & Forestry. By 2010, it would appear that of every five units of emissions, four will come from Energy and one from Agriculture, but reliable LUC emission forecasts are not yet available.

Table 1 Greenhouse Gas Emissions 1990, 1995 and 2010

Sector	1990	1995	2010	% change
	(reported)	(reported)	(forecast)	(2010 v 1990)
1. **All Energy**				37
1A. Energy - Fuel Combustion	267.3	291.7	373.4	40
1B. Energy – Fugitive Emissions	26.0	25.6	29.2	12
2. **Industrial Processes**	12.1	9.0	12.1	0
3. **Solvents**	NRS	NRS	NRS	
4. **Agriculture**	88.8	87.4	94.9	7
5. **LUC & Forestry**				
5A. Forestry	-23.1	-21.1	-32.8	-42
5B & 5C	122.6	84.6	Not Predicted	Not Predicted
5D	-6.3	-6.5	Not Predicted	Not Predicted
6. **Waste**	14.8	16.4	17.2	16
Total without LUC	**385.9**	**408.9**	**494**	**28**
Total with LUC	**502.2**	**487.0**	**Not Predicted**	**Not Predicted**

Units: Mt CO_2 equivalents and percent.

Source: Australia's Second National Report to UNFCCC, Nov 1997.

NRS = Not Reported Separately. Solvent emissions are included in other categories in Australia's Inventory.

LUC = land use change (taken as the sum of 5B, 5C and 5D).

5B is forestry and grassland conversion, 5C is abandonment of managed lands, 5D includes carbon removal from pasture improvement.

The net emissions are dominated by Energy (eg. 65% in 1995) followed by Agriculture (18%) and Land Use Change & Forestry (12%). Industrial Processes and Waste make up the remaining 5% of the net emissions. (Solvents are not reported separately in Australia's Inventory.)

Estimates of emissions from land clearing, which is part of the Land Use Change & Forestry sector, have potentially large uncertainties associated with them. Agriculture and the Fugitive

Emissions component of Energy also have large uncertainties associated with some or all of their components.

LUC makes a significant contribution to the Inventory, but because of large uncertainties, its emissions are particularly difficult to forecast accurately and, as Table 1 shows, Australia's Second National report contains no forecasts for this sub-sector. This situation is expected to improve over time as BRS and others refine the data.

Figure 1 shows the data from Table 1 in the form of a histogram. It also includes other data from the same source for the forecast years 2000, 2005 and 2020. The forecasts are for 'business as usual' which is considered to be a condition with all pre-November 1997 greenhouse and energy efficiency policies in place.

The highest forecast growth rate for any emission sector is for the 'All Energy' sector (37% from 1990 to 2010) with its sub-sector 'Energy – Fuel Combustion' growing even faster (40%). The lowest growth rate is for Industrial Processes (0%), and the second lowest is for Agriculture (7%). Partially countering this growth in emissions from sources, the Forestry carbon dioxide sink is predicted to increase (by 42%). The net effect is a forecast growth in emissions, from all sectors except LUC, of 28% from 1990 to 2010.

Because energy emissions tend to be quite well known and are readily calculated for most OECD countries, greenhouse gas emissions have tended to be compared internationally on the basis of energy emissions only (The OECD Observer, 1996). Unlike some other OECD countries, approximately one-third of Australia's emissions come from sectors other than energy. In contrast, for example the UK 1990 Inventory indicates that only about one-seventh of its emissions come from sectors other than energy.

An approach considering only energy emissions will not display the full picture of Australian emissions. By focussing solely on energy emissions the true effects on the atmosphere can be distorted and it is the atmosphere that is the primary element being protected by the Kyoto Protocol. Hence it is logical for Australia to consider all sectors in its Inventory.

2.2 Emissions by Location

BRS has examined the geographical distribution of Australia's greenhouse gas emissions from the energy sector. Figure 2 shows the spatial distribution of emissions using a perspective view of a 'three dimensional histogram' with columns standing on 10 km square pixels. This diagram emphasises the different characteristics of greenhouse gas emissions from energy emission sources.

Characteristically, energy transformation processes such as electricity production[3] and liquefaction of natural gas produce large point sources of emissions. Other point sources include some fugitive emissions from energy supply. In contrast, transport emissions are much more widely distributed.

[3] Though electricity transformation can produce large point sources of emissions the users of the electricity are widely dispersed. Care needs to be exercised to differentiate between energy production, transformation and energy end use when attributing emissions to sources.

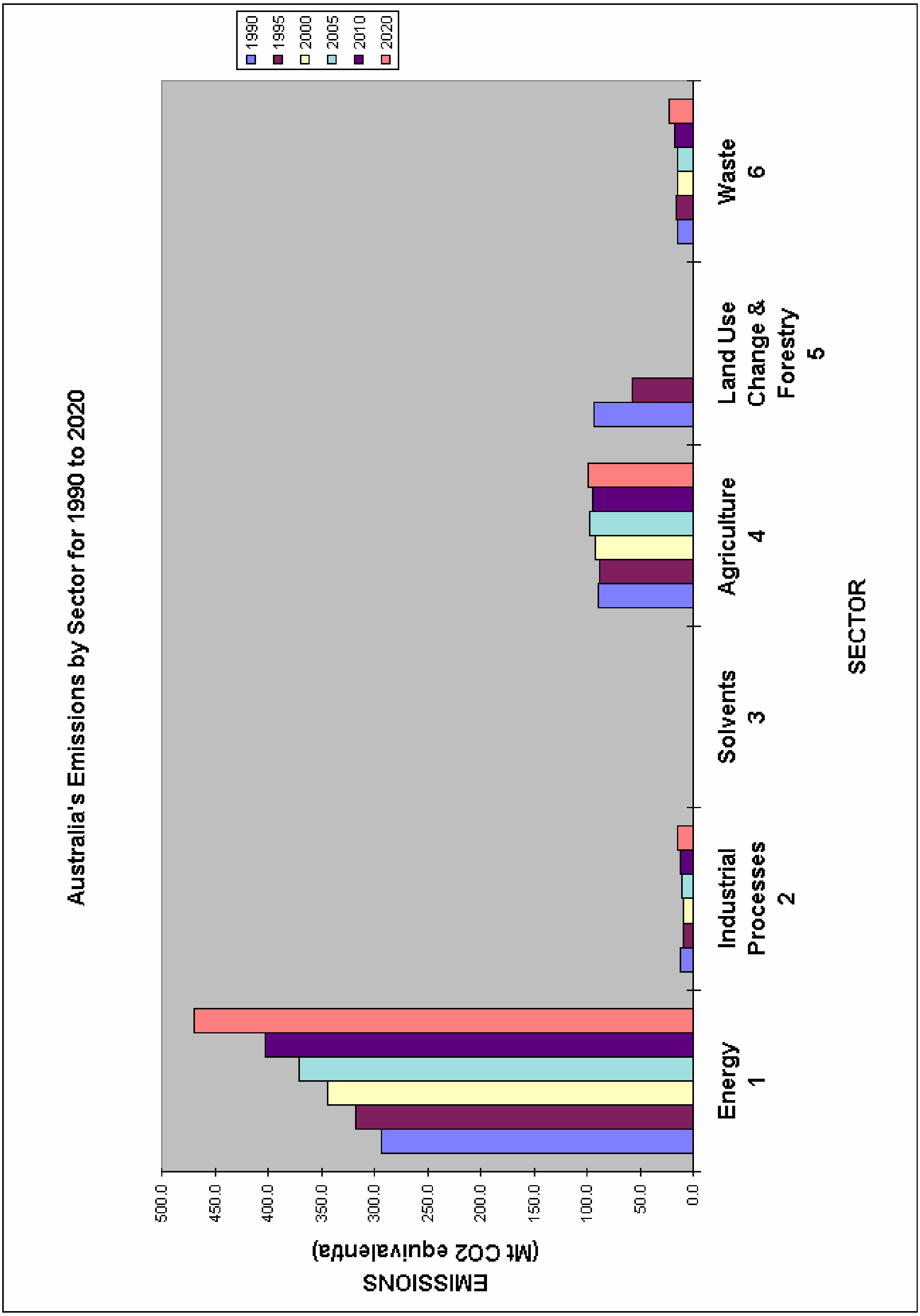

Figure 1 — Australia’s Emissions by IPCC Sector 1990 to 2020
Source: BRS based on data from Australia’s Second National Report 1997 to UNFCC

Figure 3 shows similar information to Figure 2 except the emission pixels are 100 km squares and a logarithmic scale is used. The range of emissions from the shaded pixels covers six orders of magnitude. Figure 3 shows more clearly that the distribution of emissions is related to the population density, but some major point emitters can still be identified.

Figures 2 and 3 illustrate the diversity of sources of emissions – point and distributed sources. Some emissions come from distinctively point sources and others from distributed sources. Clearly, if these emissions are to be reduced, different methods will be appropriate for the different source types. Although it may at first appear easier to capture carbon dioxide at point sources, it may be more economical to reduce the total quantum of emissions from all sources by more efficient use of energy or similar methods.

The magnitude of the emissions shown in Figure 3 can be related to the existing pool of carbon in the atmosphere. The total quantity of carbon in the atmospheric pool has been estimated to be 775,000,000 Gg. In carbon dioxide equivalents, that is approximately 80,000 Gg per 10,000 km^2 of the earth's surface[4]. It is interesting to compare this total existing atmospheric carbon dioxide equivalent with the scale of the annual emissions shown on Figure 3. The red areas on Figure 3 represent an annual rate of production of carbon dioxide that is approximately equal to the total existing carbon dioxide equivalent in the atmosphere. If no circulation, diffusion and loss of carbon dioxide from the atmosphere occurred, the atmosphere above each of the red pixels would approximately double in carbon dioxide equivalent content in one year.

[4] IPCC uses Gg (gigagrams) as a 'standard' unit. 1 Gg is a thousand tonnes and 80,000 Gg per 10,000 per square kilometre is equivalent to 8 kg per square metre of the earth's surface. If all atmospheric carbon dioxide were condensed into liquid form, it would form a layer about 4 mm thick over the whole surface of the earth. This has been compared to the thickness of frost on a car window in winter.

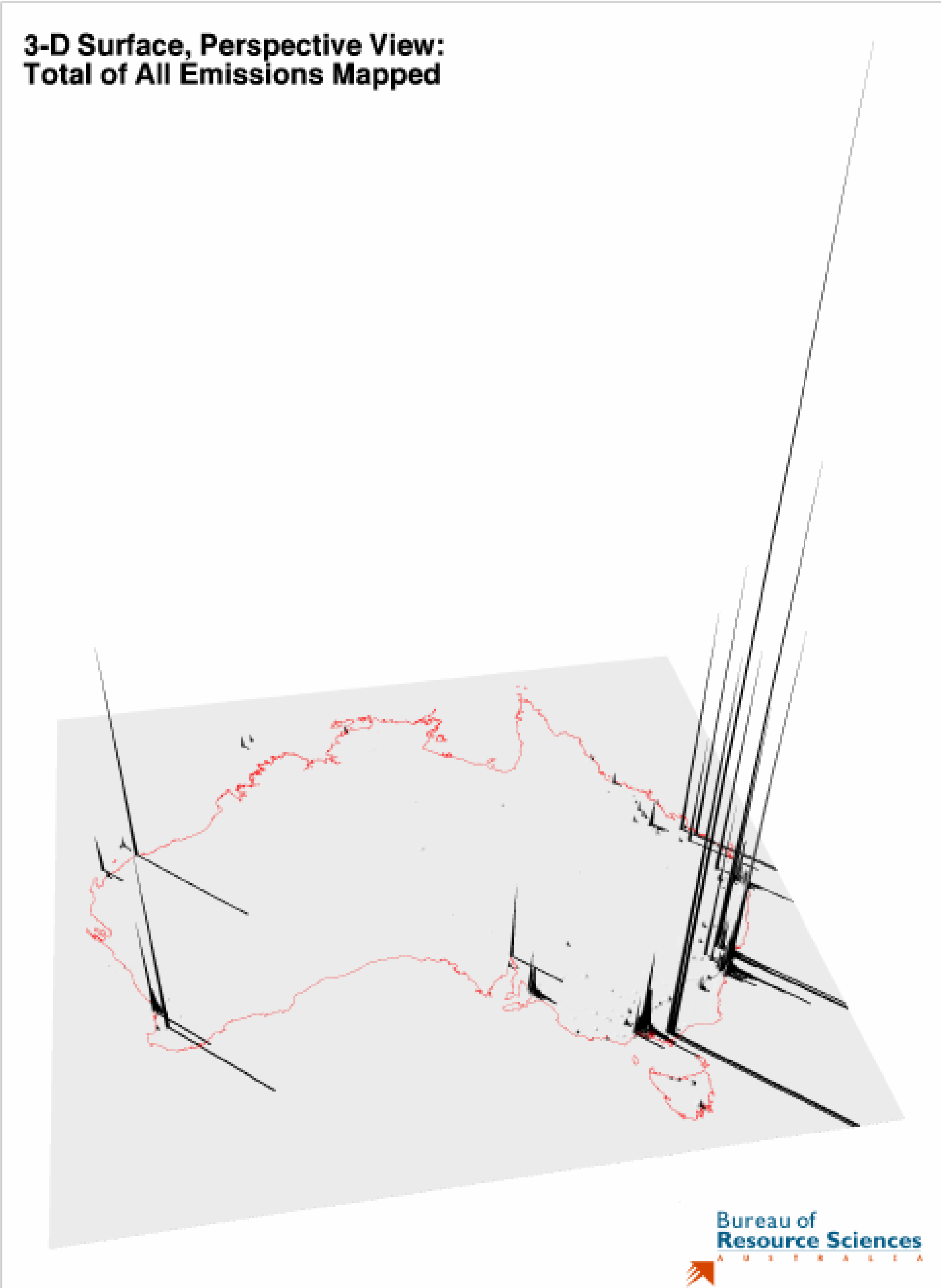

Figure 2 — Spatial Distribution of Australia's Energy Emissions 1995 (linear scale)
Source: BRS based on data from National Greenhouse Gas Inventory Committee, 1997. Units: CO_2 equivalents per 100 km^2

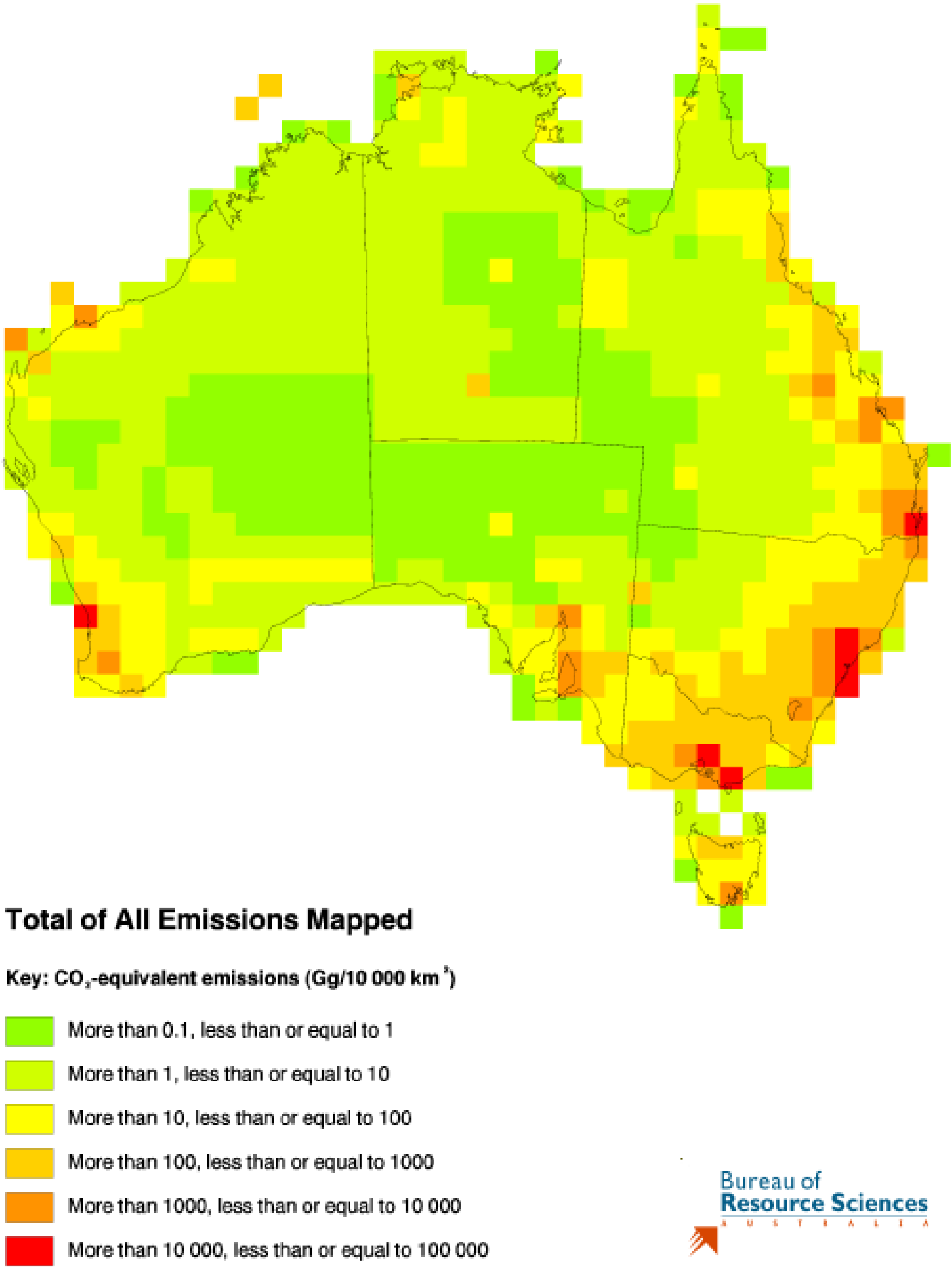

Figure 3 — Spatial Distribution of Australia's Energy Emissions 1995 (logarithmic scale)

Source: BRS based on data from National Greenhouse Gas Inventory Committee, 1997. Units CO_2 equivalents per 10 000 km^2

3. OUTCOME FROM KYOTO – AUSTRALIA'S REDUCTION TARGET

The Kyoto Protocol to the United Nations Framework Convention on Climate Change lays down the basis of Australia's potential commitments on greenhouse gas emissions. Australia signed the protocol on 29 April 1998.[5] Annex B of the protocol indicates that Australia could commit to limiting its 2010[6] emissions to 108% of its 1990 emissions.

The Kyoto Protocol considers human induced emissions from the following sectors:

- energy (fuel combustion and fugitive emissions);
- industrial processes;
- solvents;
- agriculture; and
- waste.

But it also allows…..*'net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks....'* (Article 3, paragraph 3, Kyoto Protocol)

However, this latter allowance is subject to three further conditions. Firstly, the 'trigger' that land use change and forestry emissions must have been a net source in 1990 (Article 3, paragraph 7, Kyoto Protocol). Secondly, the claimed emissions must be verifiable and, thirdly, they must be human induced (Article 3, paragraph 4, Kyoto Protocol).

Thus Australia can also include land use change and forestry subject to the caveats of the Protocol.

[5] Though Australia has signed the protocol (it was the fifteenth signatory, as part of a group of 21 countries that signed on that day) the protocol cannot come into force until 90 days after it has been ratified by not less than 55 Parties who account for at least 55% of the 1990 emissions of the Parties in Annex I. The protocol will not be open for ratification until the day after it is closed for signature, which is 15 March 1999.

[6] Strictly the protocol uses a compliance period of the five years 2008 to 2012 inclusive. However, to simplify the analysis here, the target is described as an 8% increase in the year 2010.

4. IMPLICATIONS OF 'KYOTO' FOR AUSTRALIA'S EMISSIONS

For the reasons indicated earlier in this document, emissions from land use change should be considered in Australia's Inventory, but without forecasts of LUC emissions (see Table 1) it is difficult to estimate the implications of the target on any sectors of Australia's emissions.

Until better information is available, two broad assumptions could be made about LUC emissions:

a) assume the 2010 LUC emissions remain constant at 1990 LUC levels; or
b) assume the 2010 LUC emissions remain constant at 1995 LUC levels.

Using these two scenarios, it is possible to predict a range of emission reduction targets that might be required from the other sectors and facilitate policy advancement. Table 2 shows the implications of these scenarios.

Table 2 Estimated Greenhouse Gas Emission Reductions Needed by 2010

Scenario for LUC Emissions	**1990 Emissions (Mt) (actual)**	**2010 Emissions (Mt) (forecast)**	**% change (2010 compared with 1990)**	**Apparent Kyoto Target 2010 (+8%) (Mt)**	**Reduction to meet target in 2010 (Mt)**
A: 2010 LUC equal to 1990 LUC(116.3 Mt)	502.2	610.3	22%	542.4	67.9
B: 2010 LUC equal to 1995 LUC(78.1 Mt)	502.2	572.1	14%	542.4	29.7

LUC = Land Use Change

Table 2 shows that if LUC emissions were to remain at 1990 levels the growth in total emissions would be 22%, and if the LUC emissions were to remain at 1995 levels the overall growth in emissions would be reduced to about 14% from 1990 to 2010. If LUC emissions were ignored, the expected growth in total emissions from 1990 to 2010 would be about 28%.

It is apparent that the inclusion of LUC emissions can have a significant effect on the expected growth rate of total emissions. This will be a key element for policy development and selection of reduction strategies. Thus the most important outcome from the Kyoto Protocol for Australia is that all emission sectors should be considered, including LUC and Forestry.

If it is assumed that LUC and Forestry emissions will not exceed those of 1990, the change to business as usual would need to be a reduction of 68 Mt to achieve the Kyoto target. On the other hand, if the lower 1995 LUC and Forestry emissions can be maintained in 2010 then a reduction of only about 30 Mt would be needed to meet the Kyoto target.

For broad planning purposes and if Australia is to meet its potential obligations, a target emission reduction range is needed of between 30 Mt and 68 Mt CO_2 equivalent, by 2010 relative to business as usual.

Concern must arise about what happens when LUC and Forestry can no longer diminish any further but Energy continues to grow unabated. That situation will probably not arise until after the first compliance period, which ends in 2012. However, with about 50% of the energy emissions currently coming from electricity generation, strategies for meeting further reductions in future compliance periods have to be developed sooner rather than later. This is because lead times for new plants are of the order of 2 to 10 years and operating lives vary from 10 to 50 years. To maintain the broadest range of emission reduction options, emission control planning for the second compliance period needs to be considered in all proposals for additional power generating capacity.

5. RECENT GOVERNMENT PROPOSALS TO REDUCE EMISSIONS

In *Safeguarding the Future*, released on 20 November 1997, immediately before the Kyoto meetings, the Howard Government announced further proposals to reduce greenhouse gas emissions from Australia. The package, which is costed at A$180 million, has yet to be fully developed and enacted, but it has been estimated that it will achieve a saving of about 39 million tonnes of emissions compared with business as usual. The measures included in this Package are:

- Cities for climate protection campaign
- Household greenhouse action
- Extension and expansion of Greenhouse Challenge
- Codes and standards for appliances and equipment
- Codes and standards for buildings (mixed VERSION)
- Benchmarking and best energy practice strategies
- Environmental Strategy for the Automotive industry
- Vehicle fuel labelling
- Light commercial vehicles - CNG infrastructure
- Ethanol pilot plant
- Accelerating energy market reform
- Emission standards for new power generation
- Mandatory targets for uptake of renewable energy in power supply
- Renewable energy innovation investment fund
- Renewable energy technology commercialisation loans and grants
- Renewable energy showcase
- Renewable energy Internet site
- Activities implemented jointly
- Plantations for Australia – The 2020 vision
- Bush for Greenhouse
- National carbon accounting system for land based sinks and sources
- Reducing methane emissions from livestock
- Energy efficiency in Commonwealth operations
- Establishment of Commonwealth Greenhouse Office
- Other NGS measures (e.g. inventory, public info, science)
- Emissions Trading

Clearly, the quantum of reduction of this package is well targeted relative to the subsequent outcome from the Kyoto negotiations. An emissions reduction of 39 million tonnes fits neatly in the target emission reduction range of 30 million tonnes to 68 million tonnes.

6. OPTIONS FOR GREENHOUSE GAS EMISSION REDUCTIONS

6.1 Candidate Options

Candidate options were generated for each of the main emission sectors in Australia's inventory. The list of options generated was not intended to be exhaustive but representative of some of the choices being canvassed.

Only four IPCC sectors are used here; that is Energy, Agriculture, Land Use Change and Forestry, and Waste. This is because Australia does not report any emissions separately for the solvents sector (they are included elsewhere), and the Industrial Processes sector options are common to the Energy sector, where they have been included for simplicity.

6.2 Evaluation of Options

Where possible, individual options were examined to identify:

- their technical feasibility;
- the approximate cost ranges in A$ per tonne of carbon dioxide avoided or, where these are difficult to estimate, the relative costs (expressed as no regrets[7], low, medium, high and very high[8]); and
- the scale of emission reductions that they might achieve (expressed as small, moderate and large[9]).

Thus the options were appraised on the basis of technical, environmental and comparative cost feasibility. Though no formal attempt has been made to test policy or social acceptability of the options these issues have been highlighted for some options (such as nuclear), where clearly such matters could be a barrier to acceptability.

For each case an 'avoided cost per tonne of carbon dioxide' is needed. This has to be related to a baseline case, which has generally been considered to be the 'business as usual' condition. As described in section 5, the 'business as usual' condition is that prevailing prior to the Howard Government's proposals of 20 November 1997.

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[7] 'No regrets' in this report refers to the economic drivers experienced by an individual project (not by the wider economy or the government). A 'no regret' solution occurs when discounted benefits exceed discounted costs to the individual project. In other words, project profitability is enhanced by 'no regrets'.

[8] Qualitative costs are given as follows: no regrets (savings to nil cost), low (approximately \$0-\$15 per tonne of carbon dioxide), medium (approximately \$15-\$50 per tonne of carbon dioxide), high (approximately \$50-\$100 per tonne of carbon dioxide) and very high (above approximately \$100 per tonne of carbon dioxide).

[9] Capability is given as follows: small, less than 5 million tonnes of carbon dioxide equivalent avoided per year; moderate, less than 50 million tonnes; large 50 million tonnes or more.

6.3 Selection of Options

Tables 4, 6, 7 and 8 summarise the options, their relative costs and emission reduction capabilities estimated for various carbon dioxide abatement technologies, by IPCC sectors. About 175 options and sub-options were examined and they are summarised in the following sections and tables.

Due to the limitations of the scale of reductions attainable from some reduction options, a range of options is needed to meet the target reduction range identified above (namely 30 to 68 million tonnes of carbon dioxide equivalent).

7. ENERGY AND INDUSTRIAL PROCESSES OPTIONS

7.1 General

The energy sector is divided into two main categories under the IPCC emissions methodology. They are fuel combustion and fugitive emissions. Many of the options for these two categories and for the IPCC sector industrial processes are common and hence they have been grouped together here under one heading – Energy and Industrial Processes.

More specifically, in the energy sector fuel combustion category, a dominant influence on the emissions is the Energy and Transformation Industry. This sub-category produces over half the emissions from the energy sector and these emissions mostly come from electricity generation.

When calculating ‘costs per tonne of carbon dioxide avoided’ a baseline is required, which has been described elsewhere in this report as ‘business as usual’. Table 3 shows some of the options for generating electricity and demonstrates the diversity of options for a business as usual scenario. Coal is used to produce about 85% of Australia’s electricity[10], hydro produces another 10% and gas is used to produce the rest. As coal is available in all States, and is the fuel of choice in most of them, the baseline for many of the electricity comparisons has been taken as a new power station fired by black coal.

Though coal power plants in Australia typically operate using a coal-fired steam raising boiler driving a steam turbine (Rankine cycle), gas-fired plants have more options. They can work on the Rankine cycle (steam raising boiler), or using gas turbines (Brayton cycle), or as a combined cycle, where the hot exhaust gases from the gas turbine (Brayton cycle) are used to raise steam in a waste heat boiler (Rankine cycle). This last method is often called combined cycle gas turbine (CCGT). All of these methods are already in use in Australia.

Integrated gasification combined cycle (IGCC) is a further option for coal-based electricity generation and is emerging overseas at a demonstration scale. In these plants, gas is obtained from the coal to operate a gas turbine (Brayton cycle) and then the remnant char from the coal and the hot exhaust gases from the gas turbine are used to raise steam for a Rankine cycle. A variant to this method for wetter brown coal involves drying the coal before using it in an IGCC plant. This is called IDGCC with the D symbolising drying. Some research is being conducted in Australia into IGCC and IDGCC.

[10] Electricity Australia 1998, ESAA.

Electricity generation options by fuel type

Fossil

				Australian Example
Coal	Brown	Steam cycle only		Loy Yang Vic
		Integrated Drying Gasification Combined Cycle		Experimental at Morwell, Victoria
	Black	Steam cycle only		Eraring NSW
		Integrated Gasification and Combined Cycle		(Only demonstration plants overseas)
Oil	Fuel oil	Steam cycle only		Bell Bay Tas
	Jet fuel	'Gas' turbine		Proposed at Yabulu, Townsville Qld
	Diesel	Internal combustion		Argyle Diamond Mine WA
	Shale			Pilot level only
Gas	Natural	Steam cycle only		Newport D Vic
		Gas Turbine		Dry Creek SA
		Combined cycle		Channel Island NT
	Town			Nil
	LNG			Nil

Non-fossil

			Australian Example
Biomass	Bagasse		CSR Sugar Mills Qld and NSW
	Wood		Naracoorte SA
	Peat		Nil
	Methanol		Nil
	Ethanol		Proposal Nowra NSW
	Biogas	Landfill	Lucas Heights NSW
		Sewage	Brisbane Qld
	Waste	Waste-to-energy	Part biomass/part fossil (eg paper/plastic). Nil
Solar	Photovoltaic	Concentrator dish	White Cliffs NSW
		Concentrator trough	ANU Canberra ACT
		Plate	Singleton NSW
	Thermal	Concentrator dish	ANU Canberra ACT
		Concentrator trough	(Crete)
		Plate	Domestic water heater displaces some electricity
Wind	Conventional		Newcastle NSW
	Vortex		(NZ)
Hydro	Storage	Pumped storage	Jindabyne NSW
		Non-pumped storage	Gordon Tas
	Non-storage	Run-of-river	
Tidal	Storage		Proposal Derby WA
	Non-storage		Apsley Strait, Bathurst Island NT
Geothermal	Hydro thermal		Birdsville SA (closed)
	Hot dry rocks		Proposal Hunter Valley NSW
Wave	Concentrator		Nil
	Non-concentrator		Proposal by Ocean Power, Victoria
Ocean	Thermal		Needs temp diff in 1000m depth > 20 degrees C only north of tropic in Australia
Nuclear	Fission		Nil, but Lucas Heights reactor is similar technology
	Fusion		Nil

Table 3 — Electricity Generation Options by Fuel Type
Source: BRS

Table 4 IPCC Sectors 1 and 2 - Energy and Industrial Processes

Option	Abatement Technique	Cost range	Capability	Comment
E1	Vehicle motor downsizing (one of many fuel efficiency options)	No regret	Small to moderate	Depends on take up rate.
E2	Residential heating fuel switching from electric resistance heating to either heat pump, gas or wood	No regret	Small	Needs ten years or more to have full effect as appliances are replaced.
E3	Retrofit combined cycle gas systems to fully amortised black coal power stations	No regret	Not estimated	No regret is measured relative to building a new black-coal-fired power plant[11]. Depends on local availability and price of gas.
E4	Wood waste only fired power stations	No regret to high	Not estimated	No regret is measured relative to building a new black-coal-fired power plant. Very sensitive to cost and availability of wood waste.
E5	Convert existing gas fired steam power stations to combined cycle gas turbine operation	No regret	Small	No regret is measured relative to continued operation of gas-fired steam power plant on a base load condition. Depends on availability of space to convert power plant and condition of existing plant. Limited number of suitable applications.
E6	Co-fire wood waste and coal with/without integrated forestry	No regret to very high	Not estimated	Depends on cost of wood waste and maintenance.
E7	Advanced cycle power technologies	No regret to very high	Not estimated	Depends on technology proposed.
E8	Hot dry rocks	No regret to high	Moderate	Depends on maturing of technology, including successful 'cracking' of host rock.
E9	Waste to energy	Low to very high	Small	Depends on alternative waste disposal costs.
E10	Combined cycle gas turbine power plant	No regret to low	Moderate	Measured relative to new black-coal-fired power station. Depends on availability and cost of gas.

[11] Retrofitting combined cycle gas to a black-coal power plant can increase the power station gross output by up to 200%.

Table 4 (continued) IPCC Sectors 1 and 2 - Energy and Industrial Processes

Option	Abatement Technique	Cost range	Capability	Comment
E11	Biomass to energy	Low to medium	Large	Measured relative to new black-coal-fired power station. Depends on cost of biomass and seasonality of supplies.
E12	Nuclear power plant	Medium	Large	Measured relative to black-coal-fired power station. Environmental, political, social and policy issues need to be considered.
E13	Retrofit combined cycle gas systems to unamortised black-coal-fired power stations	Medium	Not estimated	Measured relative to building a new black-coal-fired fired power station. Depends on local availability and price of gas.
E14	Capture carbon dioxide and reinject for enhanced oil recovery	Medium to high	Not estimated	Depends on price of oil recovered.
E15	Tidal power	Medium	Not estimated	Measured relative to new black-coal-fired power station. Very site dependent. Environmental issues need to be considered.
E16	Wind power	Medium to high	Not estimated	Measured relative to new black-coal-fired power station. Site specific environmental issues. Costs falling slowly.
E17	Stabilise carbon dioxide emissions from electricity industry to 1998 levels in 2010 by using new combined cycle gas turbine power plants.	Medium	Moderate	Measured relative to using excess capacity of existing coal-fired power plants to generate energy.
E18	Storage of carbon dioxide in depleted gas reservoirs	Medium to high	Not estimated	Needs medium cost just to capture carbon dioxide before disposal.
E19	Disposal of greenhouse gases in deep aquifers	High	Not estimated	There are trade offs in separating carbon dioxide from flue gases and disposing of the larger volume of unseparated flue gas directly.
E20	Co-fire gas and black coal	High to very high	Moderate	Depends on cost of gas.[12]

[12] Gas may cost up to three or four times the cost of coal per unit of fuel energy.

Table 4 (continued) IPCC Sectors 1 and 2 - Energy and Industrial Processes

Option	Abatement Technique	Cost range	Capability	Comment
E21	Solar thermal	High to very high	Moderate	Site specific issues.
E22	Solar photovoltaics	High to very high	Moderate to large	Measured relative to a new black-coal-fired power station. Based on present costs. Capital costs expected to continue to fall in future.
E23	Fuel cells	High to very high	Moderate to large	Measured relative to a new black-coal-fired power station. Based on present costs. Capital costs expected to continue to fall in future.
E24	Mandatory 2% increase in renewables usage in electricity industry.	Very high	Small	Measured relative to using excess capacity of existing coal-fired power plants to generate energy.[13]
E25	Chemical fixation	High to very high	Small	
E26	Deep ocean disposal	Very high	Moderate	As Southern Ocean flows full depth, it is possible that carbon may be re-emitted to the atmosphere.
E27	Engineered surface repository	Very high	Large	
E28	Ocean nourishment	Low	Large	Environmental concerns of transferring problem of carbon in atmosphere to ocean. International agreement required.
E29	Flare tip improvements	Low	Small	Reduces fugitive emissions.
E30	Reduced production or shut in for unflared wells	Medium	Small	Reduces fugitive emissions.
E31	Reduced production from high carbon dioxide wells	Not estimated	Small	Reduces fugitive emissions.
E32	Secondary recovery of oil and gas by using carbon dioxide for pressure maintenance	Not estimated	Small	

[13] Though costs for this option are relatively high at present, future benefits from seeding a renewables industry may outweigh current costs.

7.2 Energy Sector and Industrial Processes Options

The following sections provide more detail on each of the options shown in Table 4.

Motor Vehicle Engines E1 - Motor vehicle engine downsizing and other fuel economy measures are ‘no regret’ measures in economic terms but historically have not been widely adopted.

The technology exists, and motor vehicles are already in the market, that offer considerably reduced carbon dioxide emissions, than the most popular market choices with comparable body space. National Roads and Motorists Association (NRMA) data indicates the fuel economy of these cars is considerably better than that of cars with larger engine, especially for urban usage. The majority of motor vehicle usage is on short trips (average trip length is about 15 km).

Therefore, the technology exists and the price signals are in place to reduce emissions from motor vehicles (and some other energy efficiency improvements eg. industrial motors and domestic appliances). The options are ‘no regrets’ but the adoption rates are low. Perceptions of safety and performance, and of the interests of the Australian vehicle manufacturers, have ranked ahead of fuel economy and greenhouse emissions. Consequently, there appears to be little capability for reducing emissions from motor vehicles without strong incentives to change attitudes.

In general energy efficiency improvement, which is the more efficient production, transformation, transmission, transportation and use of energy, is recognised as an area where savings greenhouse gas emissions can be readily achieved at nil or low cost. Though these potential energy efficiency improvements are often well documented and are technically feasible the take up of these emissions reducing alternatives have been low.

For a technology to succeed in reducing emissions, users must be **aware** of it, **believe** that it works, be **convinced** it is appropriate for them, **desire** to adopt it, **engage** in it, **fulfil** its correct use and only then will the **goal** of emissions reduction be achieved (ABCDEFG). A behavioural study is needed to examine how to increase take up rates of existing technologies that reduce greenhouse gas emissions at a ‘no regrets’ level. How does a technology get from awareness through ABCDEFG to adoption?

Fuel Switching E2 - Fuel switching from higher carbon intensity energy sources to lower carbon and non-fossil fuel based sources for residential heating (and commercial and industrial applications) can be a ‘no regret’ when new systems need to be installed. For existing systems, fuel switching may not be so attractive. As heating appliance/ system lives tend to be of the order of ten years or more, the capability for reductions in greenhouse gas emissions at a ‘no regrets’ level is spread over a long period, but nonetheless there are benefits to be had. Figure 4 shows some typical comparative costs and emissions for domestic heating options.

Combined Cycle Gas Turbines E3, E10 and E13 - Retrofitting combined cycle gas turbine power systems to existing coal-fired steam raising power plants can be a ‘no regrets’ option. Its capability is limited by several factors including:

- the condition of the existing steam turbine and its cooling system;
- the amount of capital still owing on the power plant;
- the availability of gas at the power plant site; and
- the cost of gas.

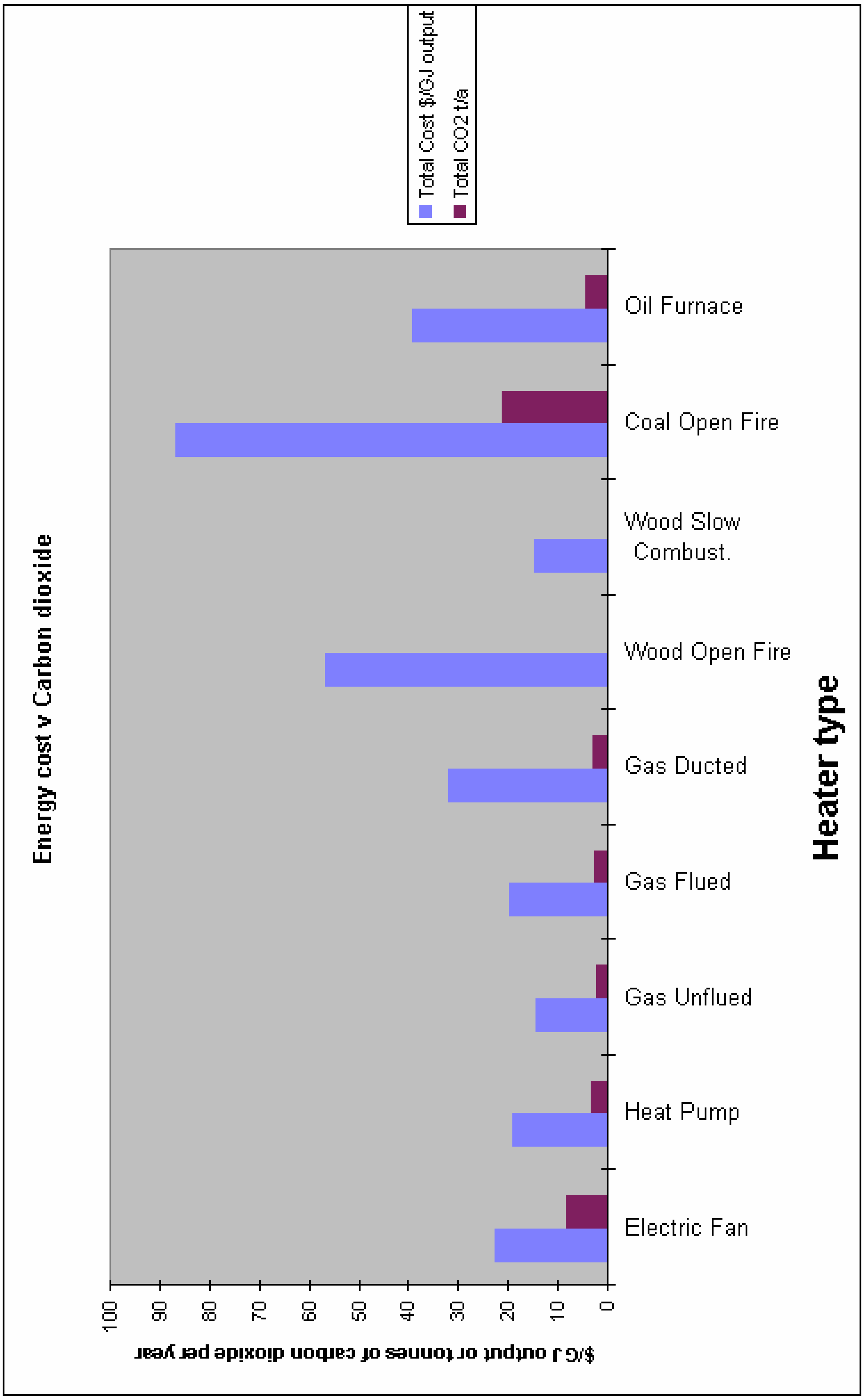


Figure 4 — Typical Energy Cost and CO_2 Emissions by Domestic Heater Type
Source: BRS

If all these factors are favourable at a given power plant the option can be a ‘no regret’ but the cost can rise rapidly should any of the factors be unfavourable.

Other benefits can be had from retrofitting gas turbines to form a combined cycle plant. These include an increased generating capacity at the site if required, and the ability to provide system load at an intermediate or even peaking part of the load curve. (The capacity of a power plant could be increased by up to about 200% by retrofitting gas turbines. Electricity generated at peak load or intermediate load conditions can be sold for higher prices than base load electricity.)

New combined cycle gas turbine power plants have the potential to generate electricity at lower costs than new coal-fired power plants, but electricity costs are very sensitive to the price and availability of gas. There is little combined cycle power plant capacity already installed, and new (greenfield) combined cycle power plants have to compete with existing spare capacity at some coal-fired power plants.

Figure 5 illustrates typical cost differentials between electricity generated from various new (greenfield) power plant types under Australian conditions. The histograms show capital, operating and maintenance, and fuel costs together with emissions. For new power plants, a gas combined cycle power plant might cost marginally less than a coal-fired power plant per unit of electrical output. However, the cost per unit of electricity for a combined cycle power plant is dominated by fuel, whereas for a coal plant it is dominated by capital costs.

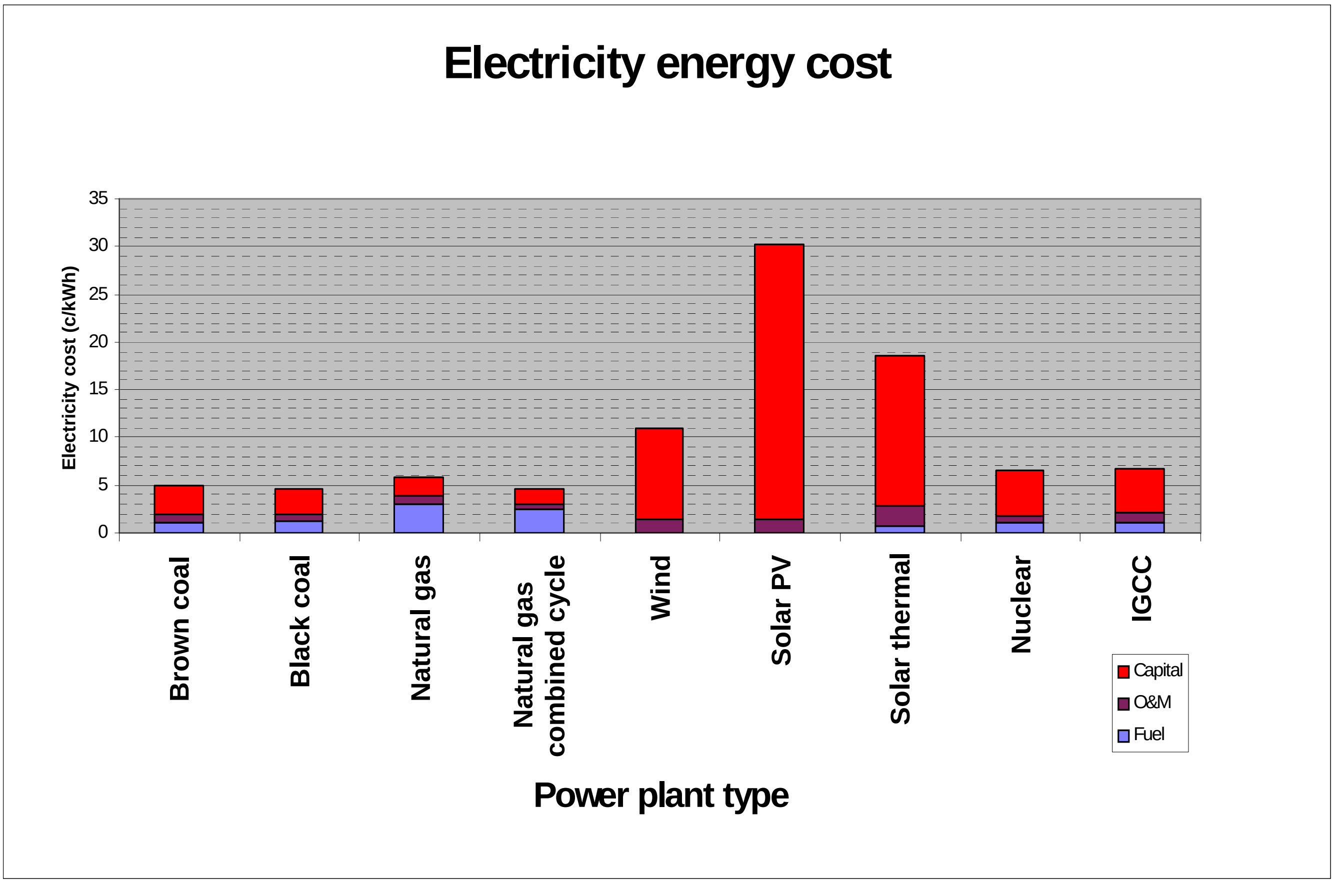
The fuel cost of coal-fired power plants is considerably lower per unit of output than for combined cycle gas fired power plants (under 40%[14] of the cost in the case of brown coal). Thus, in a situation where there is spare generating capacity in existing power plants with low fuel costs (and especially those with fully or partly repaid capital costs which reduce their electricity costs even further), existing spare capacity will tend to be used up before installing new (greenfield) capacity using more expensive fuels.

This take up of spare capacity has already happened with brown coal power plants now running at annual load factors of up to 95%, whereas historically they operated at 70% or less. A similar but not quite so extreme capital/fuel cost situation still remains for black coal versus gas fired combined cycle power plants. It is therefore likely that spare black coal power station capacity will be taken up before installing new gas-fired combined cycle power plants.

So, if solely driven by costs, the electrical power generation industry will tend to fully utilise existing plant rather than bear the capital costs of new power plants. Under this scenario, electricity costs could continue to fall in the short term (although prices may behave differently in the new National Electricity Market), but total emissions from power generation could rise by over 25% in the period 1998-2010.

This purely cost-based approach will tend to ignore the other attractions of gas fired plant. These attractions include reduced greenhouse gas emissions (under half the greenhouse gas emissions per unit of electrical output relative to coal), and, the flexibility of shorter construction lead times of gas fired plants (two years compared with five or more for coal-fired plants).

[14] Data presented by Dr David Brockway of the CRC for Low Rank Coals indicates that brown coal fuel costs may be as low as 0.3c/kWh (Canberra Times 25 November 1997) or under 15% of gas fuel costs per unit of energy generated.



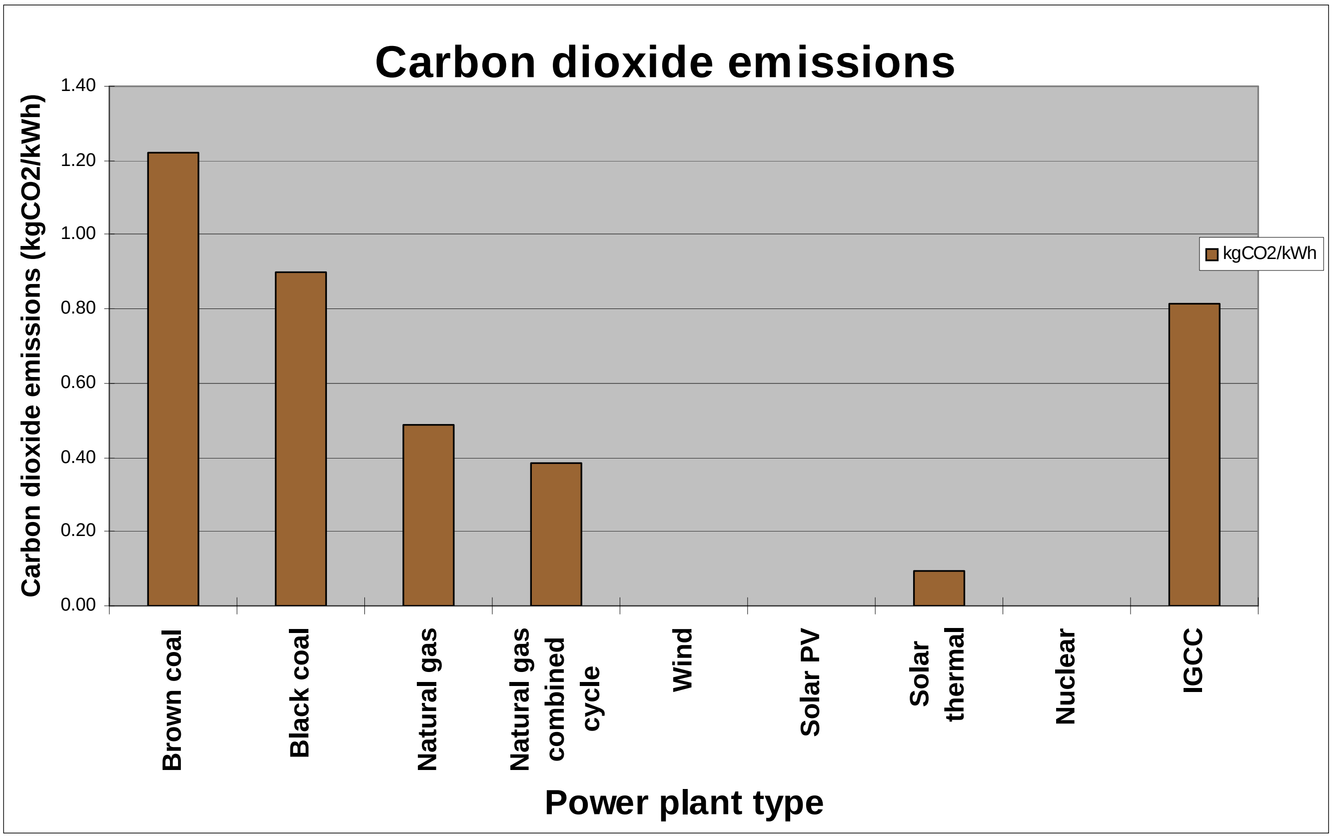


Figure 5 — Typical Electricity Costs and Emissions for Selected Technologies
Source: BRS

Figure 6 shows how thermal efficiency and greenhouse gas emissions vary for various fuel types. Point A on Figure 6 indicates the thermal efficiency of a typical brown coal power station (28%)[15] and its greenhouse gas emissions (about 340,000 tonnes of carbon dioxide per petajoule of output electricity). Point B shows similar data for a typical combined cycle gas turbine power plant (thermal efficiency 50% and 103,000 tonnes CO_2/PJ). B represents a reduction in greenhouse gas emissions of 70% relative to A. These points are approximately the extremes of conventional power plants currently installed in Australia.

In the long term, gas fired combined cycle power plants have the capability to moderately reduce greenhouse gas emissions for Australia. In the UK, it has been estimated that over 75% of their reductions in emissions from electricity generation have come from the extensive use of combined cycle power plants in preference to coal-fired plants.

Wood Waste E4 – (This is a subset of biomass to energy E11). Wood waste only fired power stations can vary from a 'no regret' option through to a high cost depending on their location. The 'no regret' situation arises where a fee can be charged for waste disposal – in other words the operator is paid to take the fuel. High costs are for situations where wood has to be hauled relatively large distances and there are no other offsetting benefits such as wood products to reduce costs.

Capability has not been estimated because of the wide range of costs. Theoretically, at the high cost end there is a very large capability whereas at the 'no regret' end there is very limited capability. Characteristically, a 'no regret' power plant using wood waste would need to be quite small (say under 50 MW) to be viable, as the fuel transport costs will rapidly dominate over the disposal fee for larger haul distances. (A 500 MW power plant needs about 2,400 km^2 of plantation wood to keep it operating for 30 years).

Gas Power Plant Conversion E5 – Converting existing gas fired steam raising single cycle power plants to combined cycle operation can be a 'no regret' action. There are a limited number of power plants that currently operate by generating steam from gas fired boilers. Those that operate as base load or intermediate load power plants may be 'no regrets' actions to convert to combined cycle operation. However the condition of the plant and the availability of sufficient space around the existing plant are constraints. The capability of this action to reduce greenhouse gas emissions is limited by the number of suitable plants.

Co-fired Wood Waste E6 – Co-firing wood waste with coal to reduce greenhouse gas emissions can be a 'no regret' action. But it is very sensitive to the costs of the wood waste. If a fee for disposal of the wood waste can be recovered to the benefit of the power plant cashflow, a 'no regret' situation may arise.

The capability is limited by the availability of wood waste at coal-fired power plants and the percentage of wood waste (up to about 10%) that can be co-fired with the coal.

Additional maintenance costs, especially related to more frequent cleaning of boilers, are difficult to estimate for fuel combinations with a limited operational experience.

If forestry is integrated with the wood production/wood waste production the action may still be 'no regrets' but can rapidly become a high cost action depending on how costs of wood and transport are shared by the wood production/wood waste used for co-firing.

[15] A typical black coal power plant might be 37 % efficient and emit about 245,000 tonnes/PJ.

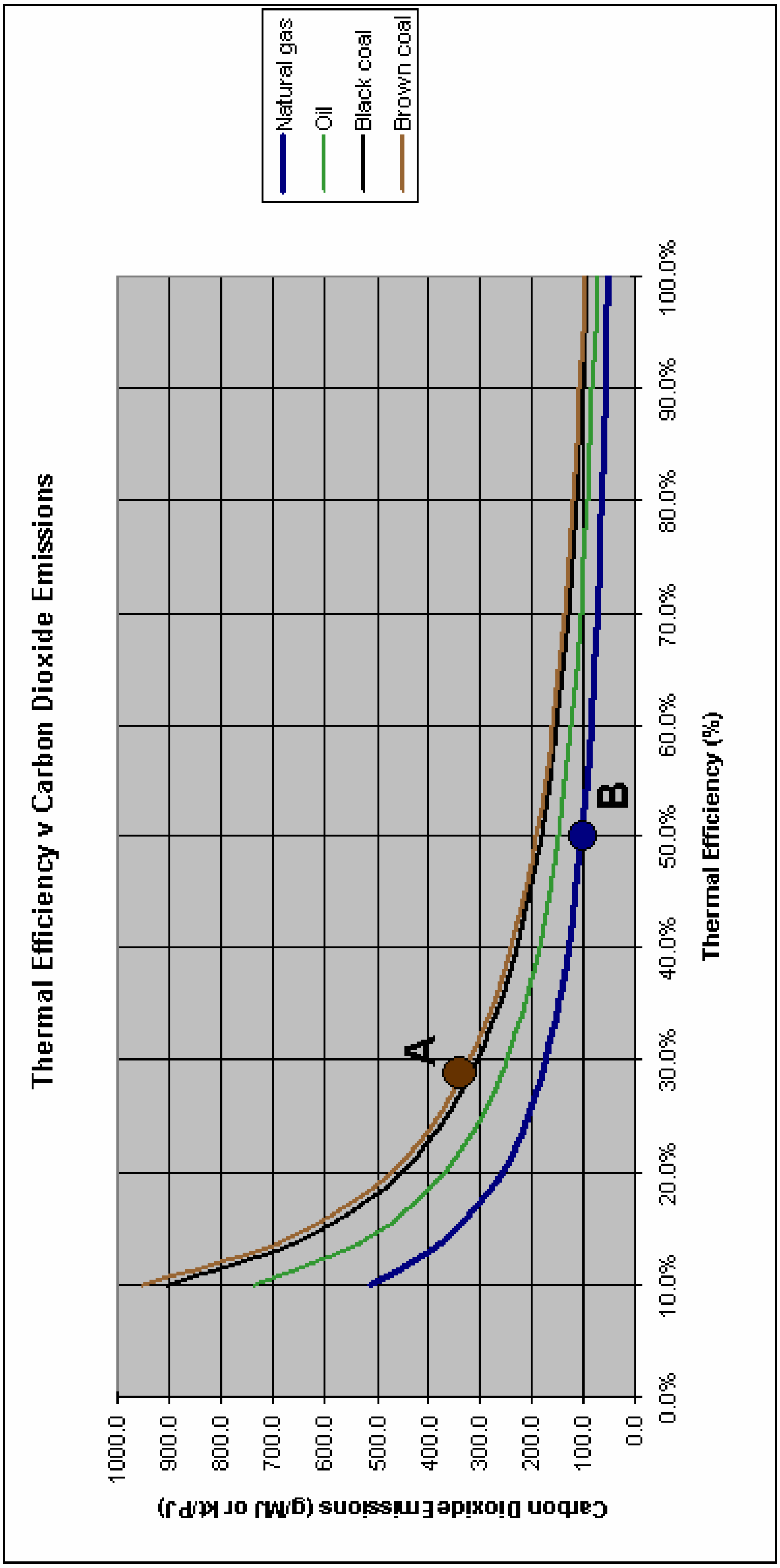


Figure 6 — Typical Thermal Efficiency and CO2 Emissions from Selected Fuels
Source: BRS

Emissions reduction capability has not been measured. At the high cost end, moderate emissions reduction could be achieved, but at the low cost/'no regrets' end there may be only a very small capability.

Advanced Power Cycles E7 – Advanced power cycles include supercritical steam boilers and pressurised fluidised bed combustors. If these elements are retrofitted to power plants, their abatement costs can be very high. However, when considered as part of the integrated development of new projects, they may reach a 'no regrets' situation.

Hot Dry Rocks E8 – Hot dry rocks can be used to both preheat water and generate steam in otherwise conventional power plants. It has been claimed that by using different working fluids (ammonia and water instead of water in the heat exchangers and condensers – Kalina cycle plants) the efficiency of the conversion of the energy from the heated water can also be improved.

However, despite extensive research internationally, there are still some barriers to the commercial viability of the method. Difficulties have been experienced in creating suitable cracking patterns in the host rock, establishing and maintaining flow in the boreholes and achieving sustainable outputs. These technical difficulties and the immaturity of the technology increase the uncertainties of the technology and must be included when evaluating hot dry rocks. Consequently, costs vary widely and have been estimated to range from 'no regrets' to high.

The emission reduction capability of hot dry rocks at a theoretical level is rated as medium.

Waste-to-Energy E9 – Burning waste to produce energy (waste-to-energy) options is a proven technology in locations where alternative waste disposal costs are already high. Alternative waste disposal costs in Australia vary from cash costs of zero to about $60 per tonne. These alternative costs need to be around $100 per tonne to justify construction of a plant in Australia, unless favourable conditions can be obtained for the sale of the energy. Overseas, alternative waste disposal costs can exceed $400 per tonne and waste-to-energy is an established method of waste mass and volume reduction before use or final disposal of the ash.

Strict emissions and ash disposal standards are needed for waste-to-energy plants due to the mixed nature of the feed waste. Emission control plant attached to the combustion facility may cost up to ten times the combustion facility itself, unless the waste composition variability can be carefully controlled.

Australia has one major waste incineration plant, which has been operating since the early 1970s in South Sydney, but it has no waste heat recovery or energy production facility attached to it. It is currently under review and may be either upgraded, refurbished, or closed down. Feasibility studies have been conducted at other locations for waste-to-energy plants but no major plant has yet overcome the dual economic and environmental hurdles and proceeded. The capability of waste-to-energy plants to reduce greenhouse gas emissions in Australia is rated as small as long as costs remain low for alternative waste disposal options.

Biomass to Energy E11 – Power generation from wood and bagasse (sugar cane waste) are examples of biomass to energy. In principle, biomass to energy can be a low cost to medium cost option with a high capability to reduce emissions of fossil fuel sourced greenhouse gases. However, there are problems at a commercial scale with availability of biomass at suitable prices, and the seasonal nature of biomass production can be a constraint too.

Nuclear Power E12 – Nuclear power plants have a medium cost in terms of avoided greenhouse gas emissions relative to new black-coal-fired power stations. This is based on a state-of-the-art plant, with waste disposal costs estimated for currently available technologies. The capability of the reduction is large as substantial quantities of power can be generated by nuclear power. However, there are strongly held environmental attitudes that would need to be addressed before nuclear power could be regarded as an option in Australia. Nuclear power has achieved substantial greenhouse gas emissions reductions in several overseas countries including Japan and France.

Enhanced Oil Recovery E14 – Capture of carbon dioxide (from perhaps gas production) and use for re-injection to enhance oil recovery is a medium to high cost option. Its capability is very dependent on the price of the recovered oil. Oil prices of over $40 per barrel are needed before this method of disposal of carbon dioxide becomes attractive. Associated benefits from the removal of carbon dioxide from gas production for example, may help offset this price.

Tidal Power E15 – Tidal power is estimated to be a medium cost option for reducing greenhouse gas emissions. At some selected locations where alternative electricity generation costs are high, net costs may be much lower. The capability of this option is considered to be small. There are environmental issues associated with tidal power developments, such as loss of fish breeding areas, and changes in estuarine or shoreline flows.

Wind Power E16 – Wind power can be a medium to high cost option. At some selected locations where alternative electricity generation costs are high, net costs may be much lower. However capital costs have fallen substantially in recent years and may continue to fall. There are environmental issues associated with wind power including aesthetics, strobe effects and noise.

Electric Power Generation E17 and E24 – A model has been prepared for predicting the effects of strategies on emissions from the electricity industry. The model is called GREENAIR[16] and it uses data on existing and proposed power stations in Australia to estimate emissions and associated costs for electricity generation up to the year 2010.

In calculating emissions, the model takes into account the existing mix of plant in Australia, capital, operating, maintenance and fuel costs, fuel types, technologies used and efficiencies. An electrical energy demand forecast is used and by annual load matching and adding new plant as required (using industry proposals where possible as a guide) future costs and emissions can be simulated for various development scenarios.

Scenarios tested to date include a business as usual scenario (base case), a 2% renewables scenario (E24) and a scenario based on maintaining electricity production emissions at 1998 levels in the year 2010 (E17). The model is still under development, but preliminary results are shown in Table 5 to illustrate its capability.

[16] GREENAIR uses data from a database (STATIONS) of existing and proposed power stations in Australia. It also uses data from an electricity technology costing methodology (COSTELEC) updated, and expanded but based on that used by Sinclair Knight Merz in their 1992 study on behalf of ERDC and ESAA - ERDC 131. Both STATIONS and COSTELEC have been prepared within this BRS Greenhouse Science project. STATIONS contains data on over 400 power plants. COSTELEC examines over 20 technologies for generating electricity including inter alia conventional brown coal, black coal, oil and gas fuelled steam raising plants, nuclear, wind, solar photovoltaic flat and concentrator, wind, tidal, landfill gas, combined cycle gas, integrated gasification of black coal combined cycle, integrated drying and gasification of brown coal combined cycle.

Table 5 Illustrative Preliminary Results - Electricity Costs and Total Emissions for Some Sample Scenarios of Electricity Industry Developments 1998 to 2010

Scenario	Electricity Cost Index in Year 2010 (1998 = 100)	Total Emissions Index in Year 2010 (1998 = 100)	Emissions per Unit of Energy in Year 2010 (1998 = 100)
Business as usual (Minimum cost)	91	126	100
Renewables increased by 2% over 1998 (E24)	98	122	97
Keep total emissions constant at 1998 value (E17)	110	100	79

The model shows that electricity costs may continue to fall in the period from 1998 to 2010, at the expense of an increase in total emissions. (Note the model looks at comparative costs and does not attempt to estimate prices in the developing National Electricity Market). This result is achieved by utilising excess capacity in existing black- coal-fired power plants, while observing the simultaneous need to fit any energy generated within the energy demand curve.

Over the period 1998 to 2010, annual load factors on coal-fired plant are progressively increased from about 61% to about 75%, while extra gas turbine peaking plant is also installed. Though the first scenario shows falling electricity costs, achieved by utilising existing power plant capacity where possible, total emissions increase by 26% due to increased generation on coal-fired plant. Meanwhile, emissions per unit of energy produced remain almost constant over the period simulated changing by less than 1%. (from 885 g/kWh to 888 g/kWh)

The model also shows that the 2% increase in renewables requirement, which is part of the Prime Minister's *Safeguarding Australia's Future* package. It will require an increase in renewables of about 4000 MW [17] by 2010 and a 9000 GWh increase in energy production from that new capacity. Australia's present 1998 installed electrical generating capacity is about 40 000 MW and the additional renewables capacity is about 10% of present installed capacity.

If this new capacity were to cost $2000/kW (typically the cost of wind plant and under half the present cost of solar photovoltaic plant) an outlay of about $8 billion is needed to install the new renewable plant alone. By way of comparison, the Electricity Supply Association of Australia estimated, in 1997, that the capital investment in generating capacity was $27 billion to date and $12 billion more would be needed in new plant by 2010.

Under this scenario it is interesting to note that total emissions would still be 122% of the 1998 emissions and that electricity costs would be about 8% higher than under the business as usual scenario. The emissions per unit of energy generated fell to about 860 g/kWh by 2010 under this renewables scenario.

A further scenario was examined to ascertain the costs to keep emissions in 2010 to 1998 levels. There are many options to achieve this objective. One scenario involves installing new gas fired combined cycle power plants and progressively displacing generation from existing plant whilst

[17] In 1997 the estimated world annual production capacity of solar cells was just over 100 MW. If the 4000 MW were to be sourced from solar power alone the requirement is 40 years of world production. Fortunately world solar cell production capacity is increasing and Australia has many renewable energy choices other than solar such as wind, tidal and biofuels.

simultaneously matching increased energy demand. The cost of electricity in 2010 was estimated to rise by about 10% over the period, or be 21% higher than the base case in 2010. The emissions per unit of energy generated had fallen with this scenario from 885 g/kWh to 701g/kWh or by 21% between 1998 and 2010.

If combined cycle gas turbine power plants were used to keep greenhouse gas emissions from electricity generation to 1998 levels in 2010, this would be a medium cost abatement option relative to using excess capacity of black coal power stations to generate electricity. This option also has a moderate capacity to reduce emissions.

Though the mandatory requirement for the increased use of renewables by 2% in the year 2010 is likely to be an additional cost to power generation, cheaper options to reduce emissions would not achieve government objectives of seeding and encouraging a larger renewables sector.

Depleted Gas Reservoirs E18 — Storing carbon dioxide extracted from flue gases in depleted gas reservoirs is a medium to high cost option for carbon dioxide abatement. This is partly because of the cost of capturing, separating and compressing the carbon dioxide from flue gases before disposal. The capability of this option has not been assessed.

Deep Aquifer Storage E19 — Disposal of greenhouse gases in deep aquifers is a high cost option. There are trade-offs between the cost of separating carbon dioxide from flue gases and disposing of unseparated flue gas which has a much larger disposal volume. The capability of this option has not been assessed.

Co-firing Gas and Coal E20 — Co-firing gas and black coal in power stations is a high to very high cost but is very dependent on the costs for gas. This is because gas can cost more than three times as much as coal on an equivalent heat energy basis. However, it does have a medium capability for greenhouse gas reduction.

Solar Thermal E21 — Solar thermal plants can use solar concentrators to heat oil for preheating water and generate steam in boilers. There is a limit to the temperature to which the oil heat transfer medium can be heated and further energy must be added to get ideal steam conditions for steam turbine operation. The additional energy normally comes from fossil fuels. This is a high to very high cost option for avoiding greenhouse gases relative to a new black-coal-fired power station, but it has a moderate capability for greenhouse gas reduction. Solar thermal plants can heat water directly to generate steam, but their cost structures are similar.

Solar Photo-voltaics E22 — Solar photo-voltaics are currently a high to very high cost option for reducing greenhouse gas emissions, relative to a new black-coal-fired power station. However, costs for solar cell production are expected to fall and solar power costs for embedded generation[18] should be compared with the higher retail prices of electricity, instead of bulk wholesale prices. This can make small solar installations more attractive.

In remote areas, solar power production can be attractive relative to alternative energy sources, but storage or firm energy back up systems (for example diesel generators) are required for system reliability.

The capability of solar photo-voltaics to reduce greenhouse gas emissions is moderate to high.

[18] Embedded generation refers to small power generating units located in the distribution network or on the consumer's premises. They have cost benefits as transmission and transformer costs can be reduced or eliminated and they can displace electricity of higher value (retail prices versus generator or wholesale prices).

Fuel Cells E23 — Fuel cells have high capital costs at present and hence their cost for avoiding greenhouse gas emissions is high to very high relative to a black-coal-fired power station. Capital costs are expected to continue to fall in the future. The capability for reduction in emissions is moderate to high.

Chemical Fixation E25 — Chemical fixation, which is the conversion of carbon dioxide into useful chemicals such as toluene and xylene, appears to be an expensive option with only a small capability to reduce total emissions. There is also some doubt about how long carbon can be sequestered in manufactured chemicals. The chemicals produced will often re-emit their carbon content when they are used.

Deep Ocean Disposal E26 — Deep ocean disposal of carbon dioxide appears to be a very expensive option but has a moderate potential for reducing emissions. In Australia, the best options for disposal are where large quantities of flue gas are generated at power plants and deep ocean areas are relatively close by. The best opportunities occur on the margins of the Southern Ocean near the Gippsland Basin. Though international modelling studies have indicated retention times of greater than a thousand years for carbon dioxide injected at greater than 3000 metres depth, more recent studies indicate that the potential for return of carbon from deep ocean areas is quite high in the Southern Ocean. This is because the Southern Ocean circumnavigates the globe, flows to its full depth and can bring water from deeper areas to the surface by mixing.

Engineered Surface Repository E27 — An insulated terrestrial repository for carbon dioxide would need to be about 150 metres high and 2.5 km diameter to sequester the carbon dioxide from a 500 MW coal-fired power plant over 30 years. This is a very high cost option relative to other options, but has a potentially large capability for emission reduction.

Ocean Nourishment E28 — Ocean nourishment involves either supplementing an iron deficiency or a nitrogen deficiency in the ocean to encourage phytoplankton growth. The cost appears to be relatively low and its capability for carbon sequestration appears to be large. However, it is a method that would involve or affect the use of international waters and would need international consultation and agreement.

Concerns have been expressed about environmental effects on the ocean. It has also been noted that the technique could be transferring a carbon problem from the atmosphere to the ocean, though the carbon content of the ocean is estimated to be orders of magnitude greater than that of the atmosphere.

7.3 Fugitive Emissions Options

The fugitive emissions sub-category covers emissions of greenhouse gases from fuel production, transmission, storage and distribution. It includes fugitive emissions from coal mining and oil and natural gas systems but does not include emissions from fuel combusted while undertaking these activities. In 1995, greenhouse gas emissions from the fugitive emissions category were 25.6 Mt CO_2 equivalent (or 5.3% of total national emissions – using data from Australia's Second National Report). The uncertainties associated with these emissions are typically in the 5-20% range, with some estimates approaching or exceeding 100%.

The dominant fugitive emissions are assessed to be methane emissions from coal mines, followed by leaks from gas distribution pipelines, flaring of gas and oil in field production facilities and carbon dioxide venting from gas processing plants.

There are many methods for reducing these fugitive emissions, however, the most promising are:

- methane drainage from underground coal mines;
- improved control of leaks from gas processing systems (by improved practices) and from gas distribution systems (by replacement of older pipelines and improved practices);
- reduced flaring from remote oil fields by reinjection or sale of gas; and
- reservoir storage or use for enhanced oil recovery of reservoir derived carbon dioxide.

Improved Flaring E29 — Improvements to existing oil and gas flare combustion is a relatively low cost abatement option that also has a low capability to reduce emissions.

Reduced Production by Shut In E30 — Reducing production or shutting in oil and gas in unflared production wells may be a medium cost option but it has a low capability for emission reduction.

Reduced Production from High CO_2 Fields E31 — Reducing production from existing high carbon dioxide wells has a low capability for reducing emissions. Costs have not been estimated.

Secondary Recovery E32 — Secondary recovery of oil and gas by using carbon dioxide for pressure maintenance has a low potential for emission reduction. Costs have not been estimated.

8. AGRICULTURAL SECTOR

8.1 General

Activities to mitigate emissions from the cropping industries, although generally low in cost, have little impact on total emissions because the contribution of cropping is small to start with. The greatest impact will be achieved by addressing the emissions from livestock because they account for 77% of the agricultural emissions. The development and use of products, which modify the functioning of rumen in live stock digestive tracts, show great potential both for reducing methane emissions and improving livestock productivity.

The agricultural sector also has the potential to provide a significant carbon sink through land rehabilitation activities. At the moment, emission of carbon from soil and sequestration of carbon in it are not included in the Kyoto Protocol or the NGGI. However, Article 3.4 of the Kyoto Protocol does provide for its inclusion in future commitment periods. This issue is the subject of an IPCC Special Report to be concluded in 2000.

Both rumen modifiers and land rehabilitation can have significant non-greenhouse benefits by improving livestock productivity and improving the economic and ecological sustainability of agriculture. They can be considered ‘no regrets’ activities.

8.2 Agriculture Sector Options

The following sections provide more detail on each of the options shown in Table 6.

Direct Biofixation A1 – Direct biofixation is the conversion of solar energy and carbon dioxide into biomass and industrial compounds using microalgae and cynanobacteria. Its success depends heavily on the growth productivity of the microalgal species, solar radiation, construction costs and the market value of the byproducts. Consequently, it can vary in cost from low to very high. Its capability for reductions can be large. Low relative cost scenarios assume high oil prices for competing product manufacture.

Minimum Tillage A2 – The use of minimum and no-till practices may reduce the level of emissions, through a reduction in loss of soil carbon and a reduction in the consumption of fossil fuels associated with cultivation.

Current experimental data give no indication that minimum tillage and no-till practices will result in significant sequestration of carbon in Australia. Although these practices may reduce the loss of carbon, it is very difficult to quantify because the implementation of minimum and no till practices will have a different impact on carbon accumulation in different regions (climate-by-soil matrix) making generalisations difficult and problematic. Given these problems, it is not possible to assess the impact of these measures on carbon dioxide emissions at this time.

Rumen Modifiers A3 — Methane is produced from livestock as a by-product of the fermentation of dietary carbohydrate. The hydrogen produced during the fermentation process is used by specific bacteria (methanogens) to reduce carbon dioxide to methane, which is then vented from the rumen. Methane losses account for about 8% of the total energy in the diet.

Table 6 IPCC Sector 4 - Agricultural sector options

Option	Abatement Technique	Cost range	Capability	Comment
A1	Direct biofixation	Low to very high	Large	Converts solar energy and carbon dioxide into biomass and industrial compounds using microalgae and cynanobacteria. Depends on oil price.
A2	Minimum or no tillage	Not estimated	Not estimated	May be insignificant but no data to assess.
A3	Rumen modifiers	No regrets to low	Small	Live weight gain can compensate for costs. There may be operational difficulties in remote areas.
A4	Land rehabilitation	Low	Moderate	Currently not admissible, but under consideration by FCCC for inclusion.
A5	Waste management improvements	Low	Small	Very low capability.
A6	Fertilizer management	Low	Small	
A7	Reduced residue burning	Low	Small	Disease and weed build up a concern.

Researchers have been interested for many years in inhibiting the activities of methanogens to improve efficiency of feed utilisation. CSIRO have developed and patented several technologies to alter the functioning of the rumen of livestock. One of these approaches is vaccination of livestock against the rumen organisms that produce methane. Documented experimental methanogen vaccines reduce methane production by about 18% per unit feed intake. Much higher reductions (80%) have been found in the laboratory with a new vaccine formulation demonstrating the further potential of this approach.

As well as resulting in a significant reductions in methane emissions, the methanogen vaccine is also likely to result in significant productivity gains from the livestock industry. Recent trials with vaccinated sheep and cattle have found liveweights increased by 20%. There may also be significant export potential for sales of the vaccine.

Costs are estimated to be ‘no regrets’ to low and the capability is small, but more research is being conducted.

Land Rehabilitation A4 — The rehabilitation of rangelands through the adoption of sustainable grazing management may provide a major sink for carbon. It has been calculated that the conversion of deteriorated rangelands in northern Australia to a sustainable condition could result in a carbon sink of about 315 million tonnes (in the top 10 cm). A further 144 million tonnes of carbon could be sequestered if degraded land were restored.

Deteriorated pastures have the potential to be rehabilitated through appropriate management (eg. reducing average stocking rates) under normal rainfall conditions, whereas the degraded pastures are considered unrecoverable without considerable energy inputs.

Research and extension activities such as Landcare and the North Australia Program (NAP3) which promote the adoption of ecologically sustainable grazing systems will help in maintaining pastures in a sustainable condition as well as restoring some deteriorated pastures. The changes in management may also improve the ecological and economic sustainability of many rangeland properties.

Emissions and sequestration of carbon associated with land degradation and rehabilitation are currently not included in the Kyoto protocol or in the NGGI. If subsequent negotiations see this component added to the protocol, then Australia will need to implement a monitoring program that documents changes in soil carbon (both positive and negative). This measure assumes that the rate of land degradation in Australia is declining and that rehabilitation activities will result in a net carbon sink. However, if land degradation were occurring at a rate faster than land rehabilitation, then Australian soils would produce a net source rather than a sink.

If land rehabilitation results in a net carbon sink, then the cost of this measure (including the monitoring program) is likely to be in the order of a few cents per tonne of carbon dioxide equivalents.

In summary, the costs are estimated to be low and the potential for carbon dioxide reductions is estimated to be moderate, but would only count towards Australia’s target if land degradation and rehabilitation were added to the Kyoto target.

Waste Management A5 — Within the pig and dairy industries, there is the potential to reduce the greenhouse gas emissions from waste collected in production and milking sheds. For example, the anaerobic digestion process, allied with some end use of the gas produced, can significantly reduce methane emissions from manure with a methane conversion factor (MCF) of 5-15% (IPCC 1995) compared with an MCF of 90% for anaerobic lagoons. The emissions from the anaerobic digester plus energy conversion facility result primarily from leakages and vary with the type of digester.

The process can significantly reduce the bulk of the slurry while increasing its value as a fertiliser. Odour problems and associated buffer zones, diseases and insects are also significantly reduced. The biogas produced can be used to provide heat and electricity for the farm and plant, with excess energy sold to the electricity grid.

Although the initial outlay costs can be high, the system can provide financial returns to the enterprise. For example, the large-scale anaerobic digester at Berrybank Farm in Victoria was a $2 million investment from which they expect to receive benefits of over $300,000 annually. Small-scale, low-tech systems are also available.

Improvements to waste management have a very small capability for emissions reduction though the costs may be low.

Fertiliser Management A6 — Although the rate of fertiliser use in Australia is already very low by world standards, there is still potential for further improvements in efficiency. The loss of nitrogen is due primarily to the denitrification of nitrogen, which releases the greenhouse gas nitrous oxide (N_2O). The loss by denitrification can be reduced by adding compounds to the soil to inhibit the oxidation of ammonium by nitrifying organisms or by better matching the time of application with the crop's demand for nitrogen.

In an experiment in a rice crop, a nitrification inhibitor treatment (wax calcium carbide) reduced N_2O emissions by 74% and methane emissions by 18%. This and other studies have shown that nitrification inhibitors reduce the loss of nitrogen from the plant-soil system, increase the efficiency of use of fertiliser nitrogen and thereby reduce fertiliser inputs. These inhibitors are currently being developed for commercial release.

Improving fertiliser application decisions by incorporating better information on seasonal forecasts, current soil moisture conditions and crop requirements will also help reduce the level of fertiliser inputs.

Improved fertilizer management is estimated to reduce emissions by a small amount and at low cost.

Residue Burning A7 — Reducing the level of residue burning will reduce emissions of carbon dioxide, methane, non-methane volatile organic compounds, oxides of nitrogren and nitrons oxide. The potential reductions are likely to be greatest in the sugar cane industry because the proportion of wheat and coarse grain crop residues burnt may already be as low as 20%. Problems of weed and disease build-up with stubble retention mean that strategic burning is likely to continue.

The retention of stubble and/or stubble mulching can help reduce soil erosion and the loss of soil organic matter. Alternative uses of residue for such things as ethanol production or for sale as mulch could have financial benefits for the farmer although removing crop residue will lower soil carbon levels over time.

The cost of reducing residue burning is estimated to be low and its capability for reducing emissions is small. The build up of disease and weed control problems are detractions.

9. LAND USE CHANGE AND FORESTRY OPTIONS

9.1 General

The land use change and forestry sector is a source of emissions but also a sink. The net effect is believed to be a source of emissions, however, there are substantial uncertainties in establishing its size. These uncertainties are due to a lack of data on the rates of land clearing, the biomass cleared, the extent of vegetation thickening[19] in the remaining vegetation and the impact of this on the magnitude of greenhouse gas emissions.

For this sector to be admissible under Article 3.7 of the Kyoto Protocol, it must be a net source of emissions in 1990; that is, sources must exceed sinks. Australia's most recent National Greenhouse Gas Inventory indicates that sinks were approximately 29 million tonnes of carbon dioxide and sources 90 million tonnes in 1990.

The following sections describe some options for reducing greenhouse gas emissions and increasing sequestration from this sector. Table 7 outlines these options, which are described in more detail below.

Table 7 IPPC Sector 5 - Land use change and forestry sector options

Option	Abatement Technique	Cost range	Capability	Comment
LUCF1	Forestry conservation including maintaining existing forest areas.	Low to high	Not estimated	Not currently included in Kyoto Protocol. If eventually included under Article 3.4, accurate estimation of sequestration will be a challenge.
LUCF2	Forestry plantations	Low	Moderate to large	Moderate to high sequestration rates, but could ultimately be limited by the availability of suitable plantation land. Practical limit could be as low as 600 million tonnes of carbon dioxide.
LUCF3	Reduced land clearing	Low	Small to moderate	Potential capability is finite at the level of clearing in 1990 of 90 million tonnes of CO_2. Large uncertainty in current estimates.

9.2 Forestry Sub-Sector Options

Forestry LUCF 1 and 2 — Forestry is seen as a very promising option for sequestering carbon dioxide emissions. The 1996 National Greenhouse Gas Inventory (NGGI) reported the net sequestration of Australia's Forests to be 30 million tonnes of carbon dioxide.

[19] Vegetation thickening is thought to result from changes in land management practices when domestic stock are introduced. The increased grazing intensity results in a reduction in grass cover and reduced fire intensity and frequency. These changes result in woody species such as eucalypts and wattles dominating sites and vegetation becoming thicker.

Managed Forests LUCF 1 — Managed forests are not currently included in the Kyoto Protocol. Potentially, they would be included under “other direct human induced activities” in Article 3.4. The activities allowable under this article of the Kyoto Protocol are currently the subject of a IPCC Special Report on “Land Use, Land Use Change and Forestry” to be considered by the 6th Conference of Parties in late 2000.

If included in the Protocol managed forests may represent a considerable low cost sink because of the area involved. The exact area of managed forests remains uncertain because of the Regional Forest Agreement process which is defining the area available for commercial forestry and that to be conserved in forest reserves which would not be managed for carbon sequestration.

The accurate cost-effective measurement and verification in changes of carbon stocks within managed forests will be the major impediment to accessing this method of emissions mitigation.

Plantation Forestry LUCF 2 — Australia’s Forest Plantations covering about 1 million hectares were responsible for approximately 15 million tonnes of forest carbon dioxide sequestration in 1996.

Under the Kyoto Protocol only Forest Plantations planted after 1990 on recently unforested land are included. It is estimated that there are 20 million hectares of cleared agricultural land potentially suitable for Forest Plantations. However, the availability of this land for forestry will depend on its ability to compete with other agricultural land uses. The current plantation 2020 vision seeks to treble Australia’s plantation area to 3 million hectares by 2020, which would require planting an average of 80 000 hectares per year for 25 years.The most recent estimates indicate that this is close to being achieved in the current year.

An additional 2 million hectares of Plantation Forests would have the potential to sequester an addition 35-45 million tonnes of carbon dioxide per year when fully established.

The harvesting of plantation forests is an integral part of the plantation cycle, which must be included in sequestration calculations under current IPCC methodologies, as illustrated in Figure 7. This illustrates that the carbon sequestration pool for any land area has finite limits, which when reached result in net sequestration reducing to zero.The only effective way of further increasing this sink is to increase the land area.

The costs of mitigation by forestry plantation are estimated to be lower, with the capability moderate to large depending on the availability of land.

9.3 Land Use Change Sub-Sector Options

Land Clearing LUCF3 — Emissions from Land Clearing were 90 million tonnes of carbon dioxide in Australia’s most recent NGGI for 1990. Under Article 3.7 of the Kyoto Protocol these emissions may be counted in Australia’s 1990 base provided they are more than Forest sequestration in that year.

The 1996 NGGI reported land clearing emissions of 62.9 million tonnes of carbon dioxide - a potential mitigation of 27 million tonnes of carbon dioxide since 1990. Continued decreases in land clearing, particularly in Queensland and NSW have the potential to provide further decreases in carbon dioxide emissions, but theoretically the total pool available for mitigation is finite at the 1990 baseline of 90 million tonnes of carbon dioxide. Practically the pool available for emission reduction, will be less than 90 million tonnes carbon dioxide, because it is unlikely that land clearing will be totally halted and secondly there is considerable uncertainty surrounding the retrospective estimation of land clearing from 1980 to 1990, necessary to establish to 1990 baseline.

Considerable work is required to decrease the uncertainty surrounding the calculation of the 1990 baseline. BRS is conducting extensive and detailed work to reduce the level of uncertainly associated with this 1990 baseline.

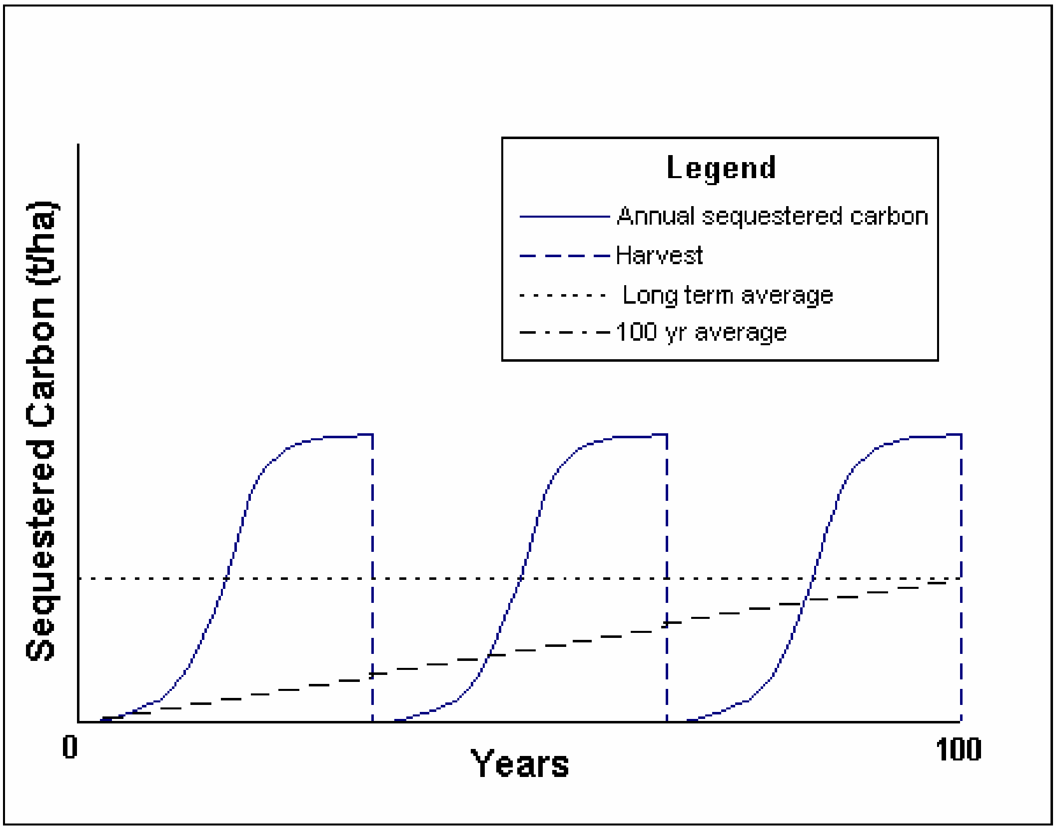


Figure 7 — Carbon Dioxide Credits from Forestry Plantations
Source: BRS evidence to the Inquiry into the Regulatory Arrangements for Trading a Greenhouse Gas Emissions conducted by House of Representatives Standing Committee on Environment, Recreation and Arts, 1998

10. WASTE OPTIONS

10.1 General

Waste emissions contributed about 15 million tonnes of carbon dioxide equivalents to Australia's inventory in 1990. Most of the emissions are in the form of methane from decomposition of waste in landfills. Reducing the amount of waste going to landfills, encouraging aerobic decomposition of waste and capturing the methane from existing landfills are ways of reducing emissions.

Table 8 IPCC Sector 6 - Waste sector options

Option	Abatement Technique	Cost range	Capability	Comment
W1	Landfill gas collection	Low	Moderate	Landfill gas is often collected for reasons other than greenhouse gas emissions abatement. Generation of electricity from landfill gas is a mature technology that has major greenhouse gas benefits.
W2	Waste minimisation	No regrets to low	Moderate	Waste minimisation is occurring for reasons other than greenhouse gas reduction. Waste minimisation can reduce landfill gas generation. Under some circumstances minimisation may not reduce net methane emissions. Properly operated centralised or domestic aerobic composting facilities can reduce methane emissions.

10.2 Waste Disposal Options

Landfill Gas W1 — The emissions credits associated with the collection of landfill gas and the generation of electrical power from its energy are substantial. As it avoids methane emissions, its reduction can be shown to be about eight times greater than those from increasing hydro, tidal, solar or wind powered electricity generation. An emissions trading scheme, if implemented, may selectively encourage the collection of landfill gas for electricity generation and substantially benefit Australia's greenhouse gas inventory.

The costs of landfill gas collection and electricity generation can be low depending on tariffs obtained for the energy. The capability for reduction is moderate.

Waste Minimisation W2 — Waste minimisation can reduce landfill gas generation if the net amount of putrescible waste going to landfill is reduced in the minimisation process. However, waste minimisation has often tended to divert selected non-putrescible waste streams away from putrescible landfills which may not reduce net gas production.

Encouragement of aerobic composting of waste streams, either at centralised or domestic facilities, can reduce methane production and minimise waste going to landfills.

Costs can vary from ‘no regrets’ to low and the capability of greenhouse gas emissions reduction is moderate.

11. PREFERRED OPTIONS

This study was commenced to find the best areas for emissions reduction and the outcomes are given in terms of a preference for further and more detailed examination. The selection of preferred options was made by examining the candidate options using four classes of criteria. The criteria used were:

- What is the technical feasibility of the option?
- What is the cost of the option?
- What is the capability of the option to reduce emissions for the Kyoto target period?
- Are there any policy and/or social issues that should be highlighted for further examination?

The options preferred on the basis of present technical risk, cost, capability for greenhouse gas emission reduction, and perceived policy or social acceptability, include:

- reducing fuel consumption of motor vehicles;
- switching fuels for domestic heating;
- utilising wood waste as an energy source for co-firing or stand alone power plants where wood waste is provided with a disposal fee, free or at low cost;
- some lower cost advanced steam cycle power station technologies such as supercritical steam boilers;
- using landfill gas for energy generation;
- waste minimisation and aerobic composting of putrescible waste;
- improved waste management from agriculture;
- improved fertiliser management;
- reducing land clearing;
- rumen modifiers for livestock;
- plantation forestry and forestry conservation;
- reduced residue burning in agriculture;
- biomass for energy;
- gas flaring combustion improvements to reduce fugitive emissions from oil and gas production;
- reducing production or shut in of unflared oil and gas wells to reduce fugitive emissions;
- converting gas fired steam only cycle power stations to combined cycle operation;
- retrofitting gas turbine power units to existing coal fired steam power plants;
- combined cycle gas fired power plants; and
- wind power as costs fall.

Other options that may become more attractive with time, but may contribute little to emission reduction capability for the 2008 to 2012 Kyoto commitment period are:

- solar photo-voltaic power - as production costs fall with developing markets and technological advances;
- fuel cells - as cost reductions and technological advances are made;
- waste to energy - as alternative waste disposal costs rise in urban areas caused by longer haul distances to landfills;

- co-fire black coal and gas - to reduce emissions and to extend life of black coal infrastructure;
- tidal power plants - may be applicable in specific locations, but environmental concerns need to addressed. The capability is limited by a lack of suitable sites near substantial energy loads;
- solar thermal options - economies of scale and alternative heat transfer mechanisms may reduce costs;
- depleted oil and gas reservoirs as disposal locations for carbon dioxide or flue gases - may be attractive if located conveniently to emission sources and no alternative options are available for large quantities of gases that must be sequestered;
- enhanced oil recovery by carbon dioxide injection - requires a higher oil price to justify its costs, or other special conditions, but may become a viable option especially as it could simultaneously reduce fugitive emissions;
- direct biofixation of carbon using microalgae - can have low costs if byproduct prices are high;
- minimum tillage techniques - more data are needed to assess carbon sequestration capability;
- ocean nourishment – would require international consultation and agreement;
- hot dry rocks for geothermal energy, boosting steam generation in power plants - technology needs to be proven as cost effective, sustainable in the long term and reliable; and,
- nuclear power - unlikely to be acceptable in Australia without a substantial education program on its risks, costs and benefits.

Other options that are less likely to be attractive as means of reducing greenhouse gas emissions are:

- chemical fixation of greenhouse gases - costs are high, the capability is small and there are doubts about how long this method will sequester carbon effectively;
- deep aquifer disposal of carbon dioxide - has high costs relative to other options;
- deep ocean disposal - has high costs relative to other options and the potential for the early return of the carbon is quite high especially in the Southern Ocean area; and,
- terrestrial (engineered surface) repositories for carbon dioxide - very high cost options at present.

12. DISCUSSION

There are many greenhouse gas emission reduction options and about 175 candidate options and sub-options were examined in this study, which was not intended to be a comprehensive review.

Preferred options are those that may be able to contribute towards Australia’s achievement of the Kyoto target because they are capable of making worthwhile and measurable reductions in emissions, are technically feasible, are economically attractive, are acceptable within the Kyoto framework and are politically and socially acceptable.

Figure 8 shows a plot of the cost of emissions reduction against the capability of greenhouse gas emissions for the options shown in Tables 4, 6, 7 and 8. (Some options do not include estimates of both these factors and have not been shown.) Figure 8 indicates options are available in all major emitting sectors – that is, Energy, Agriculture, Land Use Change and Forestry, and Waste.

Preferred options in the Energy sector include improving fuel efficiency in motor vehicles (this was the only efficiency option considered), fuel switching, wood waste and biomass to energy options, several gas fuelled options for power generation, supercritical steam boilers, wind power and some methods of reducing fugitive emissions.

Preferred options in the agriculture sector include rumen modifiers, improved waste and fertiliser management and reduced residue burning.

Preferred options in the Land Use Change and Forestry sector include forestry conservation, forestry plantations and reduced land clearing.

Preferred options in the Waste sector include landfill gas collection and waste minimisation.

The total capability of these options exceeds the Kyoto target and the availability of suitable technology will not be a barrier to achieving the target. The simplest and most ideal option would have a large (over 50 million tonnes of carbon dioxide equivalent) capability and be in the ‘no regrets’ cost category. Several ‘no regrets’ options were identified that could make small to moderate contributions towards reductions but no ‘no regrets’ option was identified that would make a large contribution to reductions.

Cost and capability of greenhouse gas emission reduction options

		CAPABILITY		
		Large	**Moderate**	**Small**
C	No Regrets		*E1, E8*,E10,W2*	*E1,E2,E5,A3*
O	Low	*E11,E28*,A1,LUCF2*	*E8*,E10,A4*,LUCF2,LUCF3,W1, W2*	*E9,E29,A3,A5,A6,A7,LUCF3*
S	Medium	*E11,E12*,A1*	*E8*,E17*	*E9,E30*
T	High	*E22,E23,A1*	*E8*,E20,E21,E22,E23*	*E9,E25*
S	Very High	*E22,E23,E27,A1*	*E20,E21,E22,E23,E26*	*E9,E24,E25*

Note:

1. Tables 4,6,7 and 8 give more details of each option code
2. Several options are expected to reduce costs with time as technology advances and markets develop

* Options marked with an asterisk may have technical or other concerns associated with their implementation

KEY

E1 Motor vehicle engines
E2 Fuel switching
E5 Gas power plant conversion
E8 Hot dry rocks
E9 Waste-to-energy
E10 Combined cycle gas turbines
E11 Biomass to energy
E12 Nuclear power
E17 Electric power generation
E20 Co-firing gas and coal
E21 Solar thermal
E22 Solar photo-voltaic
E23 Fuel cells
E24 Mandatory 2% increase in renewables
E25 Chemical fixation
E26 Deep ocean disposal
E27 Terrestrial repository
E28 Ocean nourishment
E29 Flare tip improvements
E30 Shut in for unflared wells
A1 Direct biofixation
A3 Rumen modifiers
A4 Land rehabilitation
A5 Improved agricultural waste management
A6 Fertiliser management
A7 Reduced residue burning
LUCF2 Forestry
LUCF3 Reduced land clearing
W1 Landfill gas collection
W2 Waste minimisation

Figure 8 — Cost and Capability of Greenhouse Gas Emission Reduction Options
Source: BRS

13. CONCLUSIONS

At this time, Australia cannot fully define the precise amount of emission reductions needed to comply with the Kyoto target. This is because of large uncertainties associated with 1990 baseline emission estimates from several sectors. Without good baseline data, forecasts of emissions for these sectors are even more uncertain. Land use change emission estimates are particularly crucial to Australia's compliance options and BRS is undertaking work to reduce uncertainties in this sector.

In the interim and as a means of approximately estimating the size of reductions needed, assumptions need to be made about land use change emissions. This report makes two broad assumptions about land use change and indicates that a target emission reduction range of between 30 and 68 million tonnes of carbon dioxide equivalent could be required to achieve the Kyoto target in the 2008-2012 commitment period.

The achievement of the target is likely to be at some net cost - no single option is sufficiently large and cheap to enable Australia to meet its greenhouse emissions target at no cost. Inclusion of the low cost category with 'no regrets' has the potential to reach the target emission reduction range upper limit of 68 million tonnes.

The moderate capability options in the 'no regrets' category includes some generic energy efficiency options, hot dry rocks (but technology is not proven and costs could be high where technical difficulties are encountered), combined cycle gas turbine power plants and waste minimisation. Options in the small capability category with 'no regrets' costs include further generic energy efficiency actions but also fuel switching, converting gas fired power plants to combined cycle operation and rumen modifiers.

In the low cost group, there were several options covering all capability categories from small to large. In the large capability group are biomass to energy, ocean nourishment, direct biofixation, reduced land clearing and forestry. In the moderate group there are again forestry and reduced land clearing as well as combined cycle gas fired power plants, waste minimisation, hot dry rocks (but technology is not mature), landfill gas collection, land rehabilitation (but not permitted at present by IPCC). In the small capability of reduction with low costs category, there are several options including agricultural waste management improvements, fertiliser management, reduced residue burning, rumen modifiers, reduced land use change, waste to energy and flare tip improvements to reduce fugitive emissions.

It would therefore appear that a large and diverse range of options, often with small individual capabilities, would be needed to achieve the target in the most **cost-effective** way. The most attractive of the extensive and diverse range of options fall within the generic groups:

- energy efficiency;
- fuel switching to less carbon intensive fuels;
- biomass and waste/landfill gas to energy;
- plantation forestry;
- reduced land use change; and
- revised agricultural management methods.

Some other options such as ocean nourishment and hot dry rocks, where techniques and technologies are not yet mature and cost structures may be less certain, might also prove attractive with more study.

The existing policies cover these generic option groups and some emergent industry initiatives too. The policies are estimated to be capable of reducing emissions by approximately 39 million tonnes by the year 2010 which is within the target emission reduction range.

Reducing land use change and the uncertainties associated with its measurement are crucial matters towards Australia's achievement of the Kyoto protocol. Firstly, can the 'trigger' be invoked to allow the inclusion of land use change in the protocol and secondly, can sufficient detail be established to allow its verification and inclusion in the Inventory without major uncertainties.

Specific options that are considered likely to assist Australia in reaching any future targets include:

- solar (photovoltaics and thermal);
- fuel cells;
- waste-to-energy;
- co-firing gas and coal;
- tidal power;
- disposal of carbon dioxide and/or flue gases into depleted oil and gas reservoirs;
- enhanced oil recovery (especially if oil prices rise);
- direct biofixation via microalgae;
- ocean nourishment;
- hot dry rocks; and
- nuclear power (environmental concerns).

Capital and operating costs are anticipated to fall and/or technological advancements are expected with several of these options, making them more attractive in future. Government policies are already encouraging some of these options to reduce costs by providing various forms of assistance.

Options that are considered less likely to be attractive in the next decade because of relatively high costs include:

- chemical fixation of greenhouse gases;
- deep aquifer disposal of carbon dioxide;
- deep ocean disposal; and
- terrestrial repositories.

However, some of these options may be needed if large quantities of carbon dioxide need to be sequestered for future targets.

14. RECOMMENDATIONS

That:

- a more detailed study be done of the implications of the Land Use Change and Forestry sector on the Kyoto target. The study should include reducing the uncertainty in the 1990 baseline, better estimates of emissions and forecasts of emissions for the Land Use Change and Forestry sector. In the interim period, an estimated 30 to 68 million tonnes of carbon dioxide equivalent reduction is needed in 2008-2012 to meet the Kyoto target;

- a detailed study of the capability for sequestering carbon in forestry and the availability of suitable land be done;

- more detailed work be done on the preferred options and selected other options;

- a study be done to seek better methods to encourage reduced greenhouse gas emissions from the usage of motor vehicles and other energy consuming devices, while sustaining Australia's manufacturing capabilities. Such a study would examine behavioural means to move from a general highlighting and awareness of options to their implementation;

- emission control planning be implemented for all new power generation facilities, particularly for long lead time and/or long plant life facilities.

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