Long-Term Greenhouse Gas Scenarios

A pilot study of how Australia can achieve deep cuts in emissions

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Contents

List of Tables v

List of Figures vi

Abbreviations viii

Acknowledgments x

Summary xi

Part I Overview report 1

1. Introduction: the need for deep cuts 1

2. Study approach and method 7

3. Economic structure in 2050 10

3.1 Economic growth 10
3.2 Sectoral shares 11
3.3 Trade 17

4. Future energy costs 18

5. Results and technologies in 2050 20

5.1 Agriculture, land use and forestry 20
5.2 Industrial sector 21
5.3 Commercial sector 22
5.4 Residential sector 23
5.5 Transport 24
5.6 Waste and fugitive emissions 26
5.7 Energy supply 26
5.8 Overview 29

6. Constraints on renewable energy supply 30

7. Conclusions 33

Part II Detailed sectoral analysis 36

8. Industry 37

8.1 Overview 37
8.2 Technical options to reduce energy use in the energy intensive industries 38
8.3 Technical options to reduce energy use in general industrial equipment 46
8.4 Other production and technology changes 49
8.5 Industrial sector energy use in 2050 50

9. Commercial and services sector 52

10. Residential sector 56

11. Transport 60

11.1 Land transport technologies and fuels 60
11.2 Passenger transport 61

11.3 Freight transport 65
11.4 Summary 68

12. Agriculture 70

12.1 Energy used in agriculture 70
12.2 Non-energy emissions 71
12.3 Land-use change and forestry 77

13. Waste and fugitive emissions 80

13.1 Waste sector emissions 80
13.2 Fugitive sector emissions 82

14. Energy supply 86

14.1 Stationary energy 86
14.2 Transport energy demand 90
14.3 Energy balance for 2050 92

References 94

Appendix 102

List of Tables

Table 1 Retail energy prices in Australia and Europe, 2000 (US$/unit) 9

Table 2 Annual average rate of productivity growth 10

Table 3 Average annual growth rates of the Australian population and workforce, ABS Series II 11

Table 4 Exports of major commodities, 2000-01 and projected change 17

Table 5 Estimated costs and cost trends of various energy technologies (UK pence/kWh) 18

Table 6 Current and projected emissions, 1998-99 and 2050 29

Table 7 Industrial sector energy demand under deep cuts scenario, 2050 50

Table 8 Commercial sector energy efficiency, supply and demand, 2050 54

Table 9 Residential sector energy efficiency, supply and demand, 2050 58

Table 10 Current and projected emissions from transport, 1998-99 and 2050 69

Table 11 Current and projected emissions from agriculture, fisheries and forestry, 1998-99 and 2050 79

Table 12 Current and projected waste sector emissions, 1998-99 and 2050 80

Table 13 Fugitive emissions from coal mining, 1998-99 82

Table 14 Fugitive emissions from coal mining, 2050 83

Table 15 Fugitive emissions from petroleum and gas, 1998-99 84

Table 16 Factors affecting stationary fuel combustion emissions under the deep cuts scenario, 1998-99 to 2050 89

Table 17 Energy supply and disposal, 2050 93

Table A1.1 Economic growth by sector, 1998-99 to 2050-51 102

Table A1.2 Energy supply and disposal under a 70 per cent cut in emissions scenario, 2050 103

List of Figures

Figure 1 Global primary energy consumption and greenhouse emissions under the IPCC 'deep-cuts' scenario 2

Figure 2 Industrialised country primary energy consumption and greenhouse emissions under the IPCC 'deep-cuts' scenario 3

Figure 3 Australia's greenhouse gas emissions, 1998-99 and 40 per cent target for 2050 4

Figure 4 Indexes of growth in population, workforce, labour productivity and GDP, 2000-2050 11

Figure 5 Sectoral shares of gross value added, 1998-99 (at basic prices) 12

Figure 6 Sectoral shares of gross value added, 2050-51 (at basic prices) 13

Figure 7 Factors driving emissions in agriculture, forestry and land-use change 21

Figure 8 Factors affecting emissions growth in the industrial sector, 1998-99 to 2050 22

Figure 9 Factors affecting emissions from the commercial sector, 1998-99 to 2050 23

Figure 10 Factors affecting residential sector emissions, 1998-99 to 2050 24

Figure 11 Factors affecting emissions from cars, 1998-99 to 2050 25

Figure 12 Factors affecting emissions from freight transport, 1998-99 to 2050 25

Figure 13 Primary energy supply and final energy consumption, 1998-99 and 2050 27

Figure 14 Renewable energy supply, 2050 28

Figure 15 Shares of industrial energy end-use by sub-sector, 1998-99 37

Figure 16 Shares of industrial energy end-use by equipment type, 1998-99 38

Figure 17 Changes in industrial sector emissions under the deep cuts scenario, 1998-99 to 2050 51

Figure 18 Factors affecting commercial sector emissions under the deep cuts scenario, 1998-99 to 2050 55

Figure 19 Factors affecting residential sector emissions under the deep cuts scenario, 1998-99 to 2050 59

Figure 20 Factors affecting emissions from cars under the deep cuts scenario, 1998-99 to 2050 (before biofuels) 63

Figure 21 Factors affecting emissions from freight transport under the deep cuts scenario, 1998-99 to 2050 (before biofuels) 67

Figure 22 Cattle and sheep numbers, 1964 to 2050 74

Figure 23 Factors affecting emissions from agriculture, 1998-99 to 2050 (excludes land-use change and forestry) 76

Figure 24 Electricity, cogeneration heat and hydrogen, 1998-99 and 2050 90
Figure 25 Energy supply and consumption, 1998-99 and 2050 92

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABC	Australian Broadcasting Corporation
ABS	Australian Bureau of Statistics
AC	alternating current
ACT	Australian Capital Territory
ANU	Australian National University
BOF	basic oxygen furnace
BTCE	Bureau of Transport and Communications Economics
C	carbon
° C	degrees Celsius
cal	calorie
CCGT	combined cycle gas turbine
CH_4	methane
CHP	combined heat and power
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DRI	directly reduced iron
ERCo	Energy Research Company
FBT	food, beverages and tobacco
g	gram
GCV	gross calorific value
GDP	gross domestic product
GHG	greenhouse gas
ha	hectare
HBI	hot briquetted iron
HVAC	heating, ventilation and cooling
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
J	joule
L	litre
LCV	light commercial vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LUC	land-use change
LUCF	land-use change and forestry
m	metre
N_2O	nitrous oxide
NA	not applicable
NatHERS	Nationwide House Energy Rating System
NE	not estimated
NGGI	National Greenhouse Gas Inventory
NMVOC	non-methane volatile organic compounds
NO_x	oxides of nitrogen
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development

p	pence (UK)
PCI	pulverised coal injection
p-km	passenger-kilometre(s)
PMSEIC	Prime Minister's Science, Engineering and Innovation Council
PNG	Papua New Guinea
ppm	parts per million
PV	photovoltaic
SA	South Australia
t	tonne
t-km	tonne-kilometre(s)
TRT	top gas recovery turbines
UK	United Kingdom of Great Britain and Northern Ireland
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VDU	visual display unit
VFT	very fast train
VSD	variable speed drive
W	watt
WCMG	waste coal mine gas
Wh	watt-hour
yr	year

The following prefixes have been used with W, Wh, cal, J, t, l, m and g (watt, watt-hour, joule, litre, metre and gram) to denote smaller or larger quantities:

m	milli-	x 10^{-3}
c	centi-	x 10^{-2}
K	kilo-	x 10^{3}
M	mega-	x 10^{6}
G	giga-	x 10^{9}
T	tera-	x 10^{12}
P	peta-	x 10^{15}
E	exa-	x 10^{18}

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Summary

The world's most authoritative body on climate change, the Intergovernmental Panel on Climate Change (IPCC), has warned that the nations of the world will need to shift to a low-carbon future in order avoid dangerous changes to the global climate. According to the IPCC, stabilising concentrations at double pre-industrial levels will require deep cuts in annual global emissions, eventually by 60 per cent or more.

Given the wide variation in national levels of emissions per capita and income per capita, it would be infeasible and unfair to require all nations to cut their emissions by 60 per cent of current levels. Australia might be expected to reduce emissions by 60 per cent by 2050 and by more subsequently.

Like the climate system itself, energy, transport and urban systems have great inertia. They take decades to change. This means that, to achieve deep cuts and avoid the worst effects of climate change, early planning and action are needed.

In the United Kingdom, the Blair Government has released a detailed discussion of how a 60 per cent reduction in emissions might be achieved. Noting that the UK 'is likely to face increasingly demanding carbon reduction targets', it concludes:

> Credible scenarios for 2050 can deliver a 60% cut in CO_2 emissions, but large changes would be needed both in the energy system and in society.

In Australia, many in the business community appreciate the inevitability of change and the need to prepare for it. This study is a contribution to this longer-term thinking about Australia's response to climate change and seeks to investigate a feasible scenario for reducing domestic greenhouse gas emissions by 60 per cent of 1998-99 levels by the year 2050. It is impossible to know with any confidence what the world will look like in 50 years' time, but if we want to influence the future it is important to attempt to imagine it.

Study approach

The key factors in any study of this type are projections of economic growth and social change, the opportunities for energy efficiency and the availability and cost of low- and zero-emission sources of energy. Several considerations and assumptions underpin the analysis.

- The study focuses on the end-point in 2050 rather than the paths by which it could be reached. A 50-year period allows most of the stock of energy-using equipment and buildings to be replaced.

- It is assumed that any technologies that will prevail in 2050 must already be proven (although not necessarily be cost-effective) in 2002. In other words, we do not rely on the emergence of a new solution to our energy needs. In addition, we assume that the energy production technologies in 2050 must have unit prices no greater than the prices of electricity or transport fuels that currently prevail in Western Europe.

- The analysis incorporates the effects on Australia's trade of a global deep cuts scenario where other countries are seeking to stabilise global atmospheric greenhouse gas concentrations.

This report is the product of a pilot study only. However, the broad conclusions help clarify the options facing Australia in the transition to a low-carbon future.

Economic forces

The growth in the overall size of the economy is a critical factor in the growth of emissions, as energy consumption has historically grown in tandem with economic output. Based on labour productivity growth (at a rate of 1.75 per cent per annum) and the growth of the workforce (driven by the population growing from 19.3 million in 2001 to 24.9 million in 2051), Australia's real GDP will increase by almost 180 per cent (nearly treble) between 2000 and 2050.

Although economic activity is closely related to energy consumption, different activities use vastly different amounts of energy in the production of each unit of output. How the structure of the economy will change over the next 50 years will depend on a number of factors, of which changing consumption patterns are perhaps the most important. International trade is also critical.

The share of the commercial and services sector will almost certainly increase by 2050 reflecting the long-term shift in consumption patterns and the effects of increasing specialisation in trade. This shift in consumption patterns will continue the long-term decline in the share of manufacturing in GDP, although some industries, driven in part by export demand, will grow to retain their current share of GDP.

The mining sector is expected to undergo a range of changes under a deep cuts scenario. Output of natural gas (including LNG) is expected to rise continuously through to 2050, with global demand projected to be more than three times current levels by 2050. On the other hand, declining global demand for black coal will reduce Australian production by 50 per cent. Brown coal production is expected to fall to zero.

The value output from Australia's agricultural sector is expected to grow by around 120 per cent by 2050, driven mainly by exports.

Abatement opportunities

Existing technologies provide enormous scope for reducing emissions from energy consumption. For the industrial sector, abatement opportunities arise predominantly from energy efficiency measures, particularly increased cogeneration, but with direct fuel switching and a shift to renewable electricity also playing important roles. Although the commercial and services sector will grow strongly, growth in emissions from energy use will be offset mainly by improvements in buildings, improved equipment and a switch to gas cogeneration for heating.

In the residential sector, growth in energy demand will be restricted through improvements in building design and uptake of high-efficiency appliances. Large-scale uptake of solar thermal water heating and gas-fired cogeneration (either fuel cell or microturbine) for electricity generation and space and water heating will further reduce emissions.

Growth in demand for transport will be driven by increased economic activity, higher incomes and population growth. However, major technology improvements are expected, and the relatively fast turnover of the vehicle fleet will facilitate a rapid uptake of these technologies, which include hybrids, fuel cells and biofuels. Increased patronage of public transport is not expected to have a major impact on emissions.

Overall, there are significant abatement opportunities in energy-using sectors, particularly from fuel switching. By contrast, there is limited scope to reduce emissions from the agricultural sector without major structural change, although an end to land clearing will make a major contribution towards achieving deep cuts in emissions. A range of other management activities in agriculture will also have an impact. However, growth in global demand for beef will mean that by 2050 emissions from beef cattle will alone be responsible for over half of the emissions from agriculture, forestry and land-use change combined. As a result, achieving the overall abatement target of 60 per cent actually requires a reduction in emissions from fuel combustion of closer to 70 per cent.

Australia's greenhouse gas emissions under current conditions and those envisaged in the deep cuts scenario are presented in Figure S1.

Energy supply and demand

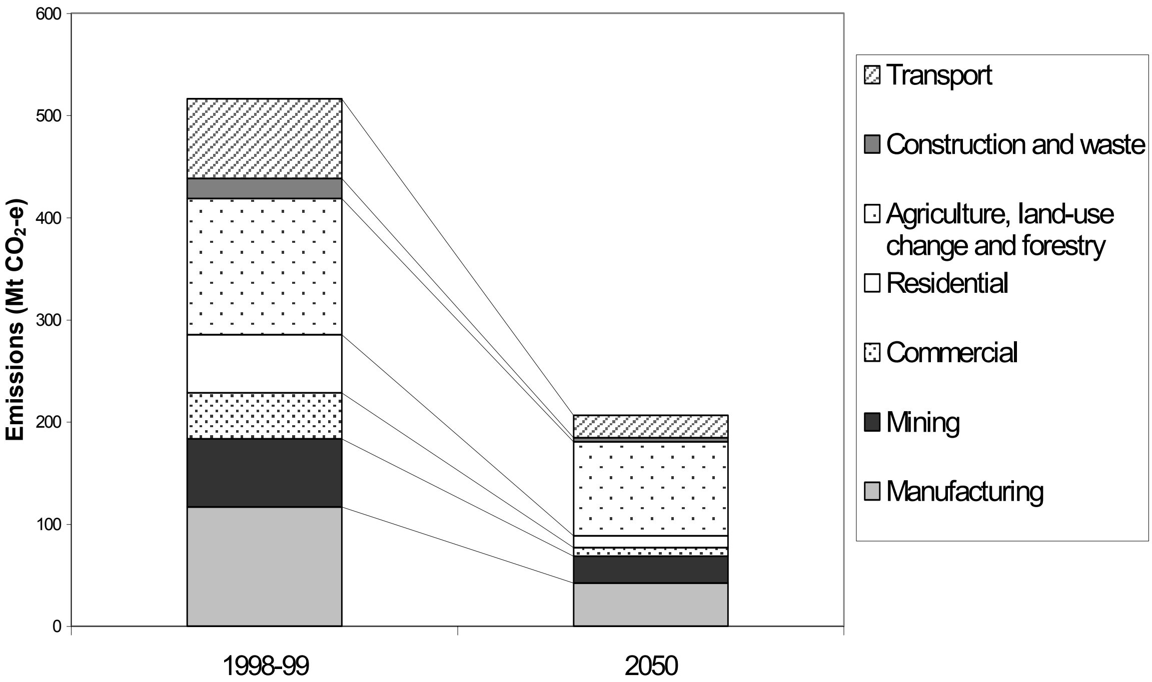
By 2050 the utilities sector is projected to have undergone a major transformation from a fossil-based system to one designed to use and deliver renewable energy. There will also be a shift away from large-scale thermal generators isolated from load centres, and towards distributed cogeneration, meeting both electricity and heat needs at load centres. An expansion in wind generation, underpinned by decreasing costs, is expected to supply a large proportion of future electricity demand. In addition, solar photovoltaics and solar electric thermal generation will supply certain significant niches, and hydroelectric generation will continue to play a major role in baseload generation and ensuring electricity market stability.

The shift from concentrated fossil energy to more dispersed renewables is expected to require a larger energy infrastructure. However, data on the expected costs of energy suggest that the transition to a low emission economy would not come at a large cost, particularly when increases in energy efficiency will offset increases in energy unit costs.

Constraints on renewable energy sources

The availability of large renewable energy resources is fundamental to the feasibility of achieving the deep cuts in emissions envisaged in this study, and it is possible that resource constraints may limit the expansion of some forms of renewable energy. Under the deep cuts scenario, wind supplies 50 per cent of gross electricity needs. Australia will need to have more than 11,000 turbines installed, or around 500-600 wind farms. One critical question is whether there are 500-600 suitable sites spread across the country, including on the coast, inland and off-shore.

Figure S1 Greenhouse gas emissions by sector under the deep cuts scenario



Photovoltaic generation is expected to remain one of the more expensive forms of renewable energy and is expected to satisfy electricity demand only in certain niches. Solar thermal electric generation is expected to supply a much larger amount of energy.

The relevant constraint for energy from biomass is the availability of suitable land, including fertility and climate. Supplying the required energy from biomass to achieve the 60 per cent cut would require the equivalent of 6-7 million ha of dedicated arable land, although much can be supplied from plantation forests and agricultural and food industry wastes. The Federal Government is currently aiming to increase the plantation stock to 3 million ha by 2020 with a further 5 million ha of land suitable for farm forestry. Consequently, by 2050 it is expected that around 8 million ha of forest plantations could be available.

Even if only part of this forest biomass were available for energy production, greater utilisation of crop and food industry wastes and cultivation of 1-2 million ha of other energy crops would be sufficient to supply the required quantity of biomass. The amount of energy obtained from biomass in 2050 is only around 70 per cent of the amount used by Brazil today.

The feasibility of achieving a 70 per cent cut in emissions was also examined. Under this scenario, the quantity of biomass is around twice that required in the 60 per cent scenario. Consequently, around twice as much productive land would be required for biomass production. This illustrates the difficulties of going beyond the 60 per cent cut under the assumptions of this study.

Conclusions

Using available technologies Australia could feasibly cut its greenhouse gas emissions by 60 per cent by 2050. However there are some significant trade-offs. Even allowing for very substantial progress in energy efficiency, supplying much of our energy needs from renewable sources will require intensive exploitation of Australia's wind resources and allocation of a substantial share of Australia's arable land to biomass crops and plantations.

This study presents only one of many possible end-points that achieve the required deep cuts in emissions. A number of other possibilities have not been considered, because they involve unpredictable technological breakthroughs or challenging social choices. They include: relying on a technological 'magic bullet' such as nuclear fusion; carbon sequestration including large-scale geosequestration; purchasing permits to emit greenhouse gases from abroad; nuclear power; and major lifestyle change.

Although the Kyoto Protocol represents an important first step towards reducing global emissions, there is gathering momentum for a longer-term approach that, in addition to reducing emissions to a safe level, leads to convergence of the per capita emissions of everyone in the world. This is known as contraction and convergence.

A 60 per cent cut in Australia's total 1999 emissions by 2050 would see per capita emissions in Australia fall from their 1999 level of 27.9 to 11.2 t CO_2-e per annum. Convergence at a per capita entitlement of 11.2 t would represent an *increase* in emissions for the UK, Japan and France. It would also mean a 45 per cent reduction for the USA. Moreover, a per capita target of 11.2 t would represent a very large increase for developing countries such as China, with per capita emissions currently around 3 t, and India, below 1 t from energy.

Understood this way, it is clear that requiring Australia to cut its emissions by 60 per cent by 2050 is not unreasonable. Over the longer term Australia may need to cut its emissions by around 85 per cent. Achieving emission cuts of this order will require major policy intervention.

PART I OVERVIEW REPORT

1. Introduction: the need for deep cuts

The world's most authoritative body on climate change, the Intergovernmental Panel on Climate Change (IPCC), has warned that the nations of the world will need to shift to a low-carbon future in order avoid dangerous changes to the global climate.

The IPCC has developed a number of climate change scenarios to evaluate future impacts. Even the most optimistic scenario, involving rapid change in economic structure and technology, shows CO_2 concentrations doubling by the end of the century, resulting in an increase in average global temperatures of around 2° C and a sea-level rise of 30 cm.[1] The IPCC notes that the climate system is subject to great inertia so that '[s]tabilization of CO_2 concentrations at any level requires eventual reduction of global CO_2 net emissions to a small fraction of the current emission level' (IPCC 2001, p. 16). There are advantages in beginning the task of reducing emissions sooner rather than later: 'The greater the reductions in emissions and the earlier they are introduced, the smaller and slower the projected warming and the rise in sea levels' (IPCC 2001, p. 19).

Doubling of atmospheric concentrations of CO_2 is expected to be associated with global warming in the range 1.4-2.6° C by the end of the century (IPCC 2001, Figure 22, p. 209). The United Nations Framework Convention of Climate Change (UNFCCC) commits nations (including Australia) to taking measures to prevent 'dangerous' levels of climate change. It is widely accepted that concentrations in excess of 550 ppm, or double the pre-industrial levels, would be dangerous, and that even a doubling is likely to be associated with major negative impacts (see IPCC 2001). According to the IPCC, stabilising concentrations at double pre-industrial levels will require deep cuts in annual global emissions, eventually by 60 per cent or more (see IPCC 2001, Figure 25).[2]

The need for deep cuts has been formally acknowledged by the Australian Government, despite its opposition to the Kyoto Protocol. The Foreign Minister Alexander Downer has stated:

> If we are going to achieve stability in global temperatures in the years ahead then CO_2 emissions will have to be reduced by between one half and two thirds.[3]

Given the wide variation in national levels of emissions per capita and income per capita, it would be infeasible and unfair to require all nations to cut their emissions by 60 per cent of current levels. Developing countries might expect to reduce their emissions by less than this amount and wealthy countries with high per capita

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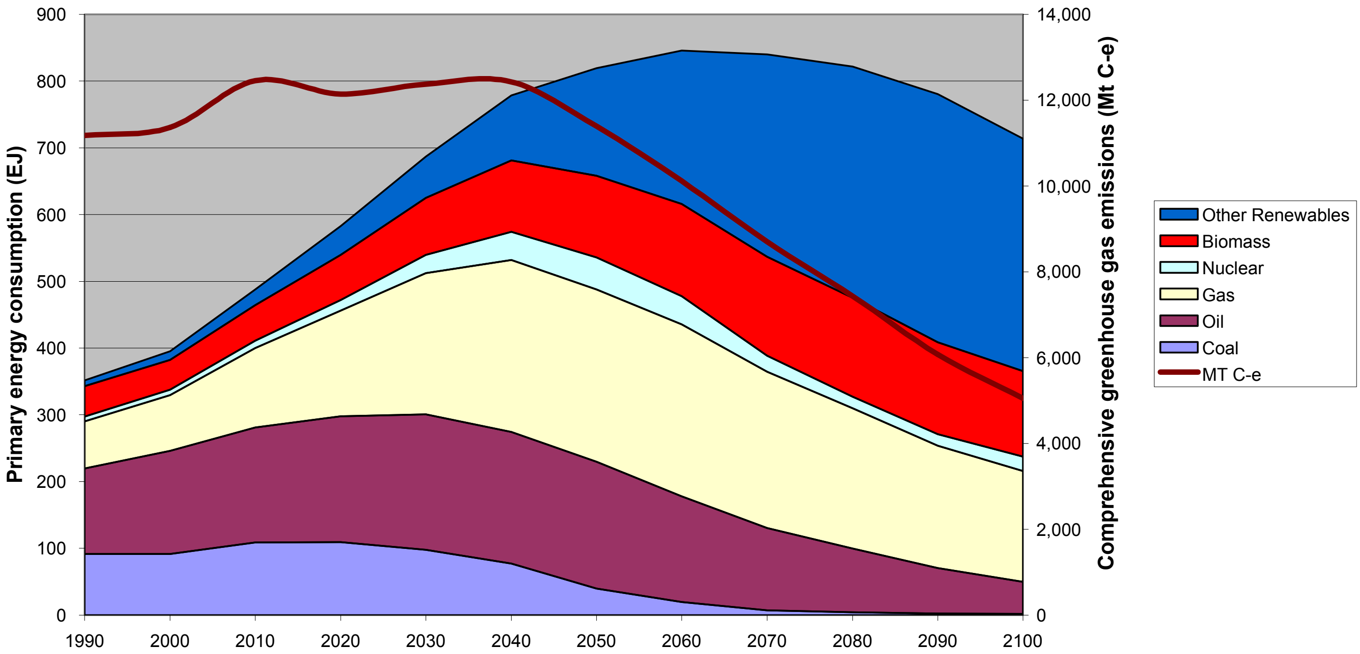
[1] Scenario B1 in IPCC 2001, pp. 10-11.
[2] IPCC 2001, Figure 25(c) shows that to achieve stabilisation of atmospheric CO_2 concentrations at 550 ppm it is necessary to reduce emissions by 40-60 per cent by the end of the century and 65-85 per cent by 2150. Further reductions will be required beyond 2150.
[3] ABC Radio News, 28 June 2002.
http://www.abc.net.au/news/politics/2002/06/item20020627170339_1.htm

emissions, such as Australia, should expect to cut their emissions by more than 60 per cent in the longer term.[4] This issue is discussed further in Section 7 of this report.

The IPCC scenario that most closely reflects the deep cut in emissions necessary to achieve stabilisation of CO_2 concentrations at 550 ppm is the B1T scenario.[5] The B1 scenarios assume 'a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development', but also incorporate high economic growth and relatively low population growth (see IPCC 2000a, Sects. 4.4.2.3, 4.3.3). The T refers to the scenario being technology-intensive, allowing for 'radical technological change in energy systems' (IPCC 2000a, Sect. 4.4.1). Global greenhouse gas emissions and demand for energy under this scenario are shown in Figure 1. Under this scenario, emissions are reduced by around 35 per cent by the end of the century, just below the range required to stabilise atmospheric concentrations at 550 ppm (IPCC 2001, Figure 25(c)). Figure 2 presents industrialised country emissions and energy use under the B1T scenario and shows how developed countries will need to, on average, reduce emissions by more than 60

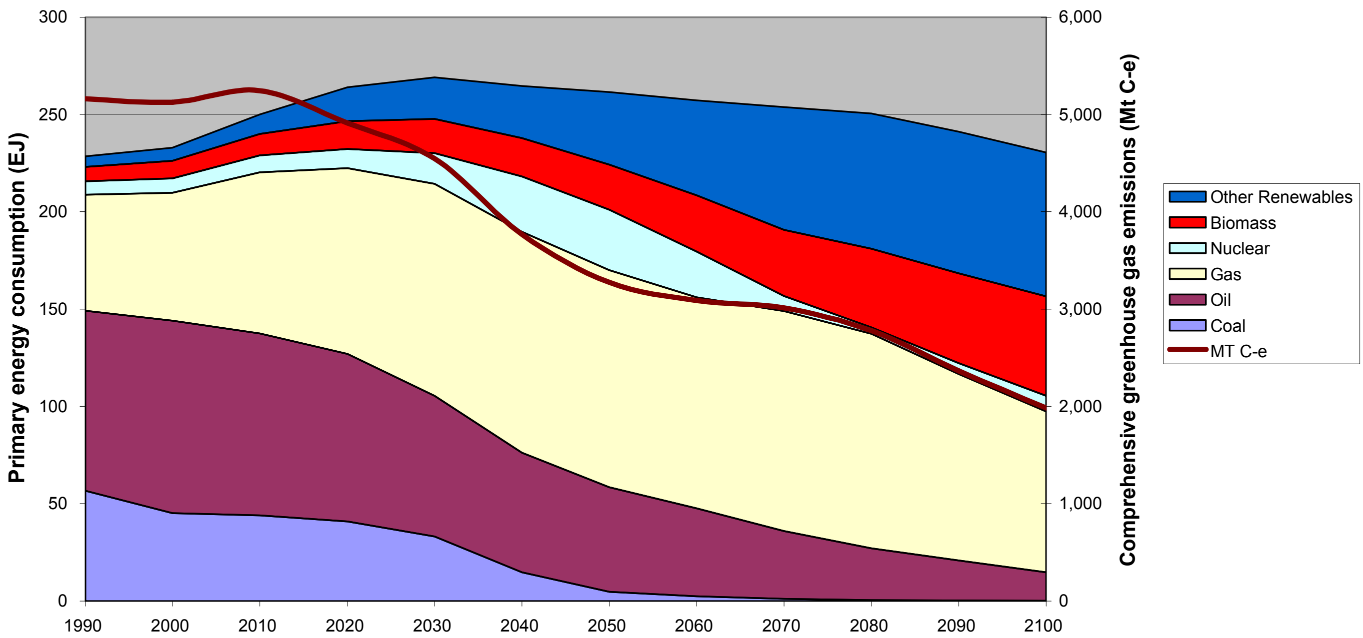
Figure 1 Global primary energy consumption and greenhouse emissions under the IPCC 'deep-cuts' scenario



Note: IPCC scenario B1T-MESSAGE
Source: IPCC 2000a, Appendix 7

[4] This was reaffirmed in the decision adopted by the UNFCCC in Bonn '[t]hat the Parties included in Annex I [industrialised countries] shall implement domestic action…with a view to reducing emissions in a manner conducive to narrowing per capita differences between developed and developing country Parties while working towards achievement of the ultimate objective of the Convention' (UNFCCC 2001, Decision 5/CP.6).
[5] Its full name is B1T-MESSAGE where MESSAGE is the name of the model used to generate the scenarios.

Figure 2 Industrialised country primary energy consumption and greenhouse emissions under the IPCC 'deep-cuts' scenario



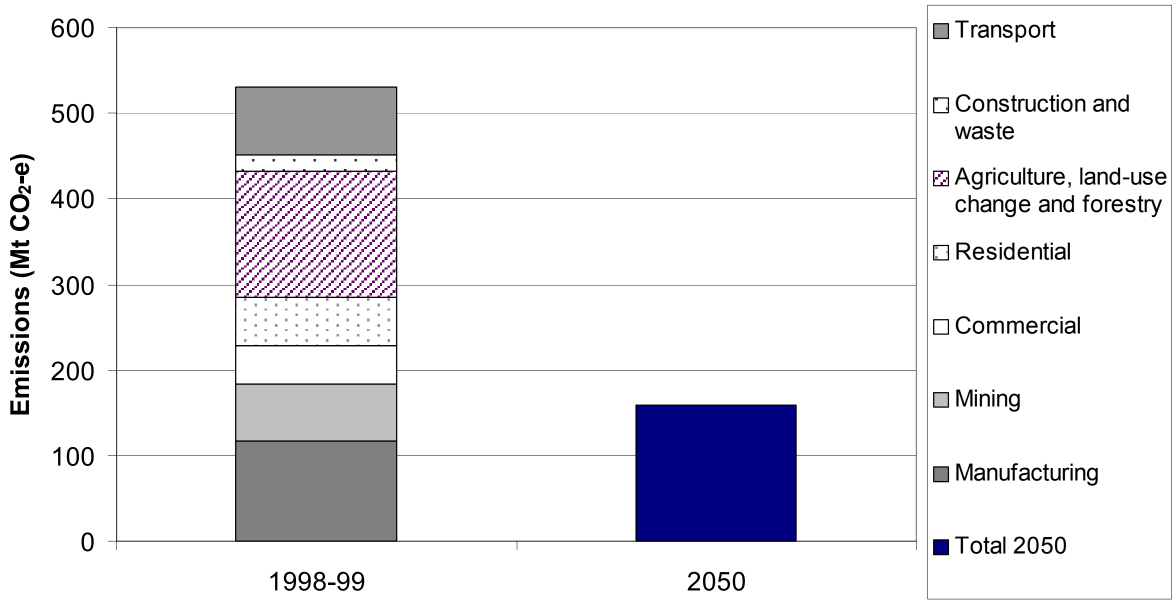
Note: IPCC scenario B1T-MESSAGE; industrialised countries include OECD and Economies in Transition.
Source: IPCC 2000a, Appendix 7

per cent by 2100, and by around 40 per cent by 2050. Australia, with the highest per capita emissions in the developed world (Turton and Hamilton 2002), would be expected to reduce emissions by a greater percentage.

The Kyoto Protocol is widely recognised as the first step in bringing about the sharp reductions needed in global greenhouse gas emissions. The Protocol is often reported as requiring industrialised countries to reduce their emissions by an average of 5.2 per cent over the period 1990 to 2008-12. Australia would be required to limit the growth of its emissions to 8 per cent above 1990 levels. However, the opening up of various loopholes in the Protocol – mainly relating to the use of forest sinks, agricultural practices and investments in developing countries – will mean that the reductions are substantially less than the headline levels. In Australia's case the special loophole relating to land clearing (Article 3.7, known as 'the Australia clause') will allow emissions other than from land clearing to increase by up to 30 per cent (Hamilton and Vellen 1999). Conversely, Australia could achieve a cut in emissions of roughly 22 per cent relative to 1990 by ending land-clearing, at almost no cost (AGO 2002, Table 3.8; Ryan 1997). Accordingly, Australia would be expected to reduce emissions by mid-century by more than the average 40 per cent required from developed countries.

Recognising both Australia's high per capita emissions and impact of the 'Australia clause', for Australia to make a reasonable and fair contribution to stabilising atmospheric greenhouse gas concentrations at double pre-industrial levels, it might be expected to reduce emissions by close to 60 per cent by 2050.

Figure 3 Australia's greenhouse gas emissions, 1998-99 and 40 per cent target for 2050



Source: derived from AGO 2001a, Dickson *et al.* 2001

In 1998-99, Australia's emissions (including forest and grassland conversion) totalled 529.9 Mt of carbon dioxide equivalent (CO_2-e) (AGO 2001a, pp. A-4, A-35).[6] The breakdown of these emissions is presented in Figure 3. The figure also shows the effect of a 60 per cent reduction in Australia's 1998-99 emissions to illustrate the extent of the cut necessary by 2050.

At the time of writing it seems most likely that the Kyoto Protocol will enter into force but without the participation of the USA and Australia.[7] However, whether the Protocol takes effect or not, the problem of climate change is not going to disappear. The scientific warnings are ringing more loudly, and sooner or later some international instrument will be agreed that will require all industrialised countries (followed by developing countries) to reduce their emissions.

The need for a long-term view

The greenhouse debate in Australia (as elsewhere) has been dominated by short-term thinking. Like the climate system itself, energy, transport and urban systems have great inertia. Transport systems, buildings, urban layouts and electric power plants have long life spans or take decades to change. This means that, to achieve deep cuts and avoid the worst effects of climate change, early planning and action are needed.

The electoral cycle, largely unfounded concerns about the immediate costs of structural adjustment and the short-term impacts on competitiveness have dominated

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[6] The latest greenhouse gas inventory indicates that emissions in 1999-2000 were 535.3 Mt CO_2-e. Revised emissions for 1998-99 are 524.0 Mt CO_2-e (AGO 2002, Table 3.8).
[7] As of 5 September 2002, the Protocol had been ratified by industrialised countries representing 37 per cent of 1990 industrialised country greenhouse gas emissions, including by the fifteen countries of the European Union, Bulgaria, the Czech Republic, Hungary, Iceland, Japan, Latvia, Norway, Romania and Slovakia (http://unfccc.int/resource/kpstats.pdf, 5 September 2002 update).

public discussion and the Australian Government's thinking. While the cynical view may be that governments never think beyond the next election, this has not always been the case. In recent decades Federal governments have shown themselves willing to embark on far-reaching policy changes that result in major structural adjustment in the economy. Trade liberalisation, the floating of the dollar, the introduction of competition policy and, more recently, the changes to social expenditures proposed in the Intergenerational Report are the best examples. In each case, governments have been willing to override the objections of vocal sectional interests to pursue what they believed to be in the longer-term interests of the nation.

While surveys consistently reveal widespread popular concern over global warming and climate change, the public has not become deeply engaged in the issue. One reason could be that in the welter of claim and counter-claim it all looks too hard. By describing and analysing a feasible long-term future in which the energy economy is radically different, the public can form a picture of how Australia and the world could be different.

In 2000, the UK Royal Commission on Environmental Pollution brought down a report examining the feasibility of achieving a 60 per cent reduction in Britain's emissions by 2050. The report observed:

> Human use of energy has grown enormously, based overwhelmingly on burning fossil fuels. This is causing a significant change in the composition of the atmosphere which, unless halted, is likely to have very serious consequences. ….
>
> In addition to previously recognised risks from obtaining and using energy, the world is now faced with a radical challenge of a totally new kind, which requires an urgent response. The longer the response is deferred, the more painful the consequences will be. (RCEP 2000, pp. 13, 16)

The Blair Government has responded with a detailed discussion of how such a reduction might be achieved. Noting that the UK 'is likely to face increasingly demanding carbon reduction targets', it concludes:

> Credible scenarios for 2050 can deliver a 60% cut in CO_2 emissions, but large changes would be needed both in the energy system and in society. … Given the strong chance that future, legally binding, international targets will become more stringent beyond 2012, a precautionary approach suggests that the UK should be setting about creating a range of future options by which low carbon futures could be delivered, as, and when, the time comes. (Cabinet Office 2002, p. 9)

In Australia, many in the business community have a similar understanding of the inevitability of change and the need to prepare for it. Perhaps the best expression of the enlightened business view was put by the Prime Minister's own Science, Engineering and Innovation Council (PMSEIC), in a report completed in 1999. The Council draws together high-powered business interests and eminent scientists.

PMSEIC urged the Government to go from a defensive to an attacking position on climate change policy. Noting that Kyoto is a watershed in the global greenhouse debate, it argued that the Protocol is a powerful instrument of change ignored at great cost. It drew an analogy with earlier industrial and social movements.

> In each, attitudes changed from defence and denial, to recognition of opportunities, and ultimately to the realisation that what is right for the community in the long term can be good for the growth and profits of industry … Increasingly the world's major corporations accept this transition. …. If we wait for ratification while other countries act, Australia runs the risk of missing out on global opportunities, and may be left behind in terms of greenhouse compliance (PMSEIC 1999 p. 3).

The report went on to observe that 'Kyoto has created a new business environment in which new industries, markets and technologies can flourish' and urged the Howard Government to adopt policies that would see Australia capture at least five per cent of the huge world market for greenhouse technologies.

The present study is a contribution to this longer-term thinking about Australia's response to climate change.

2. Study approach and method

This study seeks to investigate one feasible scenario for reducing Australia's greenhouse gas emissions to 40 per cent of 1998-99 levels by the year 2050. It is important to acknowledge that it is impossible to know with any confidence what the world will look like in 50 years' time, and the scenario developed in this study is only one of many possibilities. We only need to transport ourselves back to 1950 to realise that no-one could have predicted the enormous impact of computer technology, dramatic changes in the labour market or the emergence of sustainability as a dominant issue. On the other hand, if we want to influence the future, as we manifestly do in the case of climate change, it is important to attempt to imagine it – not only the possible effects of climate change but also the world we will need to create to mitigate its effects. Failure to do so runs the risk of much higher future costs.

The key factors in any study of this type are projections of economic growth and social change, the opportunities for energy efficiency and the availability and cost of low- and zero-emission sources of energy. It is well established that stabilising or reducing greenhouse gas emissions requires, in the first instance, continued pursuit of energy efficiency with a view to offsetting the relentless effects of economic growth on the demand for energy.[8] In addition, switching to low-emission fuels and renewable energy technologies are central to the task.

This report is the product of a pilot study only. A full and detailed study of long-term energy and greenhouse scenarios would require several experts to work over a 12-18 month period. However, the broad conclusions of this study help clarify the options facing Australia in the transition to a low-carbon future.

Assumptions and methods

In conducting this study it was first necessary to develop projections for the Australian economy in 2050, including shares of the economic sectors, by examining the factors driving overall economic growth and activity within individual industries.

The second step required, for the major greenhouse gas emitting sectors, a review of the technologies and processes that, under reasonable cost assumptions, would prevail in 2050 if governments pursued the objective of cutting emissions by 60 per cent. The opportunities for energy efficiency and fuel switching will be crucial to achieving deep cuts in emissions. This is perhaps the most ambitious part of the whole project, and the area that would be the subject of more intense analysis in a full study. Throughout the work of making economic and technological projections, various consistency checks have been made. Having established reasonable technical limits on emission reductions, the next step was to consider the expected future unit costs with the mix of energy technologies proposed.

The last step was to examine whether the scenario developed for 2050 for cutting emissions by 60 per cent is plausible, or whether technical or physical constraints or

[8] See Hamilton and Turton (2002) for a decomposition analysis of the factors driving growth in greenhouse emissions in OECD countries.

excessive increases in cost would put the target out of reach in the absence of a major technological breakthrough or change in lifestyles.

Several assumptions and considerations underpin the analysis.

1. *Time horizon*. The 50-year time horizon was chosen because it allows most of the stock of energy-using equipment and buildings to be replaced, in some cases two or three times. It therefore may allow for the full diffusion of new and emerging technologies. It also allows sufficient time to change agricultural practices and significantly enlarge the forest stock. It is not, however, a long enough time span to allow some of the major changes to urban systems that may be necessary and desirable in the very long term.

2. *No consideration of paths*. This study focuses on the end-point, 2050, rather than the paths by which it could be reached. There are a number of paths that could be followed to reach the same or a similar end-point, each with higher or lower emissions in the intervening period. Nevertheless, some clues as to the paths that could be followed will be apparent in the discussion of various technologies and structural changes. Moreover, many of the assumptions and projections will imply a range within which the actual path must lie.

3. *Existing technologies*. We have imposed the condition that any technologies that will prevail in 2050 must already be proven (although not necessarily be cost-effective) in 2002. In other words, we do not rely on the emergence of a new solution to our energy needs (such as nuclear fusion), even though such technologies will almost certainly eventuate. Some of the technologies that are likely to dominate in 2050, such as fuel cells, are in their infancy now. An essential feature of this work is to make projections about how the unit costs of these technologies will decline.

4. *Energy cost assumption and selection of technologies*. This study does not employ a least-cost optimisation approach to projecting the future, as does the MARKAL[9] model for instance. While least-cost optimisation, using various mathematical and operations research techniques, is a valid and potentially accurate way of making projections over 10 or so years, such an approach is no better than other methods for dealing with the significant uncertainties over a 50-year period.

However, the issue of costs remains important in terms of energy and technology choices, and therefore the following rule has been adopted for this study: all energy production and distribution technologies in use in 2050 must have unit costs no greater than the price of electricity or transport fuels (including taxes) that currently prevail in Western Europe. This means that overall energy prices in Australia in 2050 under the 60 per cent greenhouse gas constraint will be no higher than those of European countries now, and may be much less. A comparison of current Australian and European fuel prices is presented in Table 1. The improvements in energy

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[9] MARKAL is an energy-economy model developed by the International Energy Agency's (IEA) Energy Technology Systems Analysis Programme (ETSAP). MARKAL incorporates information on performance and cost for different energy or emission control technologies over time. Among other things, MARKAL can be used to find the least-cost mix of energy technologies that achieve a given emissions target. More information is available at http://www.ecn.nl/unit_bs/etsap/markal/main.html.

Table 1 Retail energy prices in Australia and Europe, 2000 (US$/unit)

	Australia	Europe[1]	Difference (%)
Unleaded premium petrol (L)[2]	0.550	1.033	87%
Automotive diesel (L)	0.193	0.759	293%
Natural gas for industry (10^7 kcal GCV)	97.39	138.96	43%
Natural gas for households (10^7 kcal GCV)	238.42	367.79	54%
Electricity for industry (kWh)[3]	0.0460	0.0800	74%
Electricity for households (kWh)[3]	0.0793	0.1590	100%

1. Europe is represented by a simple average of prices in Germany, France, Italy and the UK.
2. IEA reports the price for unleaded regular in Australia at US$0.502. To reflect the higher price of premium this has been increased to US$0.55.
3. Figures for electricity are for 1996
Source: IEA 2001b; IEA 1998

efficiency anticipated between now and 2050 will likely offset any increase in unit costs, resulting in households and industry paying less for energy in 2050. In other words, while unit prices of energy may rise, energy bills are likely to fall as a share of expenditure.[10]

5. The global context. As a trading nation, some of Australia's industries export a large share of their production. Accordingly, global demand has a major influence on the production decisions of Australian firms and on Australia's overall economic structure. When developing projections of the Australian economy to 2050 it is necessary to incorporate any changes that might arise as a result of changes in global demand for Australia's major exports. In all likelihood, Australia would only seek to cut domestic greenhouse gas emissions by 60 per cent if comparable action were being undertaken throughout the world. Accordingly, this analysis incorporates the effects on Australia's trade of a global deep cuts scenario, which has a particular bearing on Australia's exports of fuels, principally coal, gas and uranium.

[10] This raises the issue of a 'rebound effect' in the economy, where the efficiency savings release large amounts of capital that then drive additional consumption or investment, leading to additional energy use and hence greenhouse gas emissions. However, it is anticipated that appropriate policies can ensure any rebound effect must fit within overall emissions targets and that much of the additional consumption is of less greenhouse-intensive products, particularly services sector outputs (see discussion of sectoral shares in Section 3.2).

3. Economic structure in 2050

3.1 Economic growth

The growth in the overall size of the economy is a critical factor, as energy consumption has historically grown in tandem with economic output (see Hamilton and Turton 2002). The growth rate of GDP depends on the rate of labour productivity growth (GDP/worker) and the rate of growth of the workforce. Average rates of labour productivity growth over the last four decades are shown in Table 2, and have varied from 1.0 to 2.7 per cent per annum. On this basis it seems reasonable to assume that labour productivity will grow at an annual rate of 1.5-2.0 per cent over the period to 2050.[11] A higher growth rate could be achieved if there were some major technological breakthrough in the next couple of decades, such as another computer revolution or breakthroughs in biotechnology, but in this study a rate of 1.75 per cent has been assumed. This is the same rate assumed for the period to 2042 by the Commonwealth Treasury in its Intergenerational Report (Costello 2002, p. 25). It is possible that some of the gains in future productivity will be taken in the form of increased leisure, which would reduce the growth of real GDP.[12]

The ABS's most likely population growth scenario is reported in Table 3. This scenario assumes a total fertility rate of 1.75 and net immigration of 70,000 per year, resulting in the population growing from 19.3 million in 2001 to 24.9 million in 2051 (ABS 1998a, p. 17). Under this scenario, growth in the working-age population averages 0.3 per cent per annum and, assuming that participation rates among this group do not change significantly, the workforce will grow at a similar rate. Combined with an annual 1.75 per cent increase in labour force productivity, the growth rate of real GDP over the period is just under 2.1 per cent per annum. Under these circumstances real GDP would increase by almost 180 per cent (nearly treble) between 2001 and 2051 (see Figure 4).

Table 2 Annual average rate of productivity growth

	Real GDP per worker	Real GDP per person
1960-1970	2.7%	3.1%
1970-1980	1.7%	1.5%
1980-1990	1.0%	1.7%
1990-2000	2.1%	2.3%

Source: Dowrick 2002, Table 1

[11] This figure assumes no change in average hours worked. The productivity growth rates reported in Table 2 do not account for changes in hours worked. When adjustment is made for hours worked the mean rate of productivity growth over the four decades is 0.4 per cent higher than real GDP per worker (Dowrick 2002, Table 1).

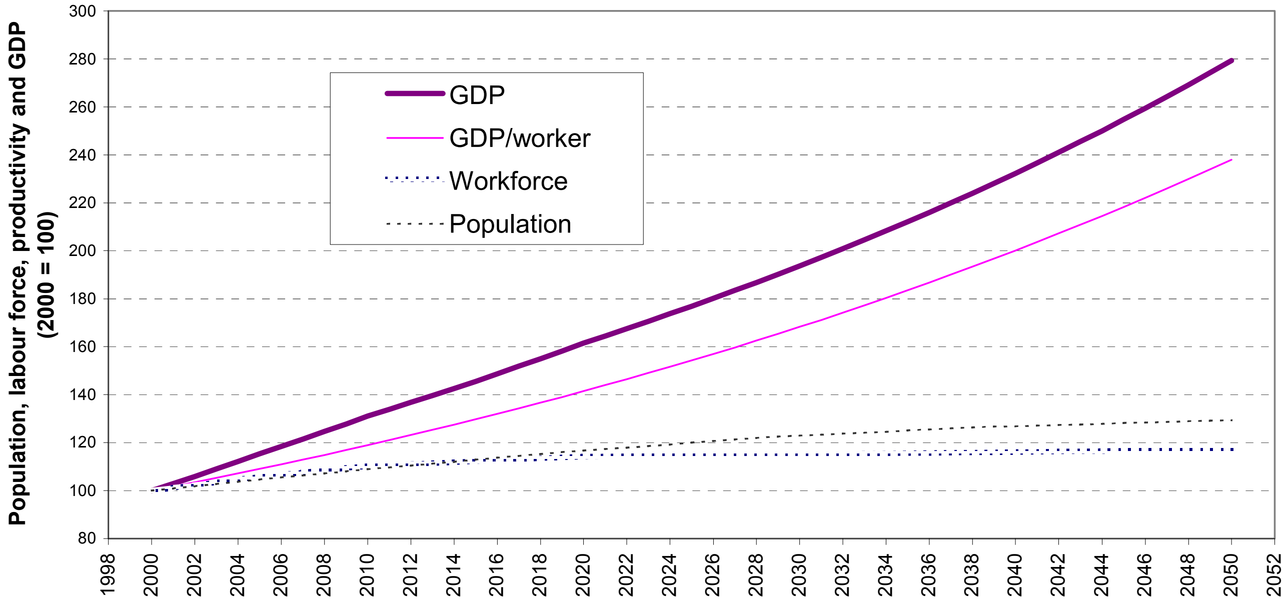
[12] We are indebted to John Quiggin for this point.

Table 3 Average annual growth rates of the Australian population and workforce, ABS Series II

Year	Population growth	Workforce growth
1997-2001	1.0%	1.3%
2001-2011	0.9%	1.0%
2011-2021	0.7%	0.4%
2021-2031	0.5%	0.1%
2031-2041	0.3%	0.1%
2041-2051	0.2%	0.1%

Note: Workforce is assumed to grow at the same rate as the population aged between 20 and 64 inclusive.
Source: ABS 1998a

Figure 4 Indexes of growth in population, workforce, labour productivity and GDP, 2000-2050



Note: Assuming labour productivity growth of 1.75 per cent per year.
Source: ABS 1998a

3.2 Sectoral shares

Although economic activity is closely related to energy consumption and greenhouse gas emissions (where this energy is supplied from fossil fuels), different industrial activities use vastly different amounts of energy for each unit of economic output. Accordingly, it is necessary to estimate the shares of the various economic sectors in the much larger economy of 2050. The main sectors are discussed below, with more detailed sub-sectoral discussion left for Part II.

The current structure of the Australian economy is shown in Figure 5. The services sector accounts for 54 per cent of value added, but a much smaller share of greenhouse gas emissions. What does the future hold for the major sectors? The answer depends on a number of factors, of which changing consumption patterns are perhaps the most important. The level of international trade is also critical. In this study it is assumed that the total share of trade in GDP is the same in 2050 as it is now, but the shares of sectors within the total vary, as described below.

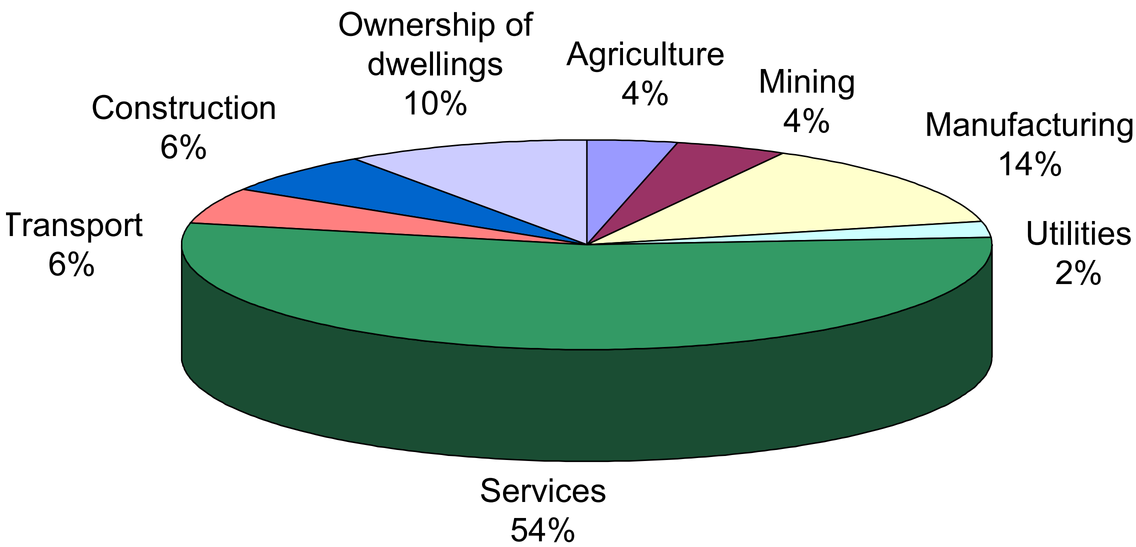
How the rest of the world responds to the need to cut greenhouse gas emissions is crucial both for the structure of Australia's trade and the availability of low and zero-emission technologies in the future. In this scenario exercise, it is assumed that other industrialised countries are also pursuing deep cuts in their greenhouse gas emissions, while developing countries will have increasing emissions for the next two to three decades, after which they too will begin to cut their emissions (see Figures 1 and 2). These assumptions are clearly important for projections about Australia's exports of energy and energy-intensive products.

The projected shares of major sectors in Australia's economy in 2050 are shown in Figure 6. The factors influencing the changes in structure between now and 2050 are discussed on a sectoral level below. Detailed projected growth rates for 36 sectors are shown in Table A1 in the Appendix.

Services

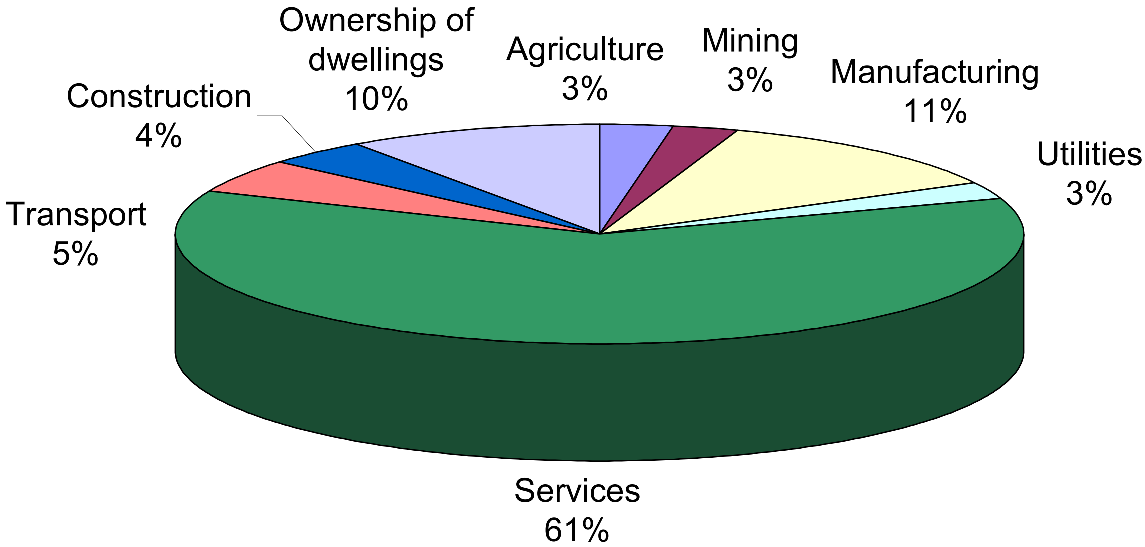
The share of the services sector will almost certainly increase by 2050 reflecting the long-term shift in consumption patterns and the effects of increasing specialisation in trade (which contributed to the decline of the Australian manufacturing sector's share of economic output in the last decades of the twentieth century). Growth in domestic

Figure 5 Sectoral shares of gross value added, 1998-99 (at basic prices)



Source: ABS 1999

Figure 6 Sectoral shares of gross value added, 2050-51 (at basic prices)



Source: Table A1 in the Appendix

demand for services such as health, education and entertainment is likely to be compounded by continued growth in the export of services, notably secondary and tertiary education, in-bound tourism, financial services, communications and a range of business services including consulting of all sorts.

On this basis, demand for health and education, community services, communications, research and recreational services is expected to grow at a faster rate than average GDP with some services (such as health, education, communications, accommodation, restaurants and gambling services) expected to grow at an even faster rate. As a result, it is estimated that the share of the services sector will increase from 54 per cent currently to 61 per cent in 2050 (see Figure 6).

Manufacturing

The share of manufacturing in GDP is expected to decline overall as consumer preferences shift to services, although some industries, driven in part by export demand, will grow to retain their current share of GDP.

Global demand for light metals, including aluminium, magnesium and titanium, is expected to grow strongly, driven partly by greenhouse gas abatement policies.[13] Australia's metal manufacturing industries may well benefit from this boom; however, this may come partly at the expense of iron and steel, which are expected to be replaced by light metals in a range of manufactured goods, particularly transport applications. Accordingly, the non-ferrous metals industry is projected to grow in line with the total economy, almost tripling in size by 2050. Iron and steel production is expected to grow more slowly (increasing in size by only 35 per cent by 2050).

[13] This increase in demand may also increase the proportion of these metals that is recycled. Demand for other strong and light-weight materials (such as carbon fibre) will also increase.

There may also be a transformation of production techniques, notably a shift to direct reduction technologies for steel production.

Demand for non-metallic mineral products (including cement, bricks and glass) is expected to grow at the same rate as construction activity, which in turn is expected to grow at around half the rate of the economy overall.

The food industry is expected to grow at a rate similar to that of the agricultural sector, although this masks sub-sectoral trends. For example, domestic demand for most food products will likely plateau after a couple of decades, in line with declining population growth. Similarly, there will be a slowing in international demand for grain products for human consumption as rising incomes in developing countries result in a shift in food consumption patterns. This same trend, however, will increase demand for meat, dairy products, fruit, vegetables and grains for animal consumption. Growth in beef production is especially important for greenhouse gas emissions and is discussed in more detail in Part II, Section 12.

Demand for wood and paper products is assumed to increase at the average rate of economic growth. This is driven by continuing demand for paper, printing and recorded media by the services sector (which itself is growing rapidly) and a shift from more energy-intensive raw materials (such as steel, bricks and cement) to wood. Improving wood utilisation efficiency will, however, result in a slightly lower increase in wood requirements.

Output from other, less energy-intensive, manufacturing activities, such as machinery and equipment and textiles, clothing and footwear is expected to increase at the same rate as the economy as a whole. However, this conceals some sub-sectoral trends. In particular, in line with historical trends Australia's textiles, clothing and footwear industries are expected to continue to decline as a share of GDP. On the other hand, a continuation of the shift in consumer preferences towards elaborately transformed products will stimulate demand for machinery and equipment. It is assumed that overall this sector will grow at a rate similar to GDP.

Demand for chemical industry products, including plastics and rubber, is also expected to grow in line with overall economic activity, driven partly by substitution of plastics for more energy-intensive and heavy products (e.g. metals). Demand for pharmaceuticals, soaps and detergents and cosmetics is also projected to grow reasonably strongly. Growth in demand for basic chemicals, fertilisers and explosives is expected to be mixed, with demand for fertilisers increasing in line with agricultural output, while demand for explosives is expected to grow at the same rate as the economy.

Utilities

Electricity generation and gas supply industries make up two-thirds of this sector at present. Demand for the services provided by these utilities will be heavily influenced by the greenhouse constraints imposed on the rest of the economy. However, it is projected that by 2050 the utilities sector will have undergone a major transformation from a fossil-based system to one designed to use and deliver renewable energy. This shift from concentrated fossil energy to more dispersed renewables is expected to require a larger energy infrastructure, and the utilities sector will therefore make a greater contribution to GDP and employment.

The other major component of the utilities sector is water, sewage and drainage, and the aggregate demand for these services is expected to grow at the same rate as construction.

Construction

Growth in residential construction activity is expected to slow in line with slowing population growth over the period. However, a number of other forces will be at work, including a shift to apartments and townhouses (although average dwelling size is expected to increase by 20 per cent with increasing affluence), and a decline in the average household size from 2.7 to 2.3 persons, requiring more dwellings relative to population (for more detail and sources, see Part II, Section 10). In the case of non-residential construction (including offices, schools, hospitals and commercial buildings), growth in the services sector will maintain building activity at a level higher than residential construction activity. Overall, over the period 1998-99 to 2050-51, construction activity is expected to increase by 75 per cent, although the share of construction in the economy will decline from around 6 per cent to 4 per cent.

Agriculture

Global demand for agricultural products is expected to expand in line with population growth and increasing incomes, particularly in developing countries. Rising global incomes are expected to increase global demand for meat products to around 2.5-times current levels, while demand for grain is expected to experience more subdued growth to a level around twice current levels (Pinstrup-Andersen *et al.* 1999, p. 5). Overall, Australia's agricultural sector is expected to grow by around 120 per cent, or around 1.6 per cent per annum. This results in a decline of the share of agriculture from 3.6 per cent to 2.8 per cent. (See Part II, Section 12 for more detail)

Mining

The mining sector undergoes a range of changes under a deep cuts scenario. Black coal exports are expected to decline as the world shifts to low- and zero-emissions sources of energy (see Figure 1), and demand is likely to shift away from developed markets (notably Japan) and towards developing countries (such as India and China). Based on the IPCC B1T-MESSAGE scenario, where global coal demand declines by over 55 per cent between 2000 and 2050, this study assumes that by 2050 Australian black coal production will be 50 per cent of its current level (see B1T-MESSAGE projection in IPCC 2000a, Appendix VII). Brown coal production is expected to fall to zero.

Output of natural gas (including LNG), as a relatively low emissions fuel, is expected to rise continuously through to 2050, with global demand projected to be more than three times current levels by 2050 (see Figure 1). Assuming an annual growth rate in domestic production of 2.0 per cent, production will increase by 170 per cent (to 2.7-

times current production levels).[14] Petroleum reserves (crude oil, condensate and LPG) will be exhausted by 2050.[15]

Overall, output of the coal, oil and gas extraction sector is expected to contract at an average annual rate of 1.0 per cent between now and 2050.[16] A number of mineral commodities will be in greater demand in a low-carbon world. A boom in demand for non-ferrous metals, notably aluminium, magnesium and titanium, is expected to drive increased demand for bauxite, magnesite and titanium ores. Because these metals are expected to replace iron and steel, demand for iron ore and coking coal is expected to decline. Demand for other mineral products, such as copper, nickel, zinc and gold is expected to increase in line with historical trends. Overall, the mining of non-energy commodities is expected to grow at around the same rate as overall GDP.

Demand for uranium may also boom in a carbon-constrained world. For example, the IPCC's B1T-MESSAGE scenario suggests that nuclear energy may grow from around 8 EJ of primary energy consumption in 2000 to 48 EJ in 2050. Accordingly, Australia's uranium industry may expand rapidly, although it is not expected to become a major mineral export.[17]

Ownership of dwellings

Between now and 2050, housing prices and rents are expected to grow in line with GDP, maintaining this sector's contribution to value-added.

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[14] Consistent with a halving of domestic demand and a septupling of exports compared to 1998-99 (Dickson *et al.* 2001, p. 65). Economic, sub-economic and predicted undiscovered natural gas reserves in 2000 were around 166 EJ (Fainstein *et al.* 2002, Table 1), while coal seam methane reserves were estimated to be at least 250 EJ (Fainstein *et al.* 2002, Table 3). Natural gas production in 1998-99 was 1,300 PJ (Dickson *et al.* 2001, p. 65). Assuming coal seam methane can be exploited as readily as natural gas, a 2 per cent annual increase in production implies a resource life of around 100 years. If only natural gas reserves are considered, the resource life is 65 years.

[15] In 1996, identified petroleum reserves (both economic and sub-economic) were 762 GL (ABS 1998b, p. 63), or around 27 EJ. Domestic production of crude oil and petroleum products in 1998-99 was 1,135.7 PJ and consumption was 1,691.2 PJ (Dickson *et al.* 2001, p. 65). Accordingly, at current production levels identified reserves will be exhausted in 20-25 years. Undiscovered resources are estimated to be a further 570 GL, which will last another 15 or so years at current production levels (ABS 1998b, pp. 69-70). However, even under the 'deep cuts' scenario discussed in this paper, it is likely that domestic demand for petroleum will increase before efficiency and fuel switching in the transport sector start to bite (see Part II, Section 11). Assuming Australia attempts to maintain current levels of petroleum self-sufficiency by increasing production, reserves will be used faster initially. It may be 2020-2025 before demand (and production) peaks, and another 10 years before it returns to current levels (although it drops rapidly after this – see discussion of vehicle technologies in Part II, Section 11). Accordingly, by 2050 it is likely that all of Australia's petroleum resources will be depleted unless more petroleum is imported between now and 2050.

[16] This masks the actual path and sub-sectoral trends. For example, Australian coal production is expected to roughly mirror global coal demand as presented in Figure 1 – increasing slightly before plateauing between 2010 and 2020, after which demand will decline to around half 2000 levels by 2050. Domestic oil production is discussed in footnote 15. Natural gas consumption is expected to grow strongly throughout the period, although initially at a higher rate as countries shift from more greenhouse gas intensive fossil fuels to gas. However, towards the end of the period a shift directly to renewable energy sources will diminish the rate of uptake of natural gas.

[17] Exports of uranium in 2000-01 accounted for less than 1 per cent of Australia's mineral exports by value (ABARE 2001, p. 5). A 6-10-fold increase in uranium output over the next 50 years would increase this to 3.5-6 per cent (after taking into account overall growth in the minerals industry).

3.3 Trade

Table 4 lists Australia's exports in 2000-01 and indicates the expected strength and direction of change to 2050. In this study it is assumed that the share of trade in GDP remains the same in 2050 as it is at present (around 20 per cent) although, as indicated above, sectoral shares will change significantly. In brief, exports of gas, light metals and services are expected to grow more rapidly and exports of iron ore and wheat to grow more slowly, while exports of coal and petroleum will decline. Changes in terms of trade will be an important influence on the value (and volume) of exports, but this pilot study does not attempt to estimate changes in world prices.

Table 4 Exports of major commodities, 2000-01 and projected change

Commodity	**Exports** $ million	**Change to 2050**
Coal, coke and briquettes	10,844	↓↓
Petroleum, petroleum products and related products	10,858	↓↓↓↓
Gas, natural and manufactured	3,504	↑↑↑↑
Iron ore	4,912	↑
Other mining	5,552	↑↑
Total mining	*35,670*	
Aluminium and alumina	9,129	↑↑↑
Gold	5,110	↑↑
Copper, zinc and nickel	2,521	↑↑
Other metals (incl. iron and steel)	3,237	↑↑
Total metal production	*19,997*	↑↑
Wheat	4,146	↑
Beef	4,108	↑↑
Other agricultural products, food, beverages and tobacco	17,432	↑↑
Total agriculture, forestry, fisheries and food	*25,686*	↑↑
Machinery, equipment and miscellaneous manufacturing	17,920	↑↑
Chemicals	5,213	↑↑
Other manufacturing	9,527	↑↑
Total manufacturing (excl. metal production)	*32,660*	↑↑
Confidential and not classified	*5,526*	
Total goods	**119,539**	↑↑
Freight services	1,038	↑↑
Other transportation services	7,024	↑↑↑
Travel services	15,366	↑↑↑
Other services	9,425	↑↑↑↑
Total services	**32,853**	↑↑↑
Total export of goods and services	**152,392**	↑↑

Note, arrow symbols represent the following changes in absolute exports:

↓	– 0-25 per cent decline	↑	– 0-100 per cent increase
↓↓	– 25-50 per cent decline	↑↑	– 100-200 per cent increase
↓↓↓	– 50-75 per cent decline	↑↑↑	– 200-300 per cent increase
↓↓↓↓	– 75-100 per cent decline	↑↑↑↑	– 300 per cent plus increase

Source: ABS 2001; ABS 2002a; ABS 2002b

4. Future energy costs

As discussed in Section 2, in this study it is assumed that unit costs for energy in Australia in 2050 can be no greater than the current costs in Western Europe. Table 5 shows estimates of unit costs for various energy technologies in the UK for the year 2020 and an indication of subsequent direction of costs. They are drawn from the UK Government's Performance and Innovation Unit study (Cabinet Office 2002). The cost projections are based in some cases on engineering assessments and in others on assessments of market growth rates and the impact of learning-by-doing.

Note that remote sources of energy (such as wind and tidal) must compete against wholesale electricity prices – currently around 2 p/kWh – while 'deeply embedded sources' (such as building-integrated photovoltaics (PV)) compete against a retail price that is currently around 5-7 p/kWh for commercial and residential customers.

With the exception of PV, by 2020 a range of renewable energy and efficient gas electricity generation technologies are expected to achieve generation costs close to the current UK electricity prices, with some expected to fall below this level by 2050. The cost of PV in 2020 is expected to be about twice the current retail price of conventional electricity. Although the cost of generation from PV is expected to experience a sustained decrease thereafter, particularly in countries receiving large amounts of solar radiation (Cabinet Office 2002, p. 101), its high capital cost and low capacity factor are expected to limit its competitiveness outside certain niche markets (although some of these may be significant, such as supplying summer peak demand).

Table 5 Estimated costs and cost trends of various energy technologies (UK pence/kWh)

Technology	Cost in 2020 (p/kWh)	Cost trends to 2050
Fuel cells and hydrogen production	Unclear	Decrease but variable
Large CHP[1]	< 2	Limited decrease
Micro CHP	2.5-3.5	Sustained decrease
Photovoltaics	10-16	Sustained decrease
Solar thermal	Not estimated	Not estimated
Onshore wind	1.5-2.5	Limited decrease
Offshore wind	2.0-3.0	Decrease
Energy crops	2.5-4.0	Decrease
CCGT[2]	2.0-2.3	Limited decrease

1. Combined heat and power (cogeneration).
2. Combined cycle gas turbine generation.
Source: Cabinet Office 2002, Annex 6

In short, with the possible exception of PV and fuel cells, all of the other technologies are likely to meet the cost test of this study as long as the expected unit costs reported for the UK are applicable in Australia. The latter is expected to hold in the case of CHP, CCGT and wind turbines. The cost of energy crops is likely to be lower in Australia. PV may well be competitive in certain niche markets, such as moderating summer peak electricity demand. Solar thermal technologies, both electric and direct heating, were not discussed in the UK Government's study (Cabinet Office 2002). However, solar thermal technologies for water heating are already competitive even in small applications, whilst solar thermal electric generation is still maturing (although electricity production costs are substantially lower than PV).

5. Results and technologies in 2050

In developing the greenhouse gas emissions scenario discussed in this report, it has been assumed that market forces and government policies encourage firms and households to adopt cost-effective energy efficiency and greenhouse-reducing technologies. Accordingly, it should be emphasised that this study is assessing the technical and economic feasibility of achieving deep cuts rather than the political feasibility (which is irrelevant if achieving deep cuts is technically infeasible or excessively costly).

This section provides an overview of the results of the analysis for each sector and for the energy economy overall. The technologies used and the factors contributing to changes in projected greenhouse gas emissions in each of the broad sectors in the year 2050 are outlined. Detailed discussion of changes in technologies and the implications for energy use and greenhouse gas emissions are reported in Part II of this report.

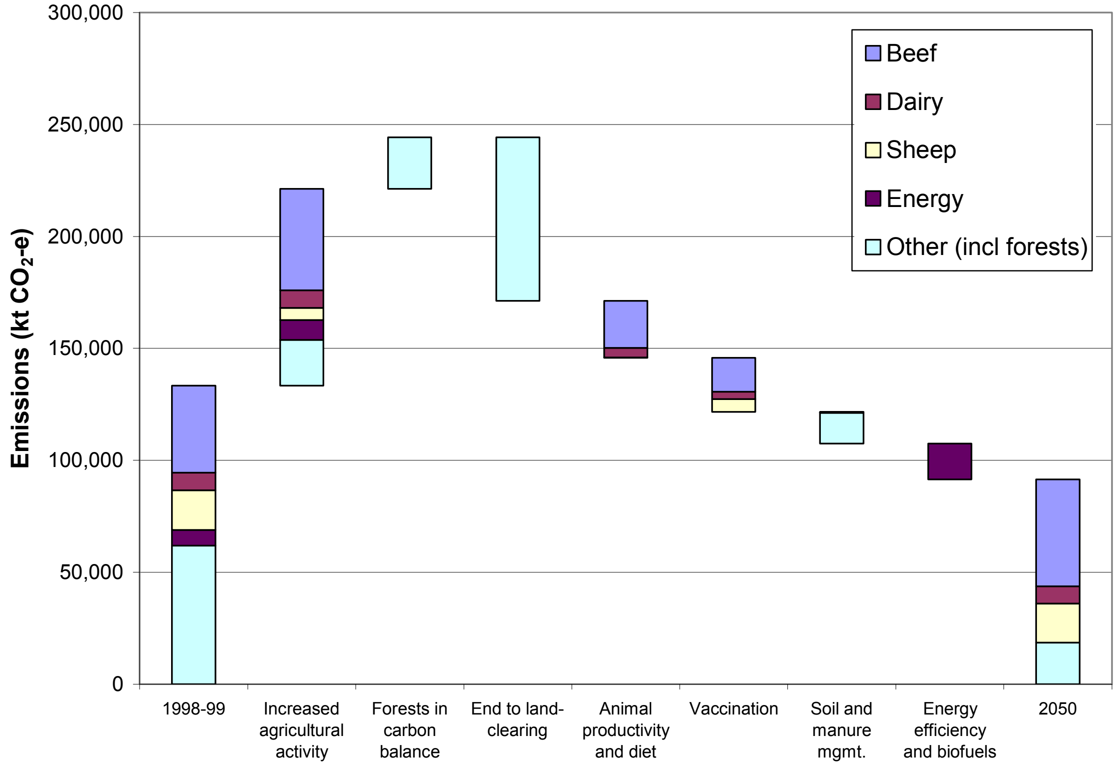
5.1 Agriculture, land use and forestry

Expansion of the beef cattle industry (driven largely by increasing incomes in Asia), along with steady growth in output of other agricultural products, will work to increase greenhouse gas emissions from agriculture. However, the following developments by 2050 are expected to offset somewhat the increases in agricultural emissions: the development and use of methanogen vaccines (for sheep and cattle); improved diets and a shift to feedlots for cattle; improved dairy and beef cattle breeds (increasing output per animal); the use of improved crop strains; the application of minimum tillage and other improved cropping practices; the use of manure and agricultural wastes for energy; and the use of better fertilisers. An end to land-clearing and field burning of agricultural residues will also contribute to reducing emissions below business-as-usual levels.

The influence of these various factors is summarised in Figure 7, which should be understood as follows. The '1998-99' column on the left-hand side of this figure presents emissions (by source) in that year, and each subsequent column shows the impact of various factors on each source between 1998-99 and 2050. For example, the second column 'Increased agricultural activity' shows how much emissions would be expected to increase as a result of increased agricultural production alone with no other factors offsetting this increase. The final column (labelled '2050') shows the level and source of emissions in 2050 after each of the impacts indicated is accounted for.

It is apparent that an end to land clearing will be the biggest offsetting factor, but a range of other management activities will, taken together, also have a major impact. By 2050, emissions from beef cattle will alone be responsible for over half of the emissions from agriculture, forestry and land-use change.

Figure 7 Factors driving emissions in agriculture, forestry and land-use change, 1998-99 to 2050



5.2 Industrial sector

Growth in chemical, non-ferrous metal, wood and paper and other product manufacturing will drive a large part of future energy demand in the industrial sector.[18] A contraction in coal, oil and gas extraction and petroleum and coal product manufacturing will offset some growth in energy demand. However, the largest offset will come from the turnover of existing manufacturing plant and the application of new energy efficient technologies and changed production processes (including changes to product mix). Fuel-switching to gas and biomass fuels where possible and a shift to cogeneration will further reduce demand for fossil fuels. The technological improvements are discussed in detail in Part II.

Figure 8 shows the main drivers of emissions growth and abatement between now and 2050. It can be seen that emission reductions derive predominantly from energy efficiency measures but with direct fuel switching and a shift to renewable electricity also playing important roles.

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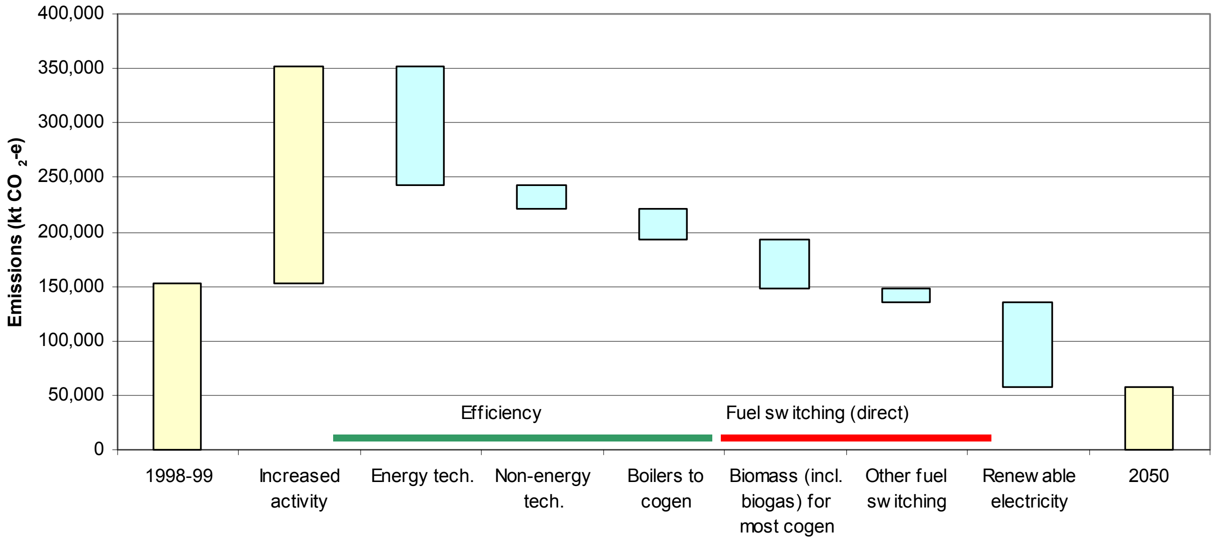
[18] These industries are expected to grow at the rates listed in Table A1 in the Appendix. It should be noted that some industries may undergo major structural change in the next 50 years, some of which is not anticipated in this study. For example, Australia's relatively small chemicals industry may well be internationally uncompetitive and may therefore disappear. However, other changes to the petroleum-chemical industry are anticipated and discussed elsewhere in this report (see Part II, Section 14).

Figure 8 Factors affecting emissions growth in the industrial sector, 1998-99 to 2050

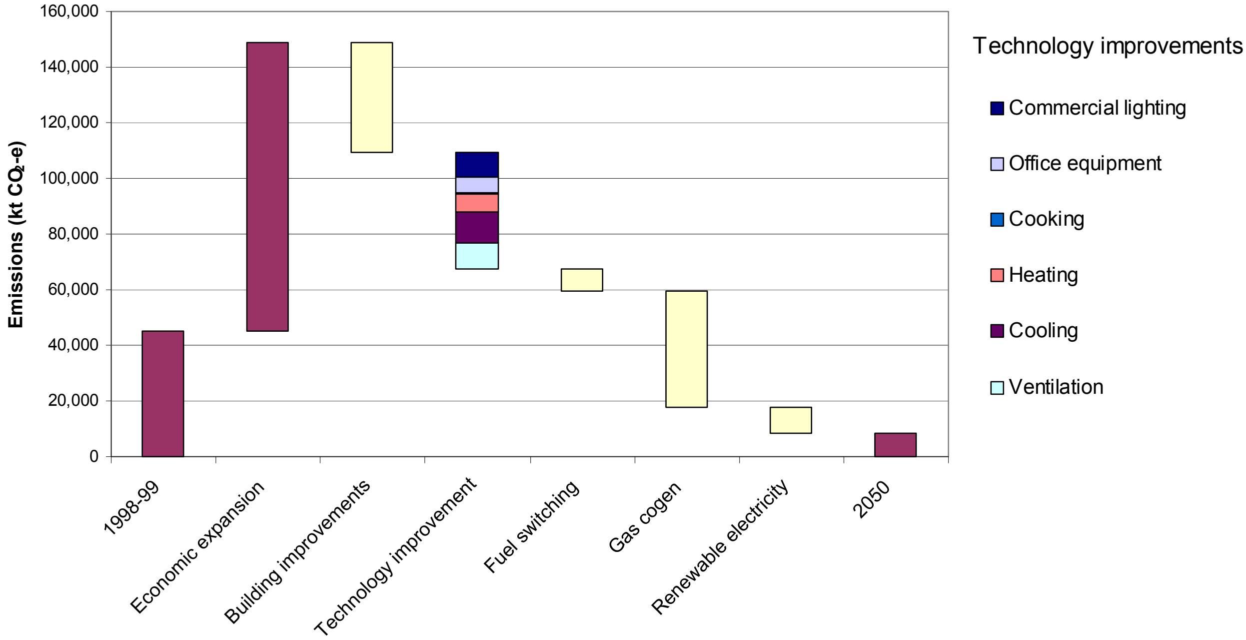


5.3 Commercial sector

Increasing demand for energy services (heating, lighting, office equipment) in the commercial and services sector will be driven by a trebling of its economic size. However, improvements in energy service technologies and improved building design (including materials, orientation and solar control) can potentially meet demand for energy services with substantially less energy. The main technological improvements are: large-scale uptake of cogeneration; the use of more efficient heating equipment (such as heat pumps); improved air conditioners and the use of absorption chillers; optimisation of control systems for heating, ventilation and cooling; improvements in efficiency of compressors, pumps and motors; more efficient office equipment; high efficiency ballasts, luminaires and reflectors (and lighting control systems); and improved building management.

The impact of economic growth and each of these technologies is illustrated in Figure 9. Growth in emissions from energy use is offset mainly by improvements in buildings, improved equipment and a switch to gas cogeneration for heating.

Figure 9 Factors affecting emissions from the commercial sector, 1998-99 to 2050

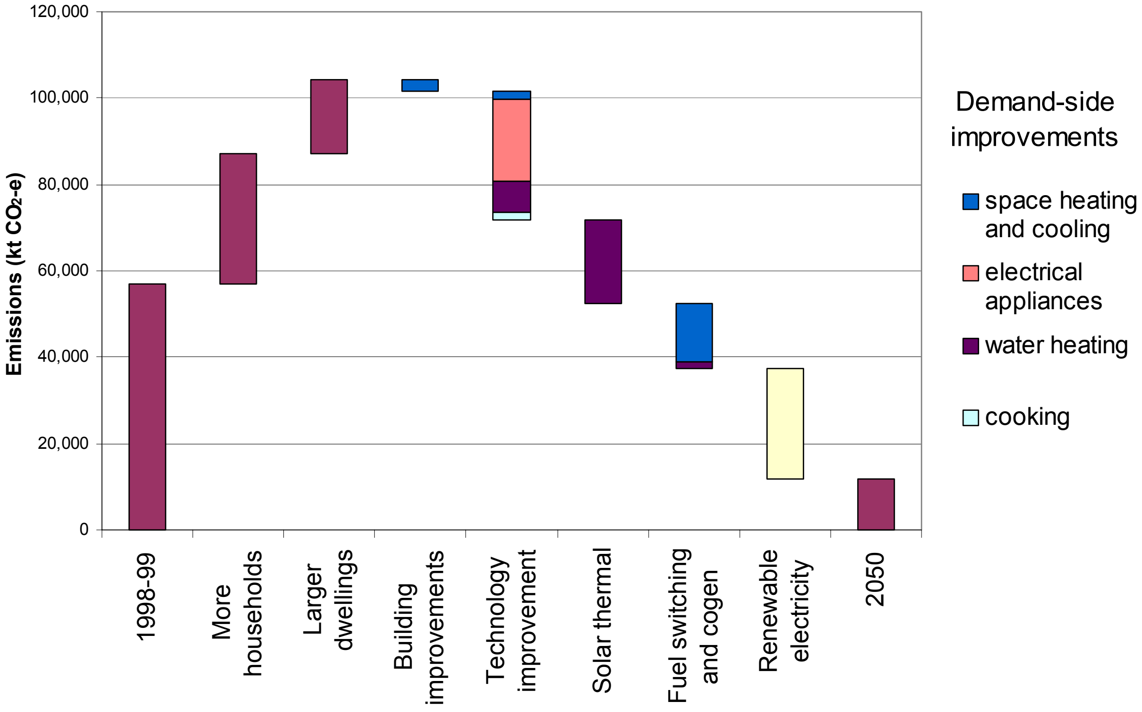


5.4 Residential sector

Total energy consumption in the residential sector in 2050 will depend on the total floor space of dwellings (itself a function of population growth, household size and changing average dwelling size) along with improvements in the overall energy efficiency of dwelling buildings and the improved efficiency of appliances and equipment. As discussed in Section 3, Australia's population is expected to increase by 32 per cent between 1998-99 and 2050, while the number of households will increase by 54 per cent (driven by a decrease in household size). Increasing affluence, offset somewhat by an increase in the share of apartments and townhouses (in total dwellings), will drive an increase in average dwelling floor area of around 20 per cent, resulting in an increase in total residential floor area of over 85 per cent.

However, energy demand will not increase in parallel with floor area because of expected improvements in building design, including improved orientation and shading, appropriate placement of windows and the use of ceiling and wall insulation (assumed to increase efficiency of space heating and cooling by 35 per cent). Energy use will be further reduced by the uptake of solar thermal water heating and gas-fired cogeneration (either fuel cell or microturbine) for electricity generation and space and water heating. In addition, it is expected that uptake of high-efficiency air-conditioners, more efficient refrigerators and freezers (i.e., with more insulation, more efficient compressors and better overall control systems) and a shift from electric resistance to gas cooking will drive further improvements in efficiency. Figure 10 illustrates the impact of the various efficiency measures and how these offset demographic factors.

Figure 10 Factors affecting residential sector emissions, 1998-99 to 2050



5.5 Transport

Growth in demand for transport will be driven by increased economic activity, higher incomes and population growth. However, major technology improvements are expected in transport, and the relatively fast turnover of the vehicle fleet will facilitate a rapid uptake of these technologies. Adoption of hybrid vehicles is projected to saturate well before 2050, dramatically cutting fuel consumption in road vehicles. In addition, lighter materials, improved aerodynamics and less rolling resistance will further improve the efficiency of all vehicles, while increased average load weight and improved logistics will drive heavy vehicle efficiency improvements. Fuel cell technology is assumed to have achieved 50 per cent penetration of the road transport market by 2050, enabling a similar proportion of transport fuel to be sourced from renewable electricity (used to produce hydrogen).

A substantial increase in public transport patronage will have a small but noticeable impact on overall emissions. Improvements in rail operations and efficiency is expected to result in a shift of some freight from road to rail, while very fast train (VFT) technology will be deployed along the Adelaide-Melbourne-Canberra-Sydney-Coolangatta-Brisbane corridor before 2050, limiting growth in air travel. Improvements in marine, air and rail efficiency, combined with electrification of the entire rail system will reduce energy use further.

Liquid biofuels have the potential to replace petroleum fuels in most transport applications (and in other applications, such as operating agricultural and construction equipment). However, there may be limits on the use of biofuels in air transport, particularly international travel where planes must be able to operate on the fuels available in destination countries.

Figure 11 and Figure 12 show the impacts on emissions from cars and freight transport, respectively, prior to the substitution of petroleum fuels by liquid biofuels. While in the case of cars the principal factors reducing emissions are the uniform adoption of hybrid engines and fuel efficiency measures associated with design, emissions from freight are brought down by several factors in combination.

Figure 11 Factors affecting emissions from cars, 1998-99 to 2050

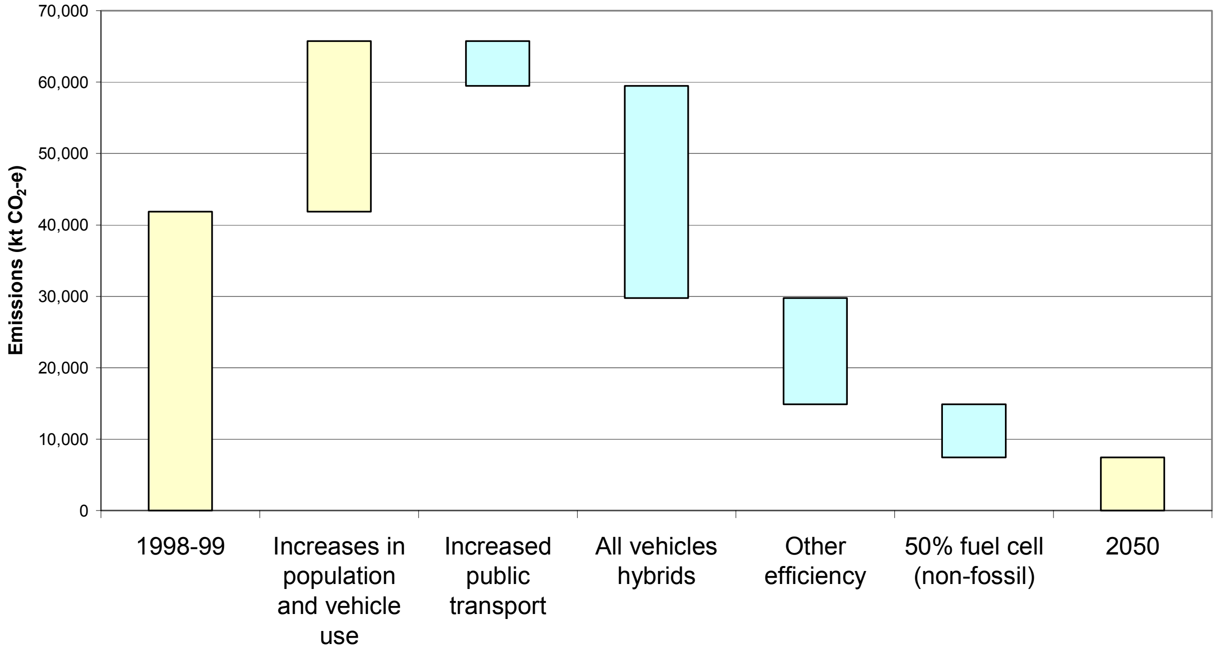
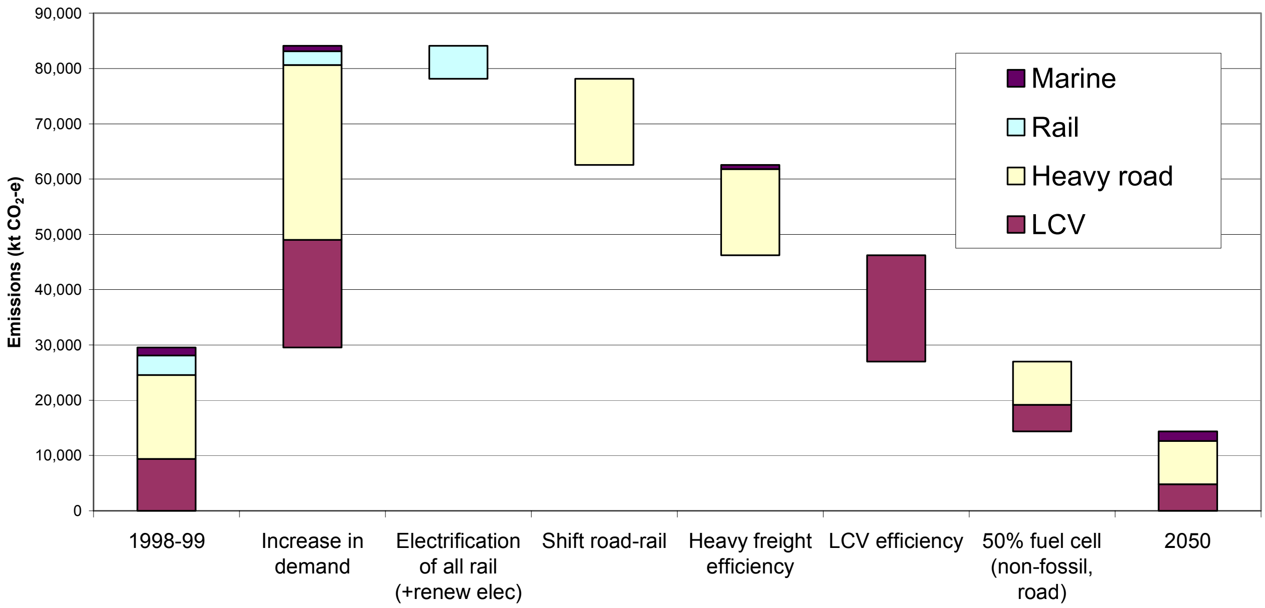


Figure 12 Factors affecting emissions from freight transport, 1998-99 to 2050



5.6 Waste and fugitive emissions

Emissions from waste make a small but significant contribution to Australia's emissions. By 2050, emissions from solid waste will be reduced by additional capture and flaring of waste methane, improved waste recovery, a high uptake of waste-to-energy technologies and high waste diversion rates. For waste water, emissions will be driven down by methane capture and utilisation, a shift to aerobic digestion and expansion of sewerage systems.

Fugitive emissions in 2050 are related to the future domestic production of fossil fuels. Declining domestic and world demand, particularly for coal, is expected to flow through to domestic production and reduce fugitive emissions from coal mining. However, gas production is projected to increase strongly to meet demand for less emission-intensive fuels. Improvements in and utilisation of reinjection technology (geosequestration) and waste gas capture, combined with reduced flaring and gas distribution system re-lining are expected to reduce fugitive emissions from both coal mining and oil and gas production.

5.7 Energy supply

To achieve a 60 per cent reduction in Australia's greenhouse gas emissions by 2050 it will be necessary for the stationary energy sector to undergo a major transformation. There will be a shift away from large-scale thermal generators isolated from load centres, and towards distributed cogeneration, meeting both electricity and heat needs at load centres. An expansion in wind generation, underpinned by decreasing costs, is expected to supply a large part of the remaining future electricity demand. In addition, solar photovoltaics will supply certain significant niches, and hydroelectric generation will continue to play a major role in baseload generation and ensuring electricity market stability. Current and projected primary energy supply and final energy consumption are presented in Figure 13.

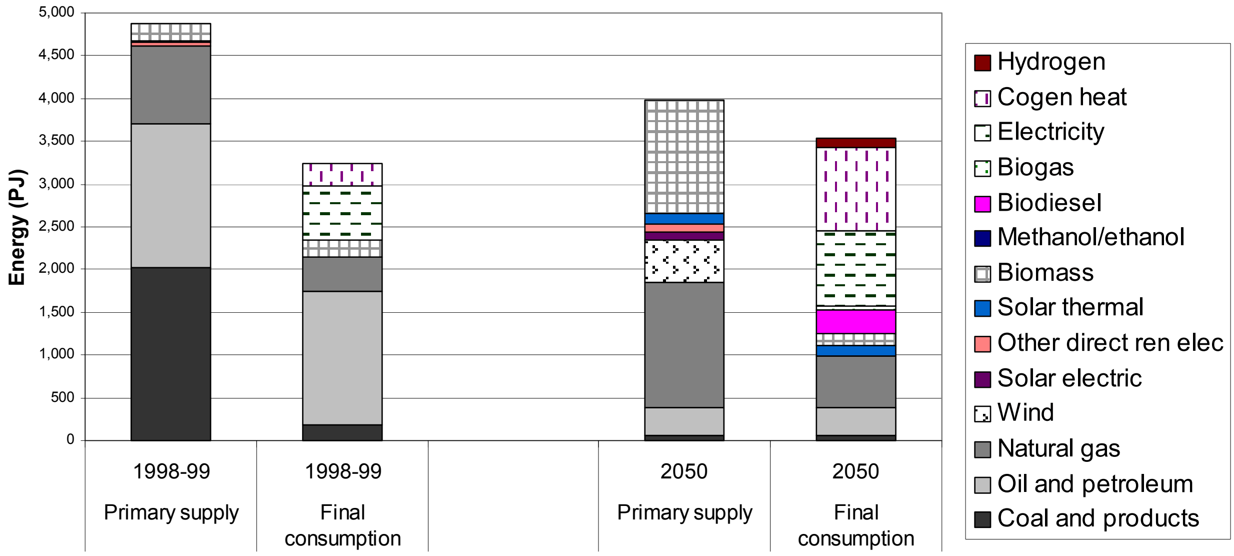
Thermal electricity

It is expected that there will be no large-scale fossil-fired generators located away from heat load centres in 2050, and all remaining fossil-only generation will be used for both heat and power. However, there may be some biomass-fired electricity-only generation (which is conservatively assumed to achieve combustion efficiencies of 35 per cent in 2050).

Improved cogeneration technologies are expected to enhance the overall efficiency of combustion, allowing the capture of close to 90 per cent of energy. However, it is conservatively assumed that gas-fired cogeneration for electricity achieves thermal efficiencies of 36 per cent (which is not substantially different from current open-cycle efficiencies). Biomass cogeneration boilers are assumed to contribute a much larger steam load (with less than 20 per cent of energy converted to electricity), mainly because it is expected that not all industrial boilers will be amenable to conversion to cogeneration. A large amount of fuel for cogeneration will be supplied from gas produced by biomass gasification.

Distributed cogeneration (in the manufacturing, commercial and residential sectors) will supply around one-third of electricity needs.

Figure 13 Primary energy supply and final energy consumption, 1998-99 and 2050



Wind energy

Average installed wind turbine size is assumed to increase significantly, from 500-800 kW in 1998 (AusWEA 2001, Table 4-2), to over 4 MW in 2050. This increase in size will also drive down costs per MW. Improved siting, design and engineering are expected to achieve average capacity factors of 35 per cent across all installed turbines in 2050. Improvements in weather forecasting are expected to improve electricity market certainty over wind power dispatch.

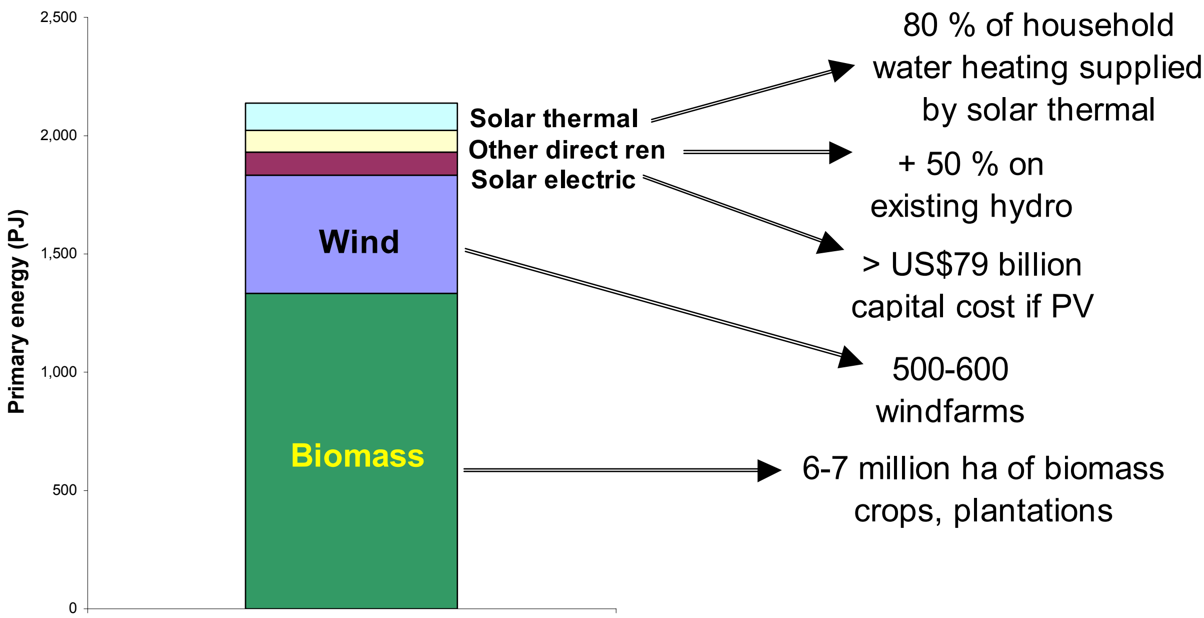
Solar PV and solar thermal

The high capital cost and low capacity factors of solar PV (discussed in Section 4) are expected to prevent this technology from supplying all but small niche markets (such as remote locations and for attenuating summer peak demand). Solar thermal electricity generation is assumed to make a small but significant contribution, and combined with PV is expected to supply around 10 per cent of total electricity demand in 2050. Solar thermal technologies will also be used extensively for direct water and space heating applications, particularly in the residential sector.

Hydroelectricity

Large-scale hydroelectric plant will be one of the few flexibly dispatchable sources of generation in 2050, and will therefore play an important role in electricity market stability. It will probably be necessary for increased use of pumped storage to balance the generation profile with the load profile.

Figure 14 Renewable energy supply, 2050



The projected total renewable energy supply in 2050 is shown in Figure 14. This figure also indicates some of the implications for resource use of the expansion of renewable energy sources (which are discussed in more detail in Section 6).

Other transformation activities

Transport fuel production

The refining sector will mainly shift from processing crude oil into petroleum products to converting biomass into biogas[19] and liquid biofuels, and using electricity to electrolyse water to produce hydrogen for transport (hydrogen will also be purified from synthesis gas from biomass gasification). This shift will coincide with a regionalisation and decentralisation of the fuel production industry as it relocates and rescales operations to take advantage of cropping, waste and forestry fuel sources. Overall, the biomass industry will be substantial in 2050. These operations will produce sufficient biodiesel, hydrogen, petroleum and methanol/ethanol to meet all transport needs. Moreover, large amounts of biogas will be produced in the same facilities and fed into the reticulated gas network.

Coke ovens and blast furnaces

The metals industries in Australia will continue to rely on fossil fuels, although mostly natural gas, for metallurgical processes. For iron and steel, although a much larger share will be produced through direct reduction with natural gas, some will continue to be produced in blast furnaces, requiring continued consumption of coal.[20]

[19] This term is used throughout the paper to denote gas produced from the gasification of biomass.
[20] This is expected even with increased recycling.

Gas production and processing

Continuing domestic demand for gas (particularly for cogeneration) and an expansion of gas production for export are expected to require a small amount of energy (which is included in the industrial sector). However, biomass gasification will become a major source of gaseous fuels by 2050 and will replace natural gas in a number of applications.

5.8 Overview

Combining the sectors and abatement opportunities reviewed in Sections 5.1 to 5.6 with the energy sources and constraints discussed in Section 5.7 enables us to examine whether a major cut in emissions is feasible. This is examined in more detail in Part II of this paper. In general, the combination of technological improvements, changes in production, fuel switching and improved management practices discussed above and in Part II appear to allow a significant cut in total emissions by 2050.

Table 6 summarises the emissions from different sectors and shows that large-scale reductions are possible in all sectors, although abatement opportunities are greatest in energy-using sectors (where possibilities for fuel switching lie).

By contrast, there is limited scope to reduce emissions from the agricultural sector without major structural change (which is not proposed in this study). As a result of growth in beef cattle numbers, and emissions from enteric fermentation, achieving the overall abatement target of 60 per cent actually requires a reduction in emissions from fuel combustion of closer to 70 per cent. The proportional level of abatement is also slightly lower in the mining sector, where fugitive emissions are difficult to eliminate (without completely ceasing fossil fuel extraction).

Table 6 Current and projected emissions, 1998-99 and 2050

	Emissions 1998-99[a] (Mt CO_2-e)	Emissions 2050-51[a] (Mt CO_2-e)
Manufacturing	116.7	41.2
Mining	66.8	26.2
Commercial	44.9	8.2
Residential	57.1	11.6
Agriculture, land-use change and forestry	133.4	92.0
Construction and waste	19.5	3.9
Transport	78.2	23.4
Total[b]	516.6	206.6
		40%

a. Includes emissions from generating the electricity used by each sector.
b. Excluding emissions from international air and sea travel (which are not included in Australia's inventory) and emissions from savanna burning, which is assumed to merely change the timing of natural wildfires (based on NGGIC 1996, p. 17).

6. Constraints on renewable energy supply

This section briefly explores the implications of the large expansion in renewable resource exploitation necessary to achieve the energy supply mix shown in Figure 14 above. In conjunction with the large improvements in energy efficiency discussed in Section 5, the availability of large renewable energy resources is fundamental to the feasibility of achieving the deep cuts in emissions envisaged in this study, and it is possible that resource constraints may limit the expansion of some forms of renewable energy. For example, this study assumes that there will be no new large-scale dams because of the absence of suitable sites, although it will be possible to generate additional electricity from existing large-scale hydro and new mini- and micro-hydroelectric systems. Some of the other likely constraints are discussed below.

Wind. The constraint on wind is the availability of exploitable wind resources subject to social limits provided by the need to protect certain environmental values. Under the deep cuts scenario, wind supplies 50 per cent of gross electricity needs. Assuming the average capacity of installed turbines is 4 MW (around 100 per cent higher than the most advanced turbines in use today)[21] and the average site capacity factor is 35 per cent, Australia will need to have more than 11,000 turbines installed, or around 500-600 wind farms. If they were all located on the southern coast from Eden to Perth, this would mean one wind farm every 20-25 kilometres, although there are many good sites located inland and offshore.

One critical question is whether there are 500-600 suitable sites spread across the country, including on the coast, inland and off-shore. While Australia has extensive wind resources, in the absence of a national assessment of potential wind power sites and a strategy to facilitate planning and approval processes for appropriate sites, this question cannot be answered with any certainty.

Photovoltaics. PV generation is expected to remain one of the more expensive forms of renewable energy over the next couple of decades, and financial constraints are likely to ensure PV satisfies only a small share of projected electricity demand in 2050. The capital cost of supplying 10 per cent of electricity demand at current prices would be in the order of US$80 billion (based on a capital cost of US$5,000/kW). However, the UK Government has said that it expects the unit cost of PV to halve over the next two decades and to fall significantly thereafter (see discussion in Section 4). Even so, PV is expected to satisfy electricity demand only in certain niches. Solar thermal electric generation is expected to supply a much larger amount of energy.

Solar thermal. The residential sector is assumed to obtain 80 per cent of water heating energy needs from solar thermal technologies (and this is assumed to represent saturation of the residential market). Solar thermal water heating systems could also supply hot water in the commercial sector, although water heating represented less than 6 per cent of commercial sector energy consumption in 1990 (EMET and SOLARCH 2000, p. 5)[22] and so is assumed to make a negligible contribution. Similarly, solar thermal water heating is not expected to make a significant contribution to industrial sector energy requirements. Solar thermal

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[21] See http://www.vestas.com/produkter/v80/v80_UK.html.
[22] This 6 per cent includes energy used in cooking.

electric generation is not expected to face any practical physical constraints in Australia, so the main constraint will remain cost.

Biomass. The relevant constraint for biomass is the availability of suitable land, including fertility and climate. As shown in Figure 14, supplying the required energy from biomass would require the equivalent of 6-7 million ha of arable land.[23]

How much is this? In 1993-94, the total area of agricultural land in Victoria was 13 million ha, while the total area under crops in Australia was around 18 million ha (ABS 1996, Tables 2.10 and 2.18).[24] However, much of the required biomass would be supplied from forest plantations. Currently, plantations cover around 1.3 million ha (AGO 2001a, p. B-148) (with an increasing share of broad-leafed species) and the Federal Government's 2020 Vision strategy aims to expand this to 3 million ha by 2020 (CIE 1997). The strategy also notes that an additional 5 million ha of land is suitable for farm forestry (CIE 1997, Chart 2.1).[25] Further, Foran and Marden (1999, p. 82) estimate that there is 16 million ha of cropping and pasture land in statistical divisions currently, or predicted to be, affected by dryland salinity.

By 2050 it is expected that all of the 8 million ha identified as suitable for farm forestry will be forested and around 50 per cent of the annual biomass production of this estate will be used for energy (with the remainder used for wood and paper products). In addition, much greater utilisation of crop and food industry wastes (including bagasse) for energy can be expected. This leaves something in the order of 1-2 million ha of agricultural land to be converted to the production of energy crops. There are a number of issues that arise in relation to using such a large area of land for biomass production, including:

- the availability of suitable land, particularly the impact on other agricultural industries;
- the availability of other resource inputs, including water and fertilisers;
- the environmental implications of a large expansion of biomass production, processing and combustion;
- transport issues, including biomass collection and distribution; and
- the effects of climate change on plant productivity.

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[23] Based on an energy density of 20 GJ/t of dry biomass (ACRE 1999) and an average annual growth rate of 10 tonnes of dry biomass per hectare (Foran 2002), with improved management practices and faster-growing tree varieties expected to increase the current broadleaf plantation average of 8.65 t/ha/yr (AGO 2001a, p. B-149). Crops are expected to achieve a somewhat higher rate.
[24] The total area of agricultural establishments in 1993-94 was almost 470 million ha (ABS 1996, Table 2.10). However, much of this is marginal for grazing and is therefore unsuitable for establishing productive biomass plantations.
[25] Further opportunities exist where establishing plantations on degraded land will have multiple environmental, social and economic benefits. For example, it is estimated that 10 million ha may be affected by soil fertility decline and loss in the future (Foran and Mardon 1999, Table 2.1).

It is worth noting that although the total amount of energy obtained from biomass in 2050 is almost 6 times the current level, it is still only around 70 per cent of the amount used by Brazil today (IEA 2001a, p. II.63).

The feasibility of achieving a 70 per cent cut in emissions was also examined. Under this scenario, the quantity of biomass is around twice that required in the 60 per scenario (energy balance is presented in Table A2 in the Appendix). Consequently, around twice as much productive land is required for biomass production. This illustrates the difficulties of going beyond the 60 per cent cut examined in this paper.

7. Conclusions

This study has explored the implications of cutting Australia's greenhouse gas emissions by 60 per cent of 1998-99 levels. It might be thought that this is an unreasonable target to set for Australia, but it should be seen in the context of the emerging global debate on climate equity. Although the Kyoto Protocol represents an important first step towards reducing global emissions, there is gathering momentum for a longer-term approach known as contraction and convergence.[26] Convergence refers to the equalisation of per capita emissions of everyone in the world, and contraction refers to the reduction of global emissions so that over time they reach a 'safe' level.

Under one scheme, put forward by the Global Commons Institute, the per capita emissions of each country in the world would converge on a uniform level by 2030 and global emissions would continue to decline until they reach a safe sustainable level at the end of the 21st century (Meyer and Evans 2001).[27] To overcome the possibility that, once a per capita limit had been agreed, some countries may increase their total emissions with faster population growth, it has been proposed that the per capita levels be applied to the populations at a fixed date, and that the product of the two sets a limit to the absolute emissions for each country.

A move to global equity has important implications. A 60 per cent cut in Australia's total 1999 emissions by 2050 would see per capita emissions in Australia fall from their 1999 level of 27.9 to 11.2 t CO_2-e without any population change (Turton and Hamilton 2002). Assuming per capita levels were fixed at population levels in 1999, we note that a per capita entitlement of 11.2 t would represent an *increase* in emissions for the UK, Japan and France (up from 1999 levels of 10.8, 10.3 and 8.2 t, respectively). It would also mean a 45 per cent reduction for the USA (20.7 t) (for more detailed discussion of per capita emissions see Turton and Hamilton 2002). Of course, a per capita target of 11.2 t would represent a very large increase for developing countries such as China, with per capita emissions of around 3 t, and India, below 1 t from energy (IEA 2001b, pp. 51, 53).[28]

Understood this way, it is clear that requiring Australia to cut its emissions by 60 per cent by 2050 is not unreasonable.[29] A more likely global per capita target would be 4-5 t CO_2-e over the longer term, the level implied by the 60 per cent cut in emissions for the UK analysed by the Royal Commission for Environmental Pollution (see RCEP 2000, Table 4.1). This would imply a cut in Australia's emissions of around 85 per cent, or more precisely a cut in Australia's *entitlement* to emit by this amount.

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[26] Even national government delegates at international climate change policy negotiation sessions are accepting this position, as evidenced by the decision adopted at COP6bis in Bonn during 2001, which states that '…Parties included in Annex I shall implement domestic action in accordance with national circumstances and with a view to reducing emissions in a manner conducive to narrowing per capita differences between developed and developing country Parties while working towards achievement of the ultimate objective of the Convention.' (UNFCCC 2001, Decision 5/CP.6)

[27] See igc.topica.com

[28] At the other extreme, it would require an 87 per cent reduction for Qatar (IEA 2001b, p. 55).

[29] It should be noted, however, that the scenario discussed in this paper actually involves a 69 per cent cut in emissions from fuel combustion, and only a 43 per cent cut in emissions from other sources. The limited abatement opportunities in agriculture produce this result.

Permits to emit more than this level would need to be purchased on the world market from nations with per capita emissions below 4-5 t, including developing countries and industrialised countries which had aggressively pursued emission reductions.

Achieving emission cuts of this order will require major policy intervention (a subject not considered in this report). But once the appropriate long-term policies were put in place – and subsequently adjusted to reflect new information – the investment required from the private sector would begin to flow. Data on the expected costs of energy (see Section 4) suggest that the transition to a very low emission economy would not come at a large cost, particularly when increases in energy efficiency will offset increases in energy unit costs.

What can we conclude from this analysis? Using available technologies Australia could feasibly cut its greenhouse gas emissions by 60 per cent by 2050. However there are some significant trade-offs. Even allowing for very substantial progress in energy efficiency, supplying much of our energy needs from renewable sources will require intensive exploitation of Australia's wind resources and allocation of a substantial share of Australia's arable land to biomass crops and plantations.

If economic growth is faster than anticipated, or the technological changes expected do not allow such large reductions in energy use or such large reductions in emissions per unit of energy, what are the other possible paths by which Australia could cut emissions by 60 per cent? There are perhaps six possible solutions, each involving technological breakthroughs or social choices. Using guesswork, they are arranged below from most preferred to least preferred by the general community in Australia.

1. The emergence of a 'magic bullet' – a technology such as nuclear fusion, cheap PV or solar photolysis of water – that delivers abundant, low-cost, zero-emissions energy.

2. The development of cheap and effective technologies for carbon sequestration, especially geo-sequestration.

3. Purchasing permits abroad to sustain an emissions-intensive economic structure and lifestyle but at the cost of lower incomes.

4. Converting large swathes of agricultural land to the production of biomass for energy, at the expense of conventional agricultural industries.[30]

5. The development of several large nuclear power plants in Australia.

6. Accepting reduced personal consumption and hence major changes to lifestyles, including: restrictions on house design and use of household appliances; giving up personal mobility, including most tourism; and changes to diet.

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[30] Table A2 in the Appendix illustrates the requirement for massive amounts of biomass to achieve a 70 per cent cut in emissions. A similar situation would prevail under a 60 per cent reduction if economic growth is faster or the anticipated technological changes do not result in as large reductions in emissions.

This study of deep cuts illustrates the sorts of changes that will need to be made if Australia is to achieve the transition to a low-carbon future and thereby play a proper part in global efforts to minimise the risks of major climate change. Energy systems have great inertia and we will need several decades to achieve the changes required. It is a commonplace to criticise governments for their short time horizons, but if we are going to tackle the climate change problem there is no escaping the need for setting long-term targets and initiating early policy changes that will bring them about.

PART II DETAILED SECTORAL ANALYSIS

This section discusses in detail, sector-by-sector, the various assumptions about the uptake of new technologies and changes in other practices.

Contents

8. Industry **37**

8.1 Overview 37
8.2 Technical options to reduce energy use in the energy intensive industries 38
8.3 Technical options to reduce energy use in general industrial equipment 46
8.4 Other production and technology changes 49
8.5 Industrial sector energy use in 2050 50

9. Commercial and services sector **52**

10. Residential sector **56**

11. Transport **60**

11.1 Land transport technologies and fuels 60
11.2 Passenger transport 61
11.3 Freight transport 65
11.4 Summary 68

12. Agriculture **70**

12.1 Energy used in agriculture 70
12.2 Non-energy emissions 71
12.3 Land-use change and forestry 77

13. Waste and fugitive emissions **80**

13.1 Waste sector emissions 80
13.2 Fugitive sector emissions 82

14. Energy supply **86**

14.1 Stationary energy 86
14.2 Transport energy demand 90
14.3 Energy balance for 2050 92

References **94**

Appendix **102**

8. Industry

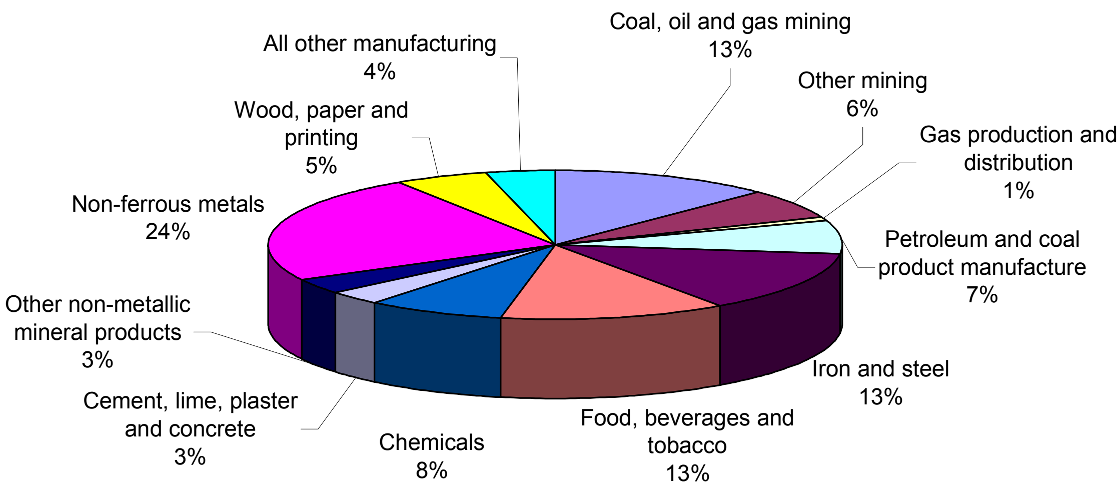
8.1 Overview

The manufacturing and mining sector is currently the largest user of energy in the Australian economy,[31] consuming over 1420 PJ in 1998-99[32] (AGO 2001a, pp. B-5, B-6; Dickson *et al.* 2001, p. 65; ABARE energy data). Figure 15 shows that non-ferrous metal production (24 per cent) and food, beverages and tobacco production (13 per cent) are among the largest individual users. Most of the energy consumed in the industrial sector is used in kilns and cogeneration boilers (see Figure 16), although if conversion losses are included, electric motors easily consume the most primary energy.

Manufacturing and mining are responsible for a large share of Australia's greenhouse gas emissions, directly and indirectly contributing around 184 Mt CO_2-e, or 35 per cent of total emissions[33] (AGO 2001a, pp. B-5, B-6, B-12, B-13, B-15, B-16). Around 95 per cent of these emissions arise from energy consumption and production.

As discussed in Section 3, between now and 2050 a variety of factors will influence activity within different industrial subsectors. Although the share of manufacturing in GDP is expected to decline as consumer preferences continue to shift to services, some industries will continue to grow strongly, including non-ferrous metals, chemicals and wood and paper products. This will alter the mix of equipment types and relative energy demands in 2050. Moreover, the energy efficiency improvements in different industrial processes and equipment types will vary widely, further altering

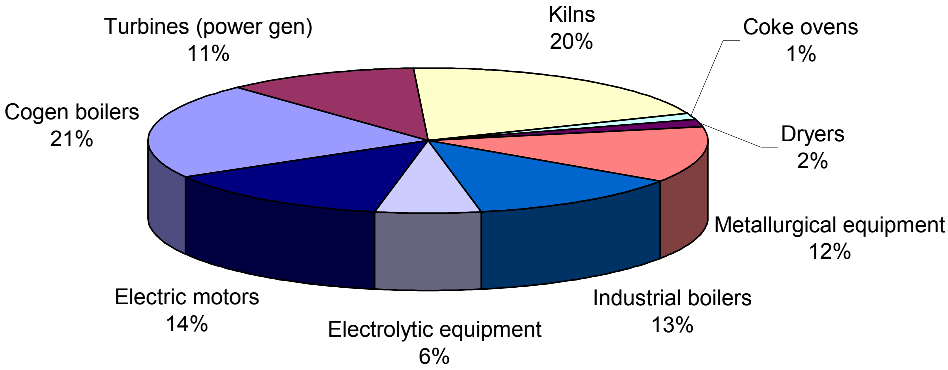
Figure 15 Shares of industrial energy end-use by sub-sector, 1998-99



Source: AGO 2001a, pp. B-5, B-6; Dickson *et al.* 2001, p. 65

[31] Electricity generation is a larger consumer of energy, but this is driven by demand for energy in other sectors.
[32] Excluding construction.
[33] Including land-use change.

Figure 16 Shares of industrial energy end-use by equipment type, 1998-99



Source: AGO 2001a, pp. B-5, B-6; ABARE energy data

the shares of industrial energy demand and greenhouse gas emissions in 2050. These energy efficiency improvements are discussed below, both in terms of process (for the energy-intensive industries[34]) and equipment.

8.2 Technical options to reduce energy use in the energy intensive industries

Iron and steel[35]

Several new steel making technologies are emerging and are likely to be adopted widely by the industry because they will lead to substantial cost reductions. The new technology will eliminate a number of existing process stages from conventional steel making and, in doing so, will reduce energy costs and lower energy intensity. It is expected that as existing plants reach the end of their natural life they will be replaced by new technology. In addition to the new production and process technologies, there are options to recover the heat and gas losses in the production.

Selected energy saving options

- Coke dry quenching: To recover the heat losses in coke-making to generate electricity.
- Pulverised coal injection (PCI) in blast furnaces: This is a technology for injecting coal directly into the blast furnace to reduce coke requirements that has become more widespread since the late 1980s. One tonne of PCI

[34] Namely, iron and steel, chemicals, cement, lime, plaster and concrete, non-ferrous metals and wood and paper products.
[35] More information on the options discussed below is available in Dickson *et al.* 2001; Batterham and Conochie 1992; DOE 1996; DOE 2002; IISI 1996; IISI 1998 and Stubbles 2000.

coal used for steel production displaces about 1.4 tonne of coking coal. Because the iron and steel industry in Australia is expected to use both blast furnace and direct reduction production methods in the future, this technology has some potential to achieve large reductions in energy consumption.

- Top gas recovery turbines (TRT): To recover the top gas from blast furnace to generate electricity.

- Basic oxygen furnace (BOF) gas/steam recovery systems: To recover the gas and steam from BOF and to realise a net negative energy use in BOF steel making process.

Emerging production technologies

- Direct reduction iron-making process: Directly reduced iron (DRI) production involves directly reducing iron ores to metallic iron without the need for smelting of raw materials in a blast furnace (which is the most energy-intensive process in iron production). In this process, reformed natural gas is used to convert iron ore into partially metallised iron granules. Direct reduction processes include Midrex, Hyl III, Circored/fer etc.

  Some DRI processes require the granules to be compressed into small briquettes (called hot briquetted iron or HBI) for use in electric arc or blast furnaces.[36]

- Thin slab and strip casting: These forms of casting replace the conventional hot rolling mill, thereby bypassing the reheating and roughing steps in the normal hot rolling mill production sequence. This produces a thin slab at lower cost with maximal use of the thermal energy of molten iron, while also minimising additional fuel and electricity use downstream.

- Smelting reduction iron making: The smelting reduction process eliminates both the coke oven and the sinter plant, and allows the use of cheap non-coking coals, thus reducing both operational and capital costs of iron making. Smelting reduction processes include COREX, DIOS and CCF, of which COREX is in commercial use.

- Advanced and high efficiency electricity generation technology: High efficiency electricity generation technology can be applied in the iron and steel industry, facilitating self-generation of some electricity needs. Combined cycle gas turbine (CCGT) is one of the promising technologies.

[36] This is the case of BHP Billiton's Port Hedland DRI facility in Western Australia (Dickson *et al.* 2001).

Overall improvement to 2050

Overall energy efficiency of the industry, through adoption of new technologies, can increase by 35 per cent (DOE 2002; IISI 1998). In addition, a shift to some of the newer processes discussed above is expected to improve overall efficiency by 70 per cent. Increased iron and steel recycling may also increase the overall energy efficiency.

Aluminium production[37]

Primary aluminium is produced by the Hall-Heroult process, the electrolysis of alumina dissolved in a molten cryolite-based electrolyte. Electric current is used to separate the alumina into aluminium and oxygen. Alumina itself is produced from bauxite ore feedstock in a thermal digestion process. Scrap pre-treating and melting to produce secondary aluminium takes place in fuel-fired (or occasionally electric) furnaces. Forming and casting processes use mainly electricity to drive casting machines, rolling mills and other forming and finishing equipment.

Refining

Alumina refining and primary aluminium production are energy intensive processes. Currently, energy consumption per tonne of alumina in Australia is 12,269 MJ/t, compared to world's best practice of 9,000 MJ/t achieved by the German company AOS[38] (DISR 2000). Major improvements in energy efficiency can be achieved by:

- minimising heat losses in digester process; and
- replacing rotary kilns with gas suspension calciners. This new technology has the potential to improve energy efficiency, including by recovering heat for use in other processes.

Smelting

Electricity intensity of electrolysis at present in Australia is 13-15 MWh/t of aluminium, over twice the absolute theoretical limit of 6.34 MWh/t. A realistic eco-technical potential is 10-11 MWh/t, which will require the use of new materials and improved pot design (DISR 2000).

Melting processes

Remelting aluminium for casting is also relatively energy intensive. Improving energy efficiency by recycling waste heat produced in gas-fired processes can be achieved in three basic ways: load recuperation; recuperative burners; and regenerative combustion (all of which are methods of re-using the waste heat in furnace exhaust gases).

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[37] More information on the options discussed below is available in CSIRO 1999; DOE 1996; DISR 2000; EIA 2001 and Martin *et al.* 2000a.
[38] Aluminium Oxid Stade GmbH.

Other emerging technologies

- Low-energy aluminium production: The CSIRO is investigating a carbothermic process as one alternative to the conventional electrolytic process for smelting aluminium. The carbothermic process would consume at least 10 per cent less energy per tonne of aluminium produced (CSIRO 1999).

- Advanced forming/Near net shape casting: Near net shape or thin strip casting is a new technology that integrates the casting and hot rolling of aluminum into one process step, thereby reducing the need to reheat the aluminum ingot before rolling it. Instead of casting slabs of a thickness of 120-300 mm, they are cast as thin as 1-10 mm.

  The energy consumption of a thin strip caster is significantly less than the current process, since the preheating requirements are eliminated. It is estimated that fuel savings of 0.5 GJ/t could be achieved for hot-rolled aluminum, with electricity savings of 20 kWh/t.

  Thin strip casting is also expected to improve the quality of the cast aluminum (surface quality, centre line segregation, geometrical tolerances) since thinner cast strips can be better controlled.

- Efficient cell retrofit designs: While a new generation of aluminum smelting technologies is being developed (see discussion of Inert Anodes in Section 8.4), there is also a series of retrofit technologies that could significantly improve cell operation and reduce electricity consumption.

  The US aluminum industry has a goal to reduce the energy intensity of aluminum production to 13 MWh/t in the near term by retrofitting existing pots with new technology.

- Improved recycling technologies: Several new technologies have emerged that help to improve the recovery or processing of scrap or reduce energy use in the preparing and melting of scrap. The New York State Energy Research and Development Authority, Energy Research Company (ERCo), Philip Services Co., and Stein Atkinson Stordy Ltd have developed a new decoating kiln (the IDEX™) that reduces kiln energy use by 41 per cent while also improving product quality and increasing metal yield by 1 per cent.

  Other new melt designs include a universal melting plant (Nottingham Metal Recyclers) that pre-heats and decoats the scrap in a dry hearth furnace before melting the scrap in a closed well furnace. This technology achieves a 25 per cent reduction in energy consumption and a 2-8 per cent increase in metal recovery compared to standard recycling technologies (Martin *et al.* 2000a).

  Importantly, increased recycling of aluminium reduces the need to smelt alumina, improving the energy efficiency in terms of overall output of aluminium.

Improvement to 2050

Overall, an average improvement in energy efficiency of 33 per cent is technically and economically achievable between now and 2050. This is based on an estimated improvement in energy efficiency of around 20 per cent in electrolysis, a slightly higher increase in efficiency in other processes and more effective recycling measures increasing the proportion of metal produced from scrap. This is broadly consistent with EIA (2001) estimates.

Cement manufacture[39]

A large proportion of the energy consumed by the cement industry is used to fire clinker kilns and grind clinker and other inputs to create cement. Over 90 per cent of the energy, usually coal or gas, is used to fire kilns to heat limestone in the calcination process. The remaining energy (less than 10 per cent) consumed by the industry is mostly electricity used to operate kilns, clinker grinding plant and other equipment.

Selected energy saving options

Energy efficiency improvement possibilities include:

- conversion from direct to indirect firing;
- improved recovery from coolers; and
- installation of roller presses, vertical mills and high efficiency separators.

By far the largest proportion of energy consumed in cement manufacture consists of fuel that is used to heat the kiln. Therefore the greatest gain in reducing energy input may come from improved fuel efficiency.

Further energy savings can be made by the greater use of extenders (potentially up to 65 per cent of content) such as fly ash, which offers additional environmental benefits because fly ash is currently viewed as a waste product.

Selected production technologies

- Alternative production processes: Another approach to improve energy efficiency is to shift to a different cement production technology. In general, the dry production process is far more energy efficient than the wet process, and the semi-wet process is somewhat more energy efficient than the semi-dry process. By 2050 it is likely that the Australian cement industry will rely entirely on the dry process.

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[39] More information on the options discussed below is available in Durine and Samarin 2001; EIA 2001; Hendriks et al. 1998; Sathaye and Meyers 1995; WEC 1995 and Worrell et al. 2000

- Conversion from dry to multi-stage pre-heater kiln: Introducing four or five stage preheating reduces heat losses and sometimes reduces pressure drop in the kiln. Application of this technology can reduce average energy use from 3.9 to 3.4 GJ/t.

- Conversion from dry to pre-calciner kiln: This technology can increase production capacity and lower specific fuel consumption. It is estimated that energy consumption can be reduced by around 12 per cent (0.44 GJ/t) through the adoption of this technology.

- Fluidised bed kiln: Replacing rotary kilns with stationary kilns not only leads to lower capital costs, but also reduces fuel consumption and allows use of a wider variety of fuels. Fluidised bed kilns can cut energy use from 3.35 to 2.9 GJ/t clinker, while also lowering NO_x emissions (Hendriks *et al.* 1998).

- Product change – blended cements: The production of blended cements involves the inter-grinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, silica fume or volcanic ash) in various proportions. The use of blended cements is a particularly attractive efficiency option since the inter-grinding of clinker with other additives not only leads to a reduction in energy use (and carbon emissions) in clinker production, but also results in a concomitant reduction in CO_2 emissions in calcination.

- Product change – hydraulic cements: Shifting to production of new hydraulic cements (i.e. cements that set and harden under water, similar to Portland cement) dramatically reduces carbon emissions, by up to 90 per cent in some cases (Durine and Samarin 2001).

Improvement to 2050

Overall, a feasible combination of the above measures is estimated to improve cement industry energy efficiency by 45 per cent[40] between 1999 and 2050. This can be achieved by increasing the product yield, recovering energy used in production, changing the product structure and adopting new process technologies.

Pulp and paper industry[41]

The pulp and paper industry uses large amounts of thermal energy (in the form of steam) and mechanical energy (converted from electricity). The thermal energy accounts for about 70-80 per cent of the total primary energy use in the industry, and is mainly used in pulping and drying processes. The process steam can be generated from waste raw material, concentrated black liquor from the industry,

[40] This figure also takes into account the estimates of Sathaye and Meyers (1995) and the EIA (2001).
[41] More information on the options discussed below is available in Beer *et al.* 1998 and Martin *et al.* 2000b

and coal, oil and gas. A large proportion (around 40 per cent) of the electricity used in an integrated mill is required for the paper forming process.

Selected energy saving options

- Recycling: An increase in the percentage of waste-paper pulp by 10 per cent can save about 6.5 per cent of energy required for the pulping process.

- Recovery of chemicals: The amount of chemicals recovered in pulping process has a great effect on the overall specific energy consumption of the industry. The recovery of chemical products by advanced membrane processes, particularly using mineral membranes and ultrafiltration, can result in higher recovery rates and less pollution.

- Cogeneration: In addition to being the feedstock for pulp and paper production, biomass is a major energy resource for the industry. Black liquor and solid biomass residues (bark and log fuel) generated at the mill can be used for cogeneration. The industry also has access to residues from pulpwood harvesting, some of which can be removed from the forest on a sustainable basis. All black liquor and most mill residues are used at mill sites to fuel cogeneration systems, providing steam and electricity for on-site use.

Selected advanced technologies

Generally, energy-efficient technology options can be classified according to the stage in paper making or the type of pulping process to which they relate, including: raw material preparation; mechanical pulping; thermo-mechanical pulping; chemical pulping; chemical recovery; bleaching; papermaking; advanced pulping; and advanced papermaking.

More specifically, some options in the pulping stage include:

- Alcohol-based solvent pulping
- Black liquor gasifier and gas turbine generation technology

Energy efficiency technologies in the paper-making stage are:

- Dry-sheet forming
- Press drying
- Condensing belt drying
- Impulse drying
- Air impingement drying
- Steam impingement drying
- Airless drying

Long-term specific heat consumption can be reduced by 75-90 per cent compared to the current average by the use of a combination of new pressing and drying technologies and latent heat recovery (Beer *et al.* 1998).

Improvement to 2050

To sum up, there is a wide range of technical options to reduce energy use and hence greenhouse gas emissions in the pulp and paper industry. The feasible potential of energy efficiency improvement based on the currently cost-effective technologies is estimated to be around 37 per cent.

The chemical industry[42]

The basic chemical industry can be broken down into the following main processes:

- steam cracking for the production of olefins, butadiene and benzene, toluene and xylene;
- separation of products/co-products by distillation, solvent extraction etc.;
- co-product processing, including catalytic dealkylation of toluene and isomerisation of xylenes; and
- steam reforming (primary and secondary) to produce syngas for ammonia and methanol production.

Heat is used in all the above processes, and motive power is normally provided by electricity, often generated on-site. Improvements in energy efficiency can be achieved through:

- production optimisation;
- optimising the efficiency of heat and power supply and use; and
- reducing the amount of wastes flared.

Selected energy efficient options

- Chemical synthesis: At the heart of the chemical industry is the synthesis of chemicals from other materials. Catalysts can lower the energy requirements for chemical reactions, thereby making processes more energy efficient.

- Separation processes: Many chemical feedstocks, such as petroleum, need to be separated into their components to be useful. Likewise, many chemical reactions produce a mixture of products that must then be separated. In chemical manufacturing processes, separations account for 43 per cent of the energy consumed and up to 70 per cent of the capital costs. A variety of energy-efficient separation technologies are available, including membranes.

- Waste recovery: The recovery and reuse of liquid and solid waste streams can increase the energy efficiency of processes, reduce the use of raw

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[42] More information on the options discussed below is available in Gale and Freund 2001 and Radgen and Patel 2001

materials and minimise water usage while reducing or eliminating the need to dispose of the waste.

- Materials technology: Using advanced materials for chemical plant hardware can reduce waste, minimise maintenance and save energy.

- Computer technology: Advanced computer programs for modelling chemical behaviour can help optimise chemical processes. Most critical for the chemical industry is better modelling of the performance of fluids, referred to as computational fluid dynamics.

Improvement to 2050

The overall energy efficiency improvement potential estimated and used in this study is 20 per cent. This figure is based on the consideration that all new facilities over the planned period will adopt currently available cost-effective energy efficiency options. Other factors will change the scale and location of chemical industry operations both in Australia and internationally: for example, declining domestic oil production, a shift to renewable feedstocks and an expansion of natural gas processing operations.

8.3 Technical options to reduce energy use in general industrial equipment

Electric motors

Electric motors account for about 60-80 per cent of industrial electricity use. They are used primarily in pumps, fans, air compressors and for materials processing and handling. The options for improving electric motor energy efficiency are listed as follows.

- *Variable speed drive (VSD)*

A VSD consists of an electronic power converter that converts constant frequency alternating current (AC) power input into a variable frequency output. AC motor speed varies in proportion to the drive output frequency.

VSDs precisely control the electricity going to the motor. This saves energy by matching motor speed (and electricity consumption) to load, rather than allowing the motor to run at constant speed and then restricting the load itself by means of throttling or bypassing the flow with valves and dampers.

Energy savings of up to 50 per cent can be achieved with VSDs installed on fan motors and up to 75 per cent on pumps (US estimate). In addition to energy savings, VSDs increase motor and system life and enable an unparalleled degree of control over the motor system. This is especially useful for motor systems dealing with fluids, allowing changes to be made to fit variable conditions faster and more efficiently.

- *High efficiency motors*

There is significant potential for productivity increases, reduced energy use (the most significant advantage) and environmental benefits with high efficiency motors. These improvements are achieved through a reduction of energy losses in motor operation, including: primary ohmic loss; iron loss; secondary ohmic loss; fraction and windage loss; and stray load loss (SEA 2002).

The net reduction in losses for the energy-efficient motor could be around 40 per cent compared with the standard machine (Jordan 1994). Similar improvements were observed in other studies, where new energy-efficient motors (in prototype testing) are expected to use 28-50 per cent less energy and have pay-back period of 1-3 years (CADDET 1995).

- *Motor system improvement*

Although individual motors can achieve efficiencies of near or above 90 per cent, the total system (including motor, shaft coupling, pump and throttle valve) may achieve an overall efficiency of 50 per cent or less. However, this can be improved substantially through the application of best practice. For example, the efficiency of industrial compressed air systems could be increased by 20-50 per cent through a combination of improved control and changes in operation and maintenance procedures (McKane 1999; Benders and Biesiot 1996). The potential for energy efficiency improvement is in the range of 56-87 per cent (Benders and Biesiot 1996).

According to Benders and Biesiot (1996), average energy-saving potentials of the motor system are 48-55 per cent for pumping systems and 30-57 per cent for ventilation systems.

Summary

The above improvements in energy efficiency achieved through the use of VSDs, high efficiency motors and improved system management are expected to deliver an average increase in electric motor system efficiency of 85 per cent by 2050 (which is equivalent to a 46 per cent decrease in energy intensity). Compared to the potential identified above, this is a feasible and readily achievable target.

High efficiency combustion

- *Regenerative combustion*

Regenerative combustion systems have built-in heat storage, with two separate lines for the flue gas and combustion air that burn alternatively to recover flue gas heat. These systems can increase overall thermal efficiency to 85 per cent, compared to the maximum of around 50 per cent in conventional systems (WEC 1998).

- *Oxygen-fuel combustion*

Oxygen-fuel combustion can produce temperatures of up to 3,000° C. This avoids the need for air pre-heating and reduces flue gas volume to 25 per cent compared to normal air firing. Heat lost in flue gases can be reduced by 75 per cent, meaning that thermal efficiency can be increased up to 50 per cent above that of air combustion. This is particularly relevant for high temperature processes where flue losses may be substantial.

- *Latent heat recovery*

A conventional boiler is designed to maintain the temperature of the flue gases at 150-200° C to prevent steam condensation that may lead to corrosion. Latent heat recovery boilers, using corrosion resistant materials, are designed to recover some of this wasted heat from flue gas, resulting in flue gas temperatures of less than 100° C. The latent heat recovery boiler has an efficiency about 15 per cent above that of conventional boilers.

Summary

The combination of high efficiency industrial boiler technology and improved combustion are conservatively assumed to increase the average efficiency of industrial boilers by 20 per cent between now and 2050. This is feasible and relatively conservative. It is also assumed that there is large scope to replace some industrial boilers with cogeneration boilers (discussed below)

Cogeneration

The on-site production of electricity is particularly attractive to industries that can also make use of the waste heat. Such combined heat and power (CHP) systems – also called cogeneration systems – achieve much higher thermal efficiencies than stand-alone power plants and avoid some of the heat losses associated with steam or hot water distribution. Cogeneration can be based around a gas turbine, internal combustion engine or steam turbine, depending on the specific situation, such as the quality and quantity of heat required by the industrial site.

Cogeneration (coal and gas), designed for power generation and heat supply, can achieve an energy efficiency of 70-85 per cent (30 per cent electricity and >50 per cent heat) (WEC 1998; OIT 1999), compared to the average 35 per cent efficiency of thermal generation.[43] Cogeneration plants can also be sized to produce the heat and electricity required for a single building, such as a hospital or hotel, or for a manufacturing process and can export excess electricity to the grid.

[43] Conventional centralised power systems in the USA average less than 33 per cent delivered efficiency for electricity (OIT 1999).

Summary

Cogeneration boiler efficiency will benefit from higher efficiency combustion, latent heat recovery (see above) and improvements in cogeneration system efficiency. Overall, cogeneration boiler based steam heating systems are assumed to become 40 per cent more efficient between now and 2050 (equivalent to a 29 per cent decrease in energy intensity). It is assumed that on average 20 per cent of cogeneration boiler fuel is converted into electricity.[44].

Heat pumps

A heat pump is the converse of a heat engine. It uses mechanical work to pump heat from a source at low temperature to a higher temperature. Heat pumps are useful where relatively low-grade heat is needed, at temperatures 10-20° C above that of the heat source, usually for space or water heating. In these circumstances the ratio of electric energy consumed by a heat pump to the useful heat delivered is typically 1:3 (with the potential for higher ratios). Heat pumps can be used in heat distribution networks or to supply heat to individual buildings. The heat source of heat pump can be a water stream (such as a river or municipal wastewater), air, groundwater or soil.

Summary

The use of heat pumps essentially involves the partial substitution of electricity for heating fuels such as natural gas. It can significantly reduce the total energy requirements for the process. Heat pumps are energy efficient and are capable of providing heating, cooling, and dehumidification in residential, commercial and industrial applications.

8.4 Other production and technology changes

Major reductions in greenhouse gas emissions are likely in non-ferrous metal production (particularly aluminium smelting). A shift from carbon-based anodes to inert anodes in smelter electrochemical pots will reduce production costs noticeably (DOE 1998), in addition to eliminating direct emissions of CO_2 (from anode oxidation) and perfluorocarbons. Alcoa already expects to convert significant test capacity to inert anodes by the end of 2002.[45]

Non-energy emissions from the non-metallic minerals industry, arising mainly in the production of cement and lime, are also likely to be reduced significantly. By 2050 it is assumed that CO_2 emissions from clinker and quicklime production can be captured and geosequestered.

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[44] Actual efficiencies will vary according to the heat needs of the specific site.

[45] See http://www.alcoa.com/global/investment/annual_report_2001/news/news_04.asp. See also Kvande and Haupin (2001) for a discussion of some of the technical issues associated with inert anodes.

Improvements in process efficiency and changes in output are expected to maintain other industrial process emissions at around 1998-99 levels (approximately 1 Mt CO_2-e).

8.5 Industrial sector energy use in 2050

Table 7 summarises projected industrial sector energy use, by sub-sector and fuel, for 2050 after taking into account the impact of economic growth and energy efficiency improvements. The use of cogeneration is discussed in more detail in Section 14. Figure 16 shows the impacts of the various factors on total emissions from the

Table 7 Industrial sector energy demand under deep cuts scenario, 2050

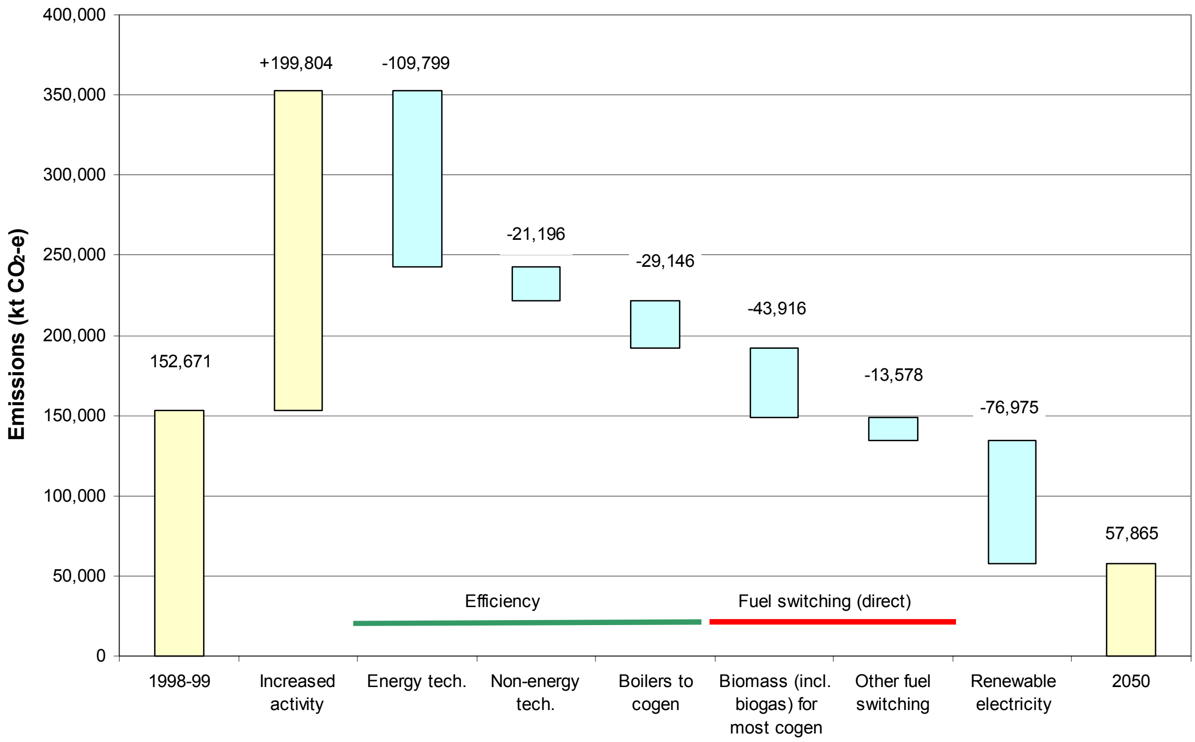
Industry sector	Coal and products (PJ)	Natural gas (PJ)	Biomass (PJ)	Biogas[a] (PJ)	Electricity[b] (PJ)	Cogen heat (PJ)	Total (PJ)
Coal, oil and gas		117.7	0.0		14.5	21.9	154.1
		(143.3)	(0.0)		(11.2)	(0.0)	(154.5)
Mining (non-energy)		51.5		3.1	88.4	9.2	152.2
		(51.5)		(13.9)	(87.0)	(0.0)	(152.4)
Gas production and distribution		30.5		0.0	0.3	0.0	30.8
		(30.5)		(0.0)	(0.3)	(0.0)	(30.8)
Petroleum and coal products		13.1		1.8	0.8	9.2	24.8
		(13.1)		(12.6)	-(0.7)	(0.0)	(25.0)
Iron and steel	58.7	67.5		1.2	7.8	25.1	160.3
	(58.7)	(67.5)		(31.7)	(2.5)	(0.0)	(160.5)
Food, beverages, tobacco		0.0	7.1		21.7	233.4	262.3
		(0.0)	(291.3)		-(27.5)	(0.0)	(263.8)
Chemicals		0.0	128.4		27.5	62.4	218.3
		(0.0)	(202.1)		(17.0)	(0.0)	(219.1)
Cement, lime, plaster and concrete		39.7		5.4	5.3	0.6	51.0
		(39.7)		(6.2)	(5.2)	(0.0)	(51.0)
Other non-metallic mineral products		41.1		5.6	6.0	1.6	54.3
		(41.1)		(7.5)	(5.7)	(0.0)	(54.4)
Non-ferrous metals		161.5		15.5	232.3	240.9	650.3
		(161.5)		(316.0)	(172.9)	(0.0)	(650.4)
Wood, paper and printing		0.0	6.2		29.7	113.7	149.5
		(0.0)	(141.9)		(8.9)	(0.0)	(150.8)
All other manufacturing		22.6		0.6	38.5	32.9	94.6
		(22.6)		(39.0)	(33.5)	(0.0)	(95.1)
Grand total	58.7	545.2	141.7	33.2	472.7	751.0	2002.6
	(58.7)	(570.8)	(635.3)	(426.9)	(316.1)	(0.0)	(2007.7)

Note: Figures in parentheses show gross energy demand, including demand for fuels used in cogeneration. Thus, the figures in parentheses under ‘Cogen heat’ are always zero, and the difference between the figure in parentheses and the figure above it is the amount of energy consumed and generated in cogeneration boilers. It should also be noted that the apparent high conversion efficiencies are artificial – they arise because it has been assumed that industries demand a total amount of heat (both useful and losses). Conversion of industrial boilers to cogeneration boilers (see Section 14) results in some additional small losses.

a. That is, gas produced from biomass gasification.

b. Negatives in the ‘Electricity’ column indicate that the subsector produces more electricity in cogeneration than it requires, and is therefore a net exporter.

Figure 17 Changes in industrial sector emissions under the deep cuts scenario, 1998-99 to 2050



industrial sector, including the impact of: economic expansion; the energy technologies discussed in Sections 8.2 an 8.3; the non-energy improvements, discussed in Section 8.4; and fuel switching and cogeneration (see Section 14).

Clearly, the largest decrease in emissions comes about through the uptake of the new technologies discussed in Sections 8.2 and 8.3 above. Much of this can be attributed to improved motor system, boiler and blast furnace efficiency. Switching to biomass fuels and to gas wherever biomass is inappropriate also has a substantial impact on emissions. However, even with major improvements in energy efficiency and fuel switching, it is clear that the availability of renewable electricity is essential for achieving substantial reductions in industry sector emissions in this scenario.

9. Commercial and services sector

In 1998-99, commercial and services sector energy consumption was 205 PJ, resulting in greenhouse gas emissions of around 45 Mt CO_2-e (derived from AGO 2001a, pp. B-5, B-8; Dickson *et al.* 2001, p. 65). Approximately 70 per cent of the energy used in the commercial sector is for heating, cooling and ventilation (based on EMET and SOLARCH 1999), and these contribute around 60 per cent of the greenhouse gas emissions from the sector.

Between now and 2050 a number of factors will affect energy consumption and greenhouse gas emissions in the commercial sector. Economic growth is expected to more than triple the output of the commercial and services sector (see Section 3), which will lead to a similar increase in energy demand in the absence of efficiency improvements.[46] On the other hand, a number of technical and design options can be pursued to reduce energy use.

Energy use can be effectively reduced through improvements in building design and construction, including walls, roofs, foundations, glazing and solar control (e.g. external shading and window system improvements to reduce heat gain in summer). The energy efficiency of a commercial building (excluding equipment), termed 'shell efficiency' can be improved by 45 per cent on average through improvements in design and construction, compared to the existing buildings (Tuluca 1997; DOE 2002). For example, with energy efficient design the Thurgoona campus (Albury) of Charles Sturt University consumes less than half the energy of the comparable building it replaced (CSIRO Built Environment 2000).

Using distributed generation technologies, particularly cogeneration, can improve the efficiency of energy (heat/electricity) supply in commercial buildings, especially in those where large amounts of heat are required (e.g. hospitals and hotels). The technology types include fuel cells, natural gas engines, oil-fired engines, natural gas turbines and natural gas micro-turbines. Distributed generation also has the advantage that electricity transmission and distribution losses are largely eliminated. Commercial buildings often have a suitable balance of energy demands – electricity is needed for operating office equipment, lighting and ventilation pumps, compressors and motors, while waste heat from cogeneration can be used for space and water heating and, in some cases, cooling (see discussion below).

Using more efficient heating equipment, such as improved heat pumps for space heating, could provide at least three times as much heat as an electric resistance heater. Various heat pump technologies can be used, including electric, ground-source and natural gas. In general, energy efficiency of space heating equipment can be improved by 60 per cent (DOE 1996; Benders and Biesiot 1996). Bouma (1996)

[46] An increase in economic activity in the services sector will only lead to an equivalent increase in energy demand under certain circumstances. Some services are substantially more energy intensive than others. For example, health and education services (requiring hospitals and schools) are probably more energy intensive (per dollar of output) than communication services. A larger increase in activity in the more energy-intensive sub-sectors will lead to a greater increase in overall energy demand in the services sector, and *vice versa*. However, based on the expected growth in different services sub-sectors (see Table A1 in the Appendix), it is reasonable to assume services sector energy consumption will increase in line with overall services sector output.

anticipated that in 2050 the energy efficiency of heat pump equipment could have roughly doubled for both residential and commercial applications. Heat pump technologies can also be applied to water heating. A US study shows on average 50 per cent of energy used in water heating can be saved through advanced and more efficient technologies (DOE 1996).

Using more efficient cooling equipment in air-conditioning installations can raise the efficiency of energy utilisation by 64 per cent (Deni Greene 1991). However, the most efficient way to cool large commercial operations may well be with absorption chillers powered by waste heat from cogeneration or solar heat. Cogeneration-chiller systems currently achieve an overall efficiency of 70 per cent (DOE 1995). In addition, between now and 2050 similar improvements in chiller and air system design are expected to deliver an improvement in efficiency similar to that anticipated for air-conditioners (64 per cent).[47]

Heating, ventilation and cooling (HVAC) control systems have the potential to achieve large energy efficiency improvements by optimising the operation of equipment throughout the year. By combining control systems with high efficiency motors and variable speed equipment, the efficiency of building ventilation systems can be improved by around 72 per cent (Watts 1997).

The amount of energy used for artificial lighting in commercial buildings can be reduced by using efficient compact fluorescent lights, installating day-lighting control systems to allow perimeter lighting to be switched off when daylight is sufficient,[48] and optimising the integration of lighting components and systems into the total building system. In addition, the installation of high frequency ballasts instead of core-coil ballasts and the addition of reflectors or high efficiency luminaries to standard fluorescent light fittings can greatly reduce energy use. These various measures can increase energy efficiency in commercial building lighting by 70 per cent (Watts 1997; Sathaye and Meyers 1995). Since artificial lighting systems generate substantial heat, improvements in efficiency will also reduce space cooling energy requirements.

The energy efficiency of office equipment, such as computers, printers, photocopiers and vending machines, will improve through the natural turnover and replacement of old equipment. Some new equipment is significantly more energy efficient. For example, the use of liquid crystal technology instead of cathode ray tubes in visual display units (VDUs) leads to improvements in energy efficiency of 60 per cent or more. Changes in computer technology and the move towards portable equipment will also reduce the electricity intensity of office equipment (EMET and SOLARCH 1999); on average, a 45 per cent gain in energy efficiency can be readily achieved. Increased use of microwave ovens in place of electric resistance, gas heating in stoves and ovens, and increasing the thermal efficiency of gas stoves and ovens can, on average, raise energy efficiency by 40 per cent.

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[47] It is expected that a large number of smaller-scale commercial operations will continue to rely on conventional electric air-conditioning in 2050. However, those located in areas of concentrated activity (central business district, shopping malls, concentrated shopping strips etc.) will have access to district-wide heating and cooling systems.

[48] Improved building design can improve access to natural lighting, further reducing artificial lighting power requirements.

The estimated overall improvements in average intensity (for equipment efficiency and improved building design) are shown in Table 8. Unlike residential buildings (discussed in the following section), there is a faster turnover of commercial buildings, meaning that many will be replaced (or undergo major renovations) between now and 2050. This results in slightly larger improvements in the average energy efficiency of the building stock compared to the residential sector. Table 8 also shows energy demand and energy supply in 2050 (although the latter is discussed in more detail in Section 14).

Figure 18 shows the impact of the various factors discussed above on greenhouse gas emissions in the commercial sector.

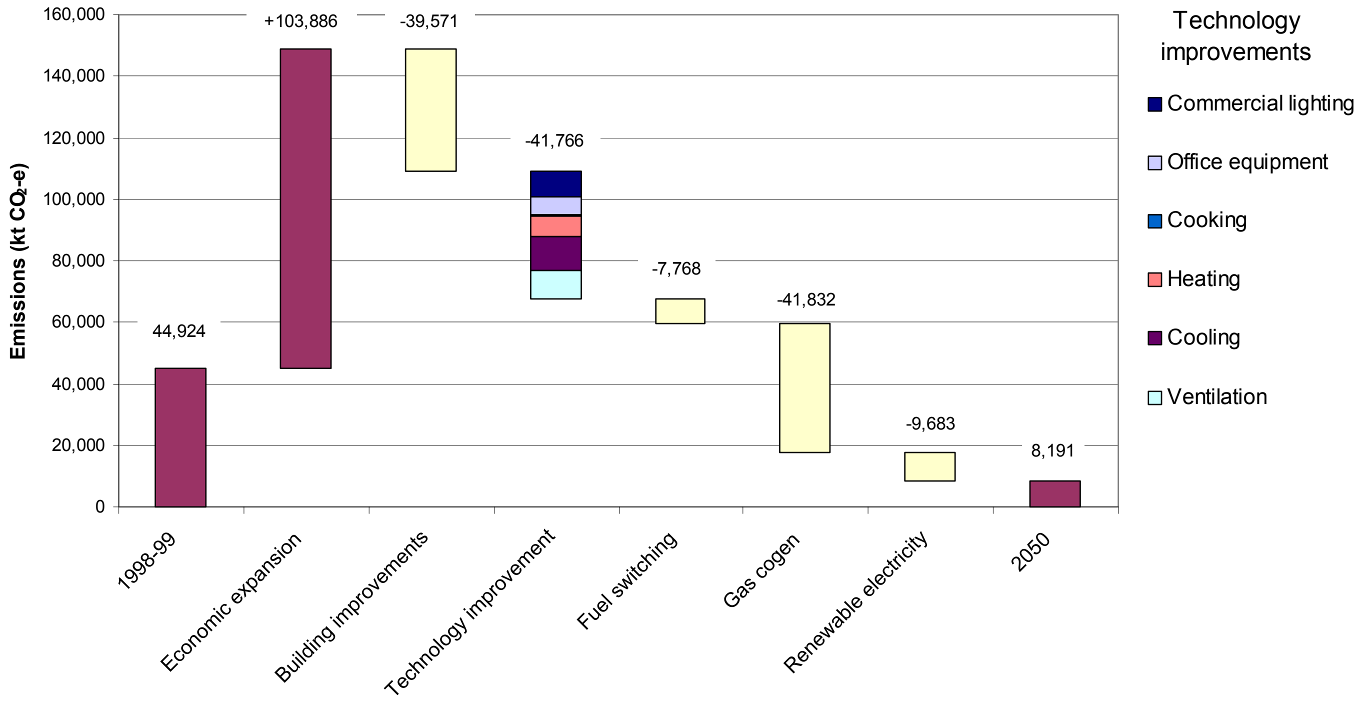
Table 8 Commercial sector energy efficiency, supply and demand, 2050

Energy service	Reduction in energy intensity	Energy demand (2050) (PJ)
Ventilation[a]	60 %	43
Space cooling[a]	58 %	60
Space heating[a]	57 %	96
Cooking and hot water	29 %	29
Office equipment	31 %	42
Lighting[a]	60 %	41
Total		**312**

Energy sources	Energy supply (2050) (PJ)
Gas and biogas[b]	
Direct combustion (gas + biogas)	29
Cogeneration heat (gas)	141
Electricity	
Renewables	39
Cogeneration (gas)	103
Total	**312**
Losses in cogeneration and absorption chilling	41
Total consumption	**353**[c]

Note: May not sum due to rounding.
a. Including the impact of improved building design.
b. Gas from biomass gasification.
c. For comparison, commercial sector energy consumption 1998-99 was 211 PJ, comprising around 145 PJ of electricity, 49 PJ natural gas, 13 PJ petroleum and 3 PJ other fuels (Dickson *et al.* 2001, p. 65).

Figure 18 Factors affecting commercial sector emissions under the deep cuts scenario, 1998-99 to 2050



10. Residential sector

The factors contributing to changes in greenhouse gas emissions from residential sector energy consumption between now and 2050 are discussed in this section. The technical options for reducing energy use are examined, as are the economic and demographic changes driving demand. Currently, most of the energy is used in space heating and cooling (37 per cent) and water heating (29 per cent) (AGO 1999a). Total energy use in 1998-99 was estimated to be 387 PJ (AGO 2001a, p. B-8; Dickson *et al.* 2001, p. 65). Total greenhouse gas emissions from residential energy use are estimated to be 57 Mt CO_2-e, of which 48 Mt CO_2-e are produced in the generation of electricity used by the residential sector (derived from AGO 2001a, pp. B-5, B-8; Dickson *et al.* 2001, p. 65).

As discussed in Section 3, Australia's population is expected to increase by 32 per cent between now and 2050 (ABS 1998a, p. 47). However, average occupancy is expected to decline from around 2.7 to 2.3 persons per household (Poldy *et al.* 2000, Appendix B), requiring an increase in the total number of dwellings of 54 per cent. While household occupancy declines and there is a shift to multiple-unit dwellings, increased incomes will drive an increase in average floor space per dwelling by around 20 per cent, increasing total floor area by around 85 per cent between now and 2050 (consistent with Poldy *et al.* 2000, Figure 5.15). It is assumed that under business-as-usual conditions energy consumption will increase by a similar amount by 2050.[49] However, design and technical improvements are expected to significantly reduce energy intensity.

Large reductions in residential energy use can be achieved through improved building design, including correct building orientation and shading, appropriate placement of windows and the use of ceiling and wall insulation. Improvements in building design generally include the maximum use of sunshine for lighting and heating, a high level of insulation on exterior surfaces and heat recovery systems. Building shell efficiency improvements can increase energy efficiency markedly. A shift to an efficiency of 5 stars under the Nationwide House Energy Rating System (NatHERS) for all new dwellings from 2000, in combination with the aggressive promotion of adding ceiling insulation to the existing building stock, is projected to save 18.4 per cent of residential heating and cooling greenhouse gas emissions by 2010 (AGO 1999b, p. ES-12). For new dwellings alone, the improvement was generally estimated at 55 per cent (from a current average of around 1.5 stars) and in the case of ACT and Victoria where wall insulation was already mandatory the projected saving was still a substantial 45 per cent (from a current average of 2.2 stars) (AGO 2000, p. ES-13). These figures are broadly consistent with equivalent estimates in the USA, where it was predicted that efficiency could increase by 55 per cent, based on a moderate uptake of potential improvements (DOE 2002).

Installing more efficient equipment can reduce emissions from space heating and cooling further. For example, a 6-star-rated gas heater will reduce emissions by 45 per cent relative to the 1-star equivalent (Lee 2000). Similar savings are available in

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[49] That is, it is assumed that appliances and equipment per unit of floor area remain roughly constant. The increasing floor area per person means that appliances per person are also increasing, with increased affluence.

air conditioners in both heating and cooling modes and further savings are quite feasible. For example, in the USA it has been estimated that using high efficiency air-conditioners with larger condenser and evaporator areas and more efficient fan motors and compressors can raise energy efficiency by around 64 per cent (DOE 2002). Improved control and management systems (such as timers, occupancy sensors and zoning) can further reduce energy used in space heating and cooling. In addition, residential distributed generation technologies such as fuel cell or micro-turbine cogeneration can be used for space heating (and cooling with absorption chillers) while supplying electricity for other residential energy requirements.

Major savings are also possible in water heating, which accounts for a large share of residential energy consumption (29 per cent). As in the commercial sector, the available technologies for water heating include high efficiency gas, heat pump and solar water heaters, and major savings are possible compared to conventional systems (see Benders and Biesiot 1996). However, significant scope exists to replace nearly all electric resistance water heating systems with solar thermal systems boosted with either high efficiency gas combustion or heat from residential cogeneration (microturbine or fuel cell) systems. Water efficiency improvements, achieved with flow control fixtures, can also achieve substantial reductions in energy consumption.

A large number of technical options are available to decrease energy used in other residential appliances. More efficient refrigerators and freezers incorporate improvements in the amount and type of insulation, compressor efficiency and control systems, with optimal integration of all components. New refrigerators with these improvements would potentially use 50 per cent less energy.[50] Standby power losses can also be largely eliminated, although increasing demands for appliances with standby systems will offset some of the gains.

More efficient electric stoves (electric induction cook-tops) incorporating reflective pans under elements and reduced electric resistance use less energy compared to conventional electric elements (resistance) or gas elements. Another option is to use gas cooking with improved combustion efficiency. As is the case for any appliance that can operate on electricity or gas, the source and generation efficiency of the electricity has a large bearing on relative greenhouse gas emissions.

In the case of residential lighting, efficient house design will allow natural light to be used at maximum level without creating major heating gain or loss pathways. Efficient artificial lighting technologies, similar to those discussed in Section 9 for the commercial sector are also available, although it is assumed unlikely that household consumers will accept lighting control systems and a significantly increased penetration of fluorescent lights (except for compact fluorescent bulbs).[51] Increases in bulb output intensity are also less likely to produce as large a reduction in residential lighting energy use, because of the layout of residential buildings. Accordingly, the energy efficiency potential is assumed to be only 50 per cent.

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[50] For example, see http://www.worthit.com.au/energylabel/refrig_srch.asp. Refrigerators with a 3.5-4 star rating use approximately half the energy of a 1-star equivalent.

[51] Recent trends towards increasing use of low-voltage halogen lighting are not expected to have a major impact on lighting energy consumption beyond that already envisaged in this study.

The overall improvements in average intensity (for equipment efficiency and improved building design) are shown in Table 9. Although much larger improvements could be achieved if the entire residential building stock were replaced, this is unlikely to occur by 2050. Table 9 also shows energy demand and energy supply in 2050 (although the latter is discussed in more detail in Section 14). Figure 19 shows the expected impacts of the various demographic, efficiency and fuel switching influences on residential greenhouse gas emissions between 1998-99 and 2050 under the deep cuts scenario.

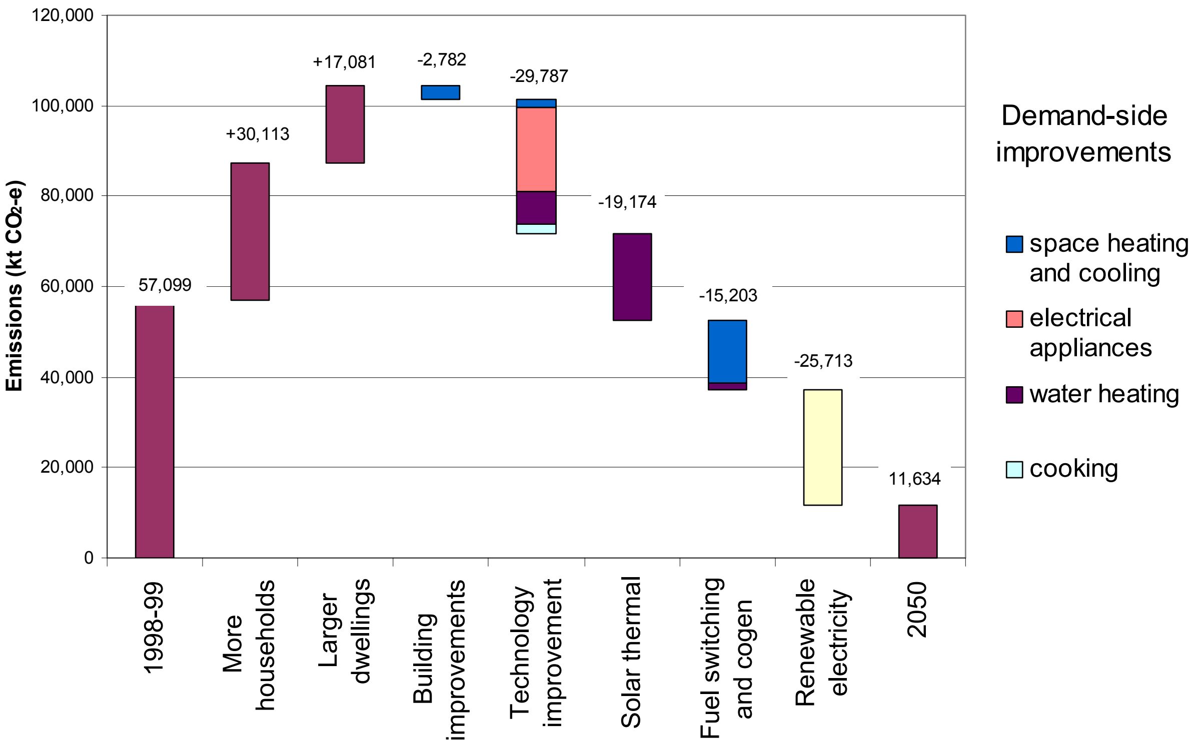
Table 9 Residential sector energy efficiency, supply and demand, 2050

Energy service	**Reduction in energy intensity**	**Energy demand (2050) (PJ)**
Cooking	36 %	19
Water heating	26 %	154
Appliances	31 %	149
Space heating and cooling (including building design)	56 %	117
Total		**439**

Energy sources	**Energy supply (2050) (PJ)**
Solar thermal	123
Gas + biogas[a]	
Direct combustion	19
Cogeneration heat	78
Electricity	
Renewables	167
Cogeneration (gas)	52
Total	**439**
Losses in cogeneration	14
Total consumption	**453**[b]

Note: May not sum due to rounding.
a. Gas from biomass gasification.
b. For comparison, residential sector energy consumption 1998-99 was 386 PJ, comprising around 170 PJ of electricity, 115 PJ natural gas, 81 PJ wood, 14 PJ petroleum and 5 PJ other fuels (including 4 PJ from solar thermal systems) (Dickson *et al.* 2001, p. 65).

Figure 19 Factors affecting residential sector emissions under the deep cuts scenario, 1998-99 to 2050



11. Transport

The factors contributing to changes in greenhouse gas emissions from the transport sector between now and 2050 are discussed in this section. Table 10 at the end of this section shows current and projected greenhouse gas emissions from transport. Currently, the subsectors contributing the greatest share of emissions are private passenger transport (cars), road freight and air transport.

Demand for transport is driven principally by increases in domestic population and economic output, although the impact of these factors is also affected by urban form. As discussed in Section 2, the 50-year time horizon used in this study does not allow for major changes in urban form, although it should be sufficient for reorganisation of some transport systems. Population is expected to grow from 18.5 million in 1997 to almost 25 million in 2050. Growth in labour force productivity is estimated to average 1.75 per cent per annum which, when combined with total workforce growth of around 17 per cent, results in an increase in economic output of 180 per cent over 50 years (or just below 2.1 per cent per annum). This will drive overall demand for transport. However, changes in technologies and shifts between transport modes (in addition to some changes in urban form) are expected to affect how this increased demand translates into energy use and greenhouse gas emissions.

11.1 Land transport technologies and fuels

Due to the relatively fast turnover of the vehicle fleet (compared to major infrastructure), it is assumed by that 2050 most of the vehicles on the road will have been built since 2030, with less than 10 per cent of vehicles built prior to 2020 (based on BTCE 1996b, pp. 7-9). It is expected that there will be general improvements in vehicle aerodynamics, weight, rolling resistance, engine efficiency and other characteristics over the next 20-50 years (for discussion of potential improvements see Greene and Plotkin 2001; BTCE 1996a, pp. 51-3). However, some of the efficiency improvements will be offset by a continuation of the current trends in consumer demand for larger vehicles such as 4WDs[52] and additional features.

All automakers are expecting to be producing petrol/diesel-electric hybrids by 2010. In fact, first-generation commercial hybrid technology will have been around for a decade by this time.[53] Further advances over the subsequent 20 years, reducing costs and improving performance, will mean that nearly all vehicles on the road in 2030 will use some sort of electric hybrid or more advanced technology. Hybrid vehicle technologies are expected to deliver in the ‘near-term … a vehicle capable of providing 100% better fuel economy than a comparable gasoline-only vehicle’ (DOE 1999). Accordingly, by 2050 it is conservatively assumed that hybrid technologies will have halved average passenger and light commercial vehicle (LCV) fuel consumption and reduced road freight vehicle consumption by 35 per cent.[54]

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[52] DISR 2001, Key Automotive Statistics 2000, http://www.industry.gov.au/industry/auto/KAS/2000/kas2000.doc

[53] The Honda Insight having been available since 1999.

[54] This conservative assumption is included to account for expected future demand for larger vehicles with additional features and a possible rebound effect from decreased travel costs. A slightly lower improvement in efficiency is assumed for trucks because these vehicles tend to spend more time

By 2010 many automakers may have introduced limited production of hydrogen fuel-cell vehicles.[55] However, this technology is expected to take somewhat longer to mature, with slower uptake and more technical issues to be resolved. The creation of a new fuel delivery infrastructure will be necessary to move beyond reformed petroleum as a source of hydrogen.[56] By 2030, it is assumed that most urban and major regional centres will have an adequate hydrogen delivery system. Reforming technologies will enable hydrogen vehicles to operate on other liquid fuels, helping overcome fuel availability concerns. However, it is assumed that other barriers to the uptake of hydrogen will mean that hydrogen vehicles become the preferred choice of passenger vehicle only after 2035. Based on vehicle survival rates and turnover (see BTCE 1996b, pp. 7-10) and likely rates of uptake, hydrogen-fuel vehicles are assumed to account for 50 per cent of passenger and light commercial vehicles in 2050.[57]

Natural gas vehicle technology is sufficiently advanced that widespread adoption could occur rapidly,[58] although once again infrastructure requirements and concerns about safety will hamper the development of this technology. There may be some scope for converting natural gas delivery and distribution systems to hydrogen delivery. It is assumed that dual-fuel hybrids account for a similar proportion of the fleet as dual-fuel LPG/petrol vehicles currently do (3 per cent).

Biofuel vehicle technologies are sufficiently mature that fleets could easily move to 100 per cent methanol, ethanol or biodiesel in a relatively short space of time. However, limits on the availability of biomass feedstocks (due to other constraints on agricultural land, including conversion to forestry, an end to land-clearing, higher demand for other agricultural products and the use of biomass fuels for electricity and cogeneration, along with anticipated reductions in waste production from other sources), are likely to limit the extent to which biofuels can supply the transport market under the scenarios examined in this paper. This is discussed in more detail in Section 14.

11.2 Passenger transport

Private passenger transport

Demand for personal transport is expected to expand rapidly in line with higher incomes and a larger population. The Australian population in 2050 is estimated to be almost 25 million based on the most likely fertility and immigration assumptions

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driving with large loads on highways, where regenerative breaking and efficient acceleration and idling provide fewer efficiencybenefits. For example, Greene and Plotkin (2001) suggest that hybrids deliver around half the improvement in efficiency under 'average' driving conditions compared to 'stop-and-go' conditions.

[55] Using hydrogen instead of petroleum-based fuels does not necessarily eliminate greenhouse gas emissions if the hydrogen is produced from a carbon-intensive source, such as from electrolysis using electricity generated from fossil fuels or by reforming petroleum fuels. However, hydrogen is an energy carrier that can be generated using renewable energy sources.

[56] For a discussion of some of the barriers to large-scale uptake of hydrogen, and the possible innovations that may overcome these barriers, see Shell (2001).

[57] This is conservative compared to the advanced scenarios examined by Greene and Plotkin (2001), where fuel-cell vehicles account for around 45 per cent of light vehicle sales in 2020, 30 years earlier.

[58] For example, several automakers produce compressed natural gas (CNG) vehicles.

(ABS 1998a, p. 2). Due to the ageing of the population, the driving-age population is estimated to rise from around 79 per cent now to 84 per cent of the total.[59]

The BTCE has found that passenger vehicle numbers are likely to saturate at a level below 550 vehicles 1000 people(or around 700 vehicles per 1000 adults with the current population structure), based on historical trends (BTCE 1996a, p. 421). Because changes in the structure of the population in the next 50 years are expected to differ substantially from historical trends, it is likely that vehicle numbers will saturate at current per adult levels rather than at current per population levels.[60] On this basis, it is estimated that in 2050 there will be almost 15 million vehicles in Australia, compared to almost 10 million now. Average passenger vehicle utilisation is expected to remain at around 15,500 km per annum, consistent with trends over the last decades (BTCE 1996a, p. 423). These two factors determine total vehicle kilometres travelled in Australia in 2050. Reducing this travel will require encouraging passengers to travel less[61] or use alternative forms of travel.

Public transport

In 1993, 8 per cent of urban passenger-kilometres (p-km) occurred on public transport, down from 12 per cent two decades earlier (BTCE 1996a, p. 340). Other evidence suggests this share has not increased since 1993 (ASEC 2001, p. 103). However, by 2050 investment in urban public transport systems is assumed in this study to increase patronage to 20 per cent of urban p-km. This is a very optimistic assumption, considering the persistent decline in the share of public transport, and will require more than a 4.5-fold increase in p-km on public transport. This assumption is included to illustrate the impact of major changes in transport patterns and to examine the extent to which this is able to offset some of the anticipated increase in demand for private travel. The increased share of urban travel on public transport is estimated to reduce annual vehicle travel by around 22 billion km (relative to the level that would prevail if the share was maintained at 8 per cent).[62] Accordingly, unless relatively massive increases (e.g. 10-fold) in public transport patronage can be realised, which is not predicted in this study, this form of transport will make a relatively small contribution to reducing greenhouse gas emissions.

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[59] Population aged 15 years and over (ABS 1998a, p. 49) is used as a proxy for driving-age population. It is possible that an older adult population will experience a higher level of disability that may reduce slightly the proportion of driving-age population.

[60] ABARE's estimates of energy consumption rely on a similar assumption (Bush *et al.* 1999, p. 71), with saturation at 710 vehicles per 1000 adults.

[61] Two factors are working in opposing directions. Increasing incomes may result in more discretionary travel. However, evolution of the services sector may reduce the need for individuals to travel (offset somewhat by increased commercial travel). However, other modellers believe that rising incomes do not significantly affect average vehicle utilisation, but do affect the rate at which the stock of vehicles is replaced (Bush *et al.* 1999, p. 71).

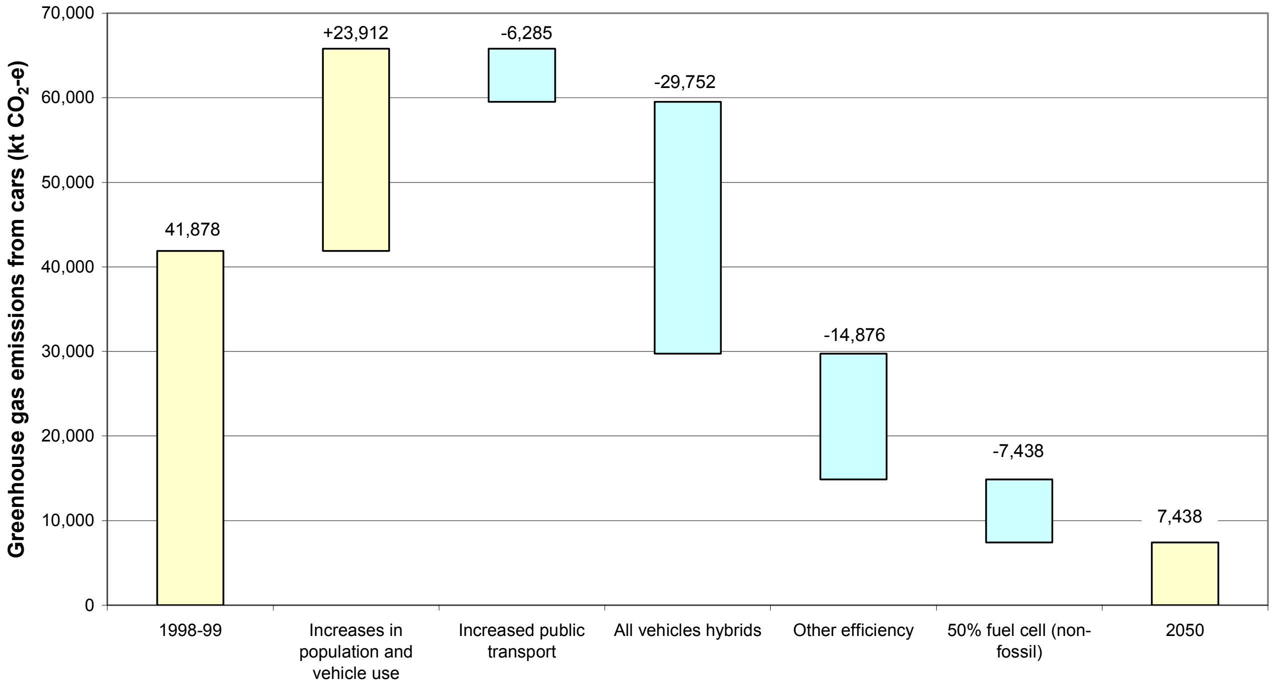
[62] After improvements in vehicle efficiency, this 22 billion km of travel is equivalent to around 1.5 Mt CO_2-e, or less than 2 per cent of current emissions from transport (see Table 10). That is, although there are good reasons for promoting public transport to reduce congestion and urban air pollution, a major expansion is not likely to result in significant reductions in greenhouse gas emissions beyond those that will be achieved from the uptake of new vehicle technologies.

Barriers to widespread use of hydrogen in urban bus transport are expected to be overcome well before similar barriers to private passenger vehicle use of hydrogen. Accordingly, all urban buses will be powered by hydrogen fuel cells by 2050.

Overall impact – passenger road transport

As discussed above, the shift to hybrid vehicles is anticipated to halve average passenger car fuel consumption, approximately halving greenhouse gas emissions. Additional improvements in efficiency are expected to reduce overall average fuel consumption to around 3 L/100 km (down from a current average of around 12 L/100 km, BTCE 1996a, Table II.4). Increasing public transport patronage will reduce emissions by around 10 per cent compared to business-as-usual. Achieving a fleet penetration of 50 per cent for hydrogen fuel cell vehicles will reduce emissions by a further 7.6 Mt CO_2-e (after all other improvements). The factors influencing emissions between now and 2050 are illustrated in Figure 20. Switching the remaining vehicles to biofuels could almost eliminate emissions from private passenger transport.

Figure 20 Factors affecting emissions from cars under the deep cuts scenario, 1998-99 to 2050 (before biofuels)



Air and rail passenger transport

Demand for air travel is closely related to GDP growth, which is expected to be 2.8-times current levels by 2050. According to ABARE, and based on historical trends, expansion of real GDP to 2.8 times its current value would increase demand for air travel to almost four times its current level (Bush *et al.* 1999, p. 70). However, improvements in aircraft technology and efficiency are expected to offset some of the increases in demand. For example, under the BTCE's 'low efficiency' scenario (which projects out to 2015), aircraft introduced after 2015 are assumed to be 45 per cent more fuel efficient (in terms of p-km per litre of fuel) and under their 'high efficiency' scenario, aircraft introduced after 2010 are assumed to be 70 per cent more efficient (BTCE 1996a, pp. 225-8; see also Greene and Plotkin 2001).[63] On the basis that aircraft have a life of 20-25 years, it is reasonable to assume that in 2050 the average aircraft will be twice as efficient (i.e., 100 per cent more efficient) as current aircraft, and fuel consumption per p-km will be half current levels.

Passenger air travel is expected to face increased competition from improved high-speed train systems between adjacent capitals and major regional centres in the eastern states.[64] Trips between these adjacent capital cities and centres (i.e., Adelaide-Melbourne, Melbourne-Canberra-Sydney, Sydney-Coolangatta-Brisbane) make up almost 50 per cent of total domestic air passenger numbers (with the rest being between non-adjacent capitals, from capitals to regions and between regions) (DOTRS 2001).[65] High-speed rail is expected to offer a near-identical travel service to air on these relatively short routes and accordingly is assumed to capture almost 50 per cent of the high-speed travel market for trips between adjacent capitals and centres by 2050. This is estimated to attenuate growth in demand for domestic air travel to around 75 per cent of the level to which it would otherwise have grown. Rail may also pick up a large share of the market for travel between capitals and regional centres along major routes.

In terms of fuel choices, it is expected that aircraft will continue to rely on turbine-based propulsion.[66] Petroleum-based aviation turbine fuels may be replaced by biofuels and hydrogen produced from a renewable primary energy source.[67] However, there is less flexibility for international air travel to use non-petroleum fuels until international hydrogen or biofuel standards are implemented.

For international travel, it is extremely unlikely that high-speed land- and water-based technologies will reduce demand for international air travel to and from Australia. Currently, emissions from international travel are not included in Australia's inventory, and Australia's commitments under the UNFCCC do not currently extend to a requirement to reduce these emissions. However, it is unlikely other sectors will accept stringent emission restrictions when international travel is unregulated. There are a number of options for addressing emissions from international travel (UNFCCC 1996), although a global environmental tax on international fuel is perhaps most likely.[68] For the purposes of this analysis, responsibility for emissions from international transport, both passenger and freight is assumed not to be assigned to individual countries, but to be covered by a separate international instrument.

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[63] Replacement of existing aircraft with 1990s technology between 1996 and 2015 was projected to increase efficiency by 28 per cent (derived from BTCE 1996a, p. 231).
[64] High-speed rail, like air transport, is expected to be a higher-cost transport option and is therefore not expected to compete directly with private passenger car inter-urban transport. However, rising incomes will increase overall demand for high-cost, high-speed transport.
[65] These trips account for a slightly smaller proportion of p-km because it does not include longer trips (with which high-speed rail is unable to compete).
[66] Other systems that can be applied to land-based transport, such as fuel cells, cannot deliver sufficient thrust for air travel.
[67] For example, DaimlerChrysler plans to start production of a hydrogen-fuelled aircraft within 10 years (see http://www.bellona.no/data/dump/0/00/08/6.html).
[68] 'Low airfares worry environmentalists,' *Moscow Times*, 27 June 2002, http://www.themoscowtimes.com/stories/2002/06/27/253.html

Accordingly, emissions from the combustion of fuels sold in Australia for international travel are excluded from total emissions in both the base year (on which the 60 per cent target is calculated) and in 2050.

11.3 Freight transport

Around one-third of total Australian freight tonne-kilometres is carried on each of road, rail and sea (BTCE 1996a, p. 337). Demand for freight is also closely related to GDP. On the basis of the BTCE's models of road freight demand (BTCE 1996a, p. 436), the anticipated growth in GDP will result in an increase in road freight to around 2.9-times current levels.

Rail and sea freight are somewhat more complicated. Around 78 per cent of the total freight carried by rail in 1993 consisted of bulk products, mainly coal, grain and iron ore (BTCE 1995, pp. 44, 225-6). Based on the projected changes in global demand for iron, coal and grains (see Section 3), demand for bulk freight is projected to grow by around 36 per cent between 1998-99 and 2050 (see BTCE 1995, p. 45).[69] Non-bulk rail freight is expected to increase in line with real gross non-farm product, that is, by 180 per cent.

The major commodities transported by coastal shipping are bauxite/alumina, petroleum, sugar, iron ore, coal/coke and fertilisers/minerals (BTCE 1995, p. 112). Movements of petroleum and coal/coke are expected to decline sharply with a decline in demand for these commodities, while bauxite/alumina, sugars and fertilisers/minerals will grow at a moderate rate. Iron ore will grow at a slower rate as global demand for iron is displaced by light metals. Overall, it is assumed that domestic shipping freight grows at 1.0 per cent per annum.

With the shift of consumption patterns to services, total freight is expected to grow more slowly than the economy as a whole. This is reflected in the projected freight movements discussed above.

Projected demand for various forms of freight and the technologies that are expected to apply in 2050 are discussed below. The implications for greenhouse gas emissions are summarised in Figure 21.

Land freight transport

Major improvements in rail infrastructure will be necessary before 2050, particularly if growth in road and air transport demand is to be curtailed (see discussion above). Accordingly, it is assumed that medium-speed rail freight will become faster and more reliable than road freight along capital city corridors, and will also maintain its cost advantage (see BTCE 1996a, p. 207). As a result most inter-capital freight and freight to major regional centres will be transported by electrified rail by 2050, reducing road freight demand to 67 per cent of business-as-usual levels.

Efficiency improvements (including hybrid engines) will reduce road freight fuel consumption per tonne-kilometre (t-km) further. In the 30 years from 1971 to 2001, fuel use per t-km fell from 2.9 MJ to 1.5 MJ (BTCE 1995, pp. 215, 217) for heavy

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[69] Assuming no other bulk products replace coal and iron ore.

road vehicles. Some of the factors responsible for this improvement in efficiency have been almost fully exploited (such as a shift to larger vehicles), but it is assumed that a similar improvement to that achieved in the last 30 years can be achieved over the next 50 years. Considering the potential of hybrid engines and lightweight materials this is quite a conservative assumption.

Rail freight efficiency is assumed to improve in line with technological developments and as a result of electrification.[70] For urban rail transport, intensity is assumed to decline from 0.46 MJ/p-km in 1990-91 (BTCE 1995, Table 3.3) to around 0.3 MJ/p-km by 2050 through general improvements in efficiency and a shift to lighter rail (for comparison, electric tram intensity was only 0.36 MJ/p-km in 1990-91). For non-urban passenger transport (much of which will be in VFTs in 2050), a similar intensity is assumed after the impact of electrification and improvements in efficiency over the next 50 years are taken into account (compared with 1.05 MJ/p-km in 1992-93). For rail freight, in 1992-93 government bulk and non-bulk and private freight intensities were 0.254, 0.530 and 0.125 MJ/t-km (BTCE 1995, Table 3.4). Electrification alone is expected to reduce average intensity to around 0.12 MJ/t-km by 2050.[71] Improvements in efficiency, design and logistics are expected to reduce average intensity to 0.08 MJ/t-km by 2050. Overall, rail will consume around 40 PJ of electricity. If this is supplied from renewable sources, then emissions from rail transport can be eliminated.[72]

With respect to freight to non-urban centres, it is assumed that real output and incomes grows by a similar amount regardless of location. Accordingly, demand for other freight will also increase.

Intra-urban freight

Intra-city freight is expected to grow at a similar, if not faster rate, than non-urban and interurban freight increasing demand for light commercial vehicle (LCV) travel (as well as heavier trucks). Except for very large orders, there is almost no scope for replacing this travel by rail. Hybrid engines and other efficiency improvements are assumed to reduce LCV fuel consumption by 67 per cent by 2050, offsetting the 2.8-fold increase in demand. That is, LCVs will achieve greater efficiency improvements than heavy vehicles, but slightly smaller than passenger vehicles.

Marine and air freight

Demand for marine freight is discussed above and is expected to grow at around 1 per cent per annum, in line with movements in output of major bulk commodities. However, general improvements in size, hydrodynamics and propulsion systems are

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[70] Electrification reduces direct fuel use because 'MJ per unit task estimates for electric rail are substantially lower than for diesel rail' (BTCE 1995, Table 3.4).

[71] For example, non-electric urban rail systems are almost three times as energy intensive as electrified systems (looking at final consumption and ignoring electricity generation losses), and an increase in the share of energy obtained from electricity from 3 per cent to 24 per cent by government bulk freight trains coincided with a 38 per cent decline in intensity (BTCE 1995, Table 3.3).

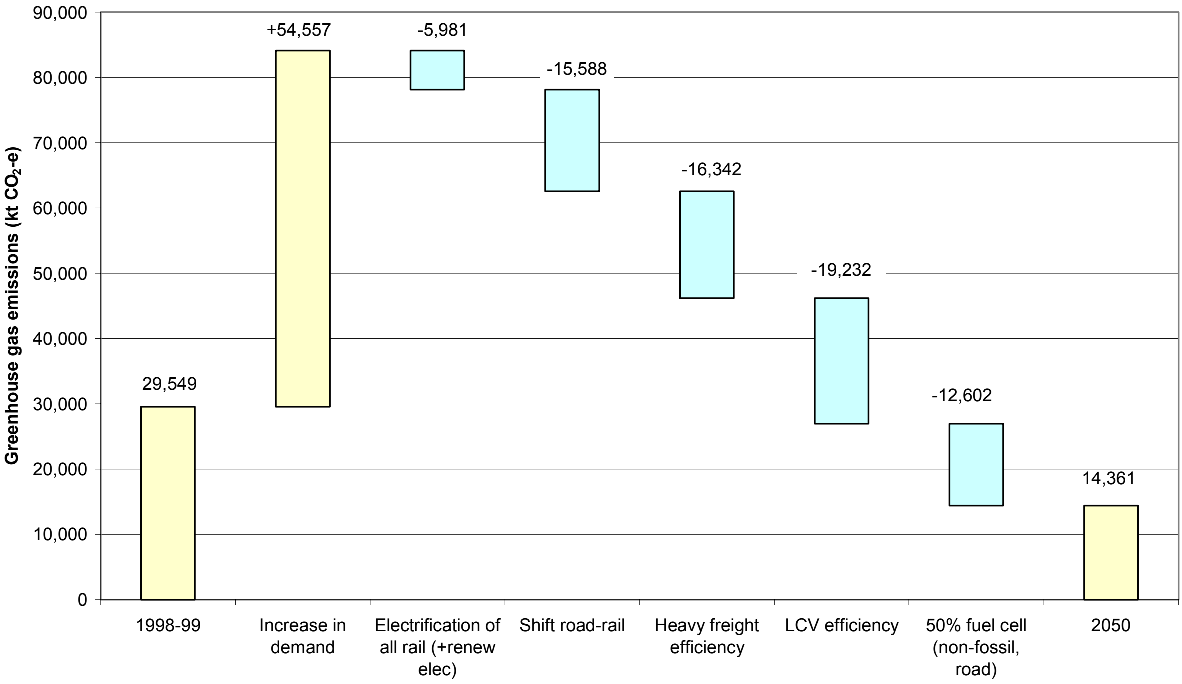
[72] On a lifecycle basis, renewable electrification should be more efficient that using renewable liquid fuels directly (while also increasing the range of sources from which the renewable energy can be obtained).

expected to reduce energy consumption by 30 per cent (0.7 per cent per annum). By comparison, between 1974 and 1992 energy consumption declined from around 0.5 to 0.3 MJ/t-km (BTCE 1995, pp. 113-114).

Hybrid engines are not suitable for powering maritime vessels, mainly because the engines tend to be operated continuously at an almost constant output. However, there may be some opportunities to switch from petroleum fuels (which dominate the sector) to either biofuels or hydrogen. Hydrogen could potentially be used to fuel ships via direct combustion,[73] although it is better to use available hydrogen in urban areas to reduce emissions of other pollutants.

As in the case of international air travel, international marine freight will require a fuel that is available in ports of major trading partners in 2050. This is less of a concern for bulk freighters visiting remote mining and agricultural centres, since many of these currently ship in fuels. Domestic air freight makes a very small contribution to total freight movements. It is assumed to grow at a similar rate as domestic passenger air travel and will continue to make an almost negligible contribution to total freight.

Figure 21 Factors affecting emissions from freight transport under the deep cuts scenario, 1998-99 to 2050 (before biofuels)



Overall impact – freight transport

Overall, electrification of rail freight (with renewable electricity) will reduce direct greenhouse gas emissions by almost 6 Mt CO_2-e below business-as-usual by 2050 (see Figure 21). Shifting around one-third of heavy road freight to rail will reduce

[73] It could also be used in fuel-cells generating electricity for propulsion. Note, electricity is used for propulsion in certain Chinese and French nuclear submarines (http://www.uic.com.au/nip32.htm).

emissions by almost 16 Mt CO_2-e, while improvements in heavy vehicle and marine freight efficiency will have a similar impact. Large improvements in light commercial vehicle efficiency (including the impact of hybrid engines) will potentially reduce emissions by a further 19 Mt CO_2-e. These just offset the 55 Mt CO_2-e increase in emissions expected in the absence of efficiency improvements and modal shift. Converting half of the road freight transport to hydrogen fuel cell power plants can reduce emissions by another 13 Mt CO_2-e, reducing emissions in 2050 to a little over 14 Mt CO_2-e. There is a large scope to convert the remaining road vehicles to biofuels, eliminating all freight emissions from fossil fuel combustion except those from marine freight transport.

11.4 Summary

Table 10 summarises current and projected emissions under the deep cuts scenario. The largest decline in emissions (prior to the impact of biofuels or a switch to hydrogen) is projected to occur in the passenger car sector, driven by uptake of hybrid vehicles and other technologies. Hydrogen fuel cells are expected to reduce emissions from cars further. On the other hand, the largest increases in emissions (prior to the impact of biofuels or a switch to hydrogen) occurs in the air transport sector and in road freight, although these increases are restrained compared to the projected business-as-usual increase in demand for both types of transport. The widespread application of biofuels and the use of fuel cells in road freight transport are expected to reduce emissions to substantially below 1998-99 levels. Other transport sectors, such as rail and marine, experience different overall changes. The electrification of all rail, combined with the use of renewable electricity generation, eliminates emissions from this sector, while the use of biofuels in marine transport, combined with energy efficiency improvements, more than offsets any demand-induced increase in emissions.

Table 10 Current and projected emissions from transport, 1998-99 and 2050

	Emissions 1998-99 (kt CO_2-e)	Emissions 2050 (kt CO_2-e)
Civil aviation		
International	7,337	NA
Domestic	4,153	6,438
Road transportation		
Cars	41,878	14,876
Light trucks	9,368	9,616
Medium duty trucks	2,886	15,588
Heavy duty trucks	10,958	
Buses	1,342	1,342
Motorcycles	208	208
Railways	**3,498**	**1,873**[a]
Marine transportation		
International	2,474	NA
Domestic	1,498	1,759
Recreational vehicles	**41**	**41**
Military	**1,361**	**1,361**[b]
Sub-total[c]	**87,001**	**53,103**
Add on impact of:		
Biofuels (approx. 170 PJ)		-11,635
Hydrogen[d]		+1,811
50% passenger cars		-7,438
all urban buses		Included above
50% other buses and motorcycles		-775
0% air travel		0
50% LCVs		-4,808
50% heavy road freight		-7,794
0% shipping		0
Total[c]	**87,001**	**22,463**
Excluding international transport[c]	77,190	22,463
Excluding military and recreational vehicles[c]	75,788	21,021

a. Around 40 PJ of electricity is estimated to be needed by railways in 2050. Based on the information in Section 14, generating this electricity will produce around 1.9 Mt CO_2-e. Current electricity consumption by railways is around 7.5 PJ. Increasing activity and mode shift will be offset somewhat by increased efficiency.
b. Ground-based military vehicles may well move entirely to biofuels, which have the advantage that they can be manufactured in the field. However, military aircraft and ships may continue to use petroleum-based fuels.
c. Excluding lubricants. This is why the 'excluding international transport' figures differ from those in Table 6.
d. Assuming this hydrogen is produced as described in Section 14.

Source: AGO 2001a, and information in above discussion.

12. Agriculture

The factors contributing to changes in greenhouse gas emissions from each major source in agriculture, land-use change and forestry are discussed below. Table 11 at the end of this section shows current emissions from each source and the emissions projected for 2050. Currently, the principal sources of emissions are enteric fermentation (in beef cattle, sheep and dairy cattle), energy use, soil disturbance, fertiliser application and land clearing. Forests are shown in the National Greenhouse Gas Inventory as a net sink (AGO 2001a, p. A-29).

Beef cattle output is examined below in more detail because of its large contribution to Australia's agricultural emissions (accounting for 38.5 per cent in 1998-99), the export-orientation of the meat and livestock industry and the expected changes in global beef demand. For instance, developing country demand for beef is expected to grow at 2.8 per cent per annum to 2020, whilst developed country demand for meat will grow at 0.9 per cent per annum (Pinstrup-Andersen *et al.* 1999, p. 11). Assuming that after 2020 the developing country rate drops to 1.8 per cent and developed country demand is stable,[74] total global demand for beef will be around 2.1 times current levels in 2050. It is assumed that Australia at least maintains its share of global beef trade, and that overall production grows at a similar rate.[75]

12.1 Energy used in agriculture

Most of the energy used by the agricultural sector is for operating mobile equipment which is powered almost entirely by diesel.[76] A small but significant amount of electricity is also used by the agricultural sector.

ABARE expects diesel demand in agriculture to increase by 1.5 per cent per annum to 2015, 'largely as a result of substituting diesel for petrol-powered plant' (Bush *et al.* 1999, p. 67). This indicates that the increase in demand may be an artefact of ABARE's accounting (that is, petrol-powered agricultural equipment is included under estimates of 'transport' fuel use rather than 'agriculture'). Accordingly, fuel consumption in agriculture is growing somewhat more slowly.

By 2050, the stock of agricultural equipment will have been replaced at least once, enabling application of new technology and large improvements in efficiency.[77] It is assumed that improvements in the fuel efficiency of farm equipment will offset the impact of increased mechanisation and the expected expansion of agriculture, forestry and fishing. The spread of less fuel-intensive and low-tillage techniques in agriculture is expected to further moderate energy consumption.

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[74] Which implicitly assumes that as population growth decreases in the developing world, per capita consumption of beef increases to maintain growth.

[75] That is, slower growth in domestic demand for beef is assumed to be taken up by a slight increase in Australia's share in the global beef market.

[76] Total energy use was 59.9 PJ in 1998-99, all of which was petroleum and around 58.8 PJ of which was used in mobile equipment (AGO 2001a, p. B-96).

[77] See Section 11 for a discussion of the potential improvements in transport equipment efficiency. Smaller improvements are expected in agricultural equipment, due to the nature of their operation and the fact that some of the biggest drivers in transport efficiency improvements (notably hybrid engines) are less suitable for farm equipment.

The agricultural industry is in an ideal position to use liquid biofuels (including methanol, ethanol and biodiesel), partly because it produces most of the inputs for biofuel production. In addition, the agriculture sector is less likely to have access to hydrogen (one of the fuels that will replace petroleum as the main transport fuel – see discussion in Section 11) because the necessary infrastructure for delivery of hydrogen transport fuels may not have been extended to rural areas by 2050. In contrast, liquid biofuel production is expected to be located near to the sources of the agricultural materials used as feedstock.[78] By 2050 it is expected that large-scale production of ethanol and methanol from starch- and cellulose-based wastes (including wood in the case of methanol) and biodiesel from oil seed and abattoir wastes and from dedicated crops will occur, producing fuels at prices well below current Western European levels.[79] This will enable the agricultural sector to source almost all fuels for mobile equipment regionally and eliminate requirements for petroleum fuels.

In addition, in larger-scale food production operations, agricultural and animal wastes can be used for electricity cogeneration, with the heat used for processing operations. Candidate industries include dairy cattle, beef cattle feedlots, piggeries and poultry farms, all of which generate a large amount of manure waste. Large-scale cropping industries, particularly where significant amounts of waste products are harvested or concentrated, also have potential. It is assumed, however, that most of this agricultural waste is exploited by the food industry[80] and the wood and paper manufacturing sector (which both have large energy needs). This is discussed further in Section 14.

12.2 Non-energy emissions

Enteric fermentation and manure management

Cattle

Total cattle numbers have been increasing at an annual average of 1.15 per cent since 1885. In the last 50 years the average has been 1.43 per cent per year, but in the last 20 years it has been only 0.6 per cent as a result of a collapse in numbers in the late 1970s and early 1980s. Cattle numbers are heavily dependent on beef prices. For example, changes in beef prices contributed to a near doubling of cattle numbers between 1966 and 1976 and a subsequent decline of 30 per cent from 1976 to 1984 (see Figure 22 below).

In the long term, beef cattle numbers in Australia will be influenced most heavily by growth in global demand for beef, driven mainly by demand in Asia where incomes are expected to continue to rise over the next 50 years (although at a declining rate towards the end of this period). As discussed above, global demand for beef is expected to increase Australia's beef output to 2.1-times its current level. However,

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[78] Most liquid biofuel production will occur in the agricultural, food, beverages and tobacco and wood products industries. Production of biofuel may also be closely linked with heat and electricity generation from biomass.

[79] See discussion of costs in Sections 2 and 4.

[80] For example, in 1998-99 the food, beverages and tobacco industry consumed around 113.6 PJ of bagasse and wood waste originating from agriculture and forestry.

improvements in productivity will result in a smaller increase in the number of cattle (Conroy *et al.* 2000, p. 139). It is assumed in this study that beef cattle output grows at an average annual rate of 1.49 per cent to 2050, with cattle numbers increasing at 1.06 per cent per annum.[81]

Feedlot beef cattle

The proportion of beef cattle in Australia fed from feedlots was 2.4 per cent[82] in 1998-99 (AGO 2001a, pp. B-126-8). The number of feedlot cattle increased by almost 9 per cent each year between 1989-90 and 1998-99 (AGO 2001a, p. A-23). It will be necessary for this trend to continue in order to reduce emissions growth from the beef cattle sector. The improved diet currently provided in feedlots is estimated to reduce methane emissions per head by 10-15 per cent (NGGIC 1996a, pp. 9-14, 19-23). If it is assumed that the proportion of cellulose and hemicellulose[83] in cattle feeds is reduced by 50 per cent by 2050, then this improvement will be closer to 30-35 per cent.[84]

Currently, feedlot cattle are assumed 'to originate entirely from the steers >1 year old beef cattle class' (NGGIC 1996a, p. 13). In 1998-99, around 10 per cent annual equivalent of steers over 1 year old were feedlot cattle (or around 550,000 annual equivalent head). In order to reduce emissions from cattle it is necessary for a much larger proportion of cattle to obtain food from feedlots in the future. Feedlots facilitate reduced enteric fermentation (from improved feed) and reduced emissions from manure (through collection), and allow ready access to animals for vaccination with anti-methanogen vaccines. Accordingly, by 2050 it is assumed that feedlots account for 70 per cent of annual equivalent steers over 1 year old. In addition, it is assumed that feedlots also account for 30 per cent of annual equivalent cows between 1 and 2 years of age. Because animals spend as little as 75 days of the year on a feedlot (AGO 2001a, p. B-128), these annualised figures represent a much higher rate of feedlot penetration. Total feedlot numbers are estimated to be 8.1 million annual equivalents in 2050 (indicating an annual growth rate of 5.3 per cent).[85]

It is also assumed that there is complete scope for collecting and utilising manure produced from feedlot cattle (and using it as a biofuel or processing it through aerobic digestion). Consequently, this is expected to reduce emissions from manure to zero (emissions from manure application are discussed below).

Range cattle

Range-kept cattle are not expected to experience any major change in feed quality. Accordingly, cattle numbers will be the main factor affecting increases in emissions

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[81] At this rate, it will take until 2018 before beef cattle numbers regain their 1976 level.

[82] Most cattle do not spend an entire year in feedlots. This figure represents feedlot cattle-years as a proportion of total cattle-years.

[83] Digestion of cellulose and hemicellulose relies heavily on enteric fermentation (in comparison to digestion of soluble residues), thereby contributing to more emissions from enteric fermentation (see NGGIC 1996a, pp. 20-21).

[84] This can be achieved by altering feed mixes. However it may be necessary to devote additional agricultural land to the production of a larger volume of higher quality feed.

[85] This is down from the 9 per cent growth rate in feedlot activity observed between 1990 and 1999 (AGO 2001a, p. A-23).

from enteric fermentation. Methane emissions from manure are assumed to be adequately accounted for in estimates of enteric fermentation, consistent with NGGIC methodology (NGGIC 1996a, p. 32).

Dairy cattle

Dairy cattle numbers approximately halved from 1964 to 1991, but have recovered by about 30 per cent since. By 2050 the output of milk is expected to be twice current levels, driven mainly by increasing exports. However, milk production is projected to increase to 6.5 tonnes per head per year (up from 4.8 t/head in 1998-99, AGO 2001a, p. B-127; Conroy *et al.* 2000, p. 139), meaning that only around 45 per cent more dairy cattle will be necessary. It is also assumed that the digestibility of dairy feed will increase to 85 per cent by 2050 as a result of supplementation of pasture feeds.[86] Improved dairy cow breeds (and possibly genetic modification) will potentially increase the metabolisable energy efficiency of milk production to 70 per cent, from its current 60 per cent (NGGIC 1996a, p. 17). It is also assumed that manure from dairy operations is collected and utilised.

Sheep

In 1999, the number of sheep in Australia was lower than at any time since 1951, largely due to removal of the wool Reserve Price Scheme in the early 1990s (sheep numbers declined by over 50 million from 1990 to 1999, to around 115 million). By 2050 sheep numbers are expected to recover to around 150 million, but will still be below the level in 1960s and late 1980s. As sheep are range-kept, it is not expected that sheep feed quality will improve significantly. However, methanogen vaccines (discussed below) are expected to reduce per head emissions significantly.

Other livestock

Pigs and poultry constitute the main source of manure not accounted for by sheep and cattle. The nature of these operations in Australia facilitates collection of manure (see discussion of manure below). Developing-world demands for poultry and pigmeat are expected to increase rapidly, at 3.6 and 2.3 per cent per annum, respectively, to 2020 (Pinstrup-Andersen *et al.* 1999, p. 11).

Vaccination

Anti-methanogen vaccines have the potential to reduce methane emissions from cattle and sheep by 30 and 32 per cent, respectively (Allen Consulting 2000, p. 118).[87] Commercialisation of this technology is expected in the short to medium term (Allen Consulting 2000, p. 120). Accordingly, by 2050 it is highly likely that this technology will have achieved a high rate of adoption (estimated to be 100 per cent in feedlot and dairy cattle and 80 per cent in other cattle and sheep by 2050).

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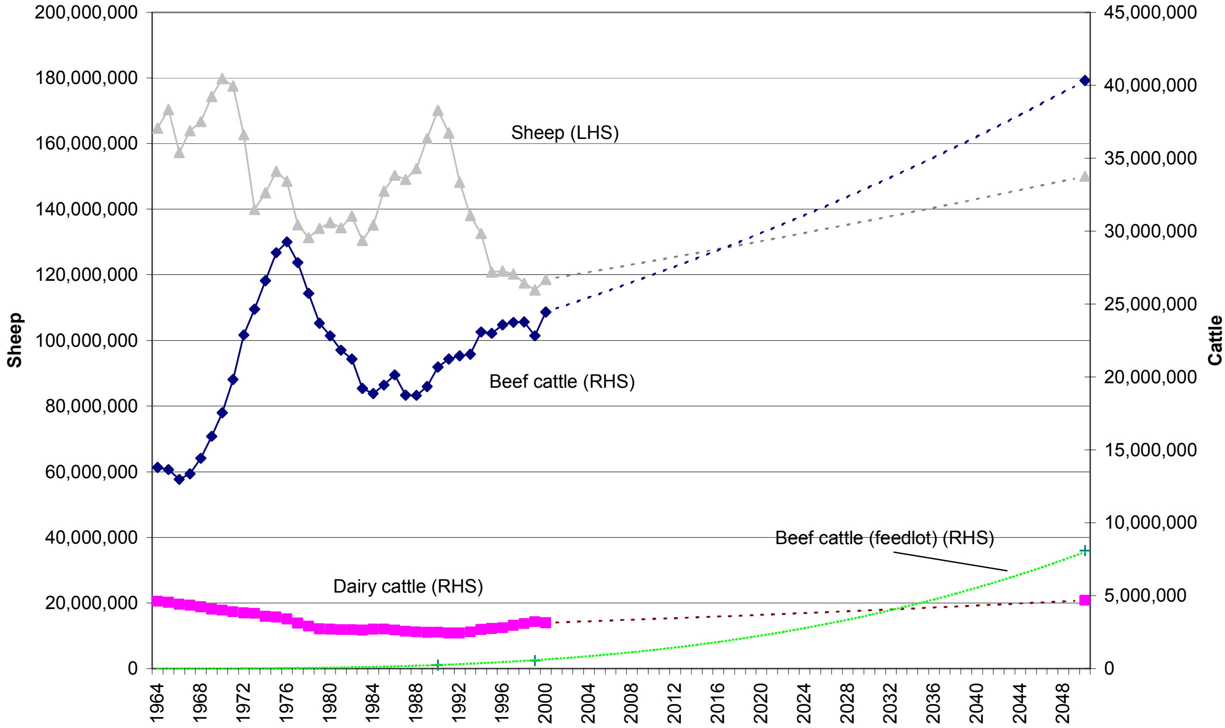
[86] Pasture digestibility ranges from 65-75 per cent (NGGIC 1996a, Appendix 1.6).
[87] Also, vaccines are expected to achieve 16 and 18 per cent reductions in N_2O emissions from beef cattle and sheep, respectively (Allen Consulting 2000, p. 118). This is discussed under Agricultural soils below.

Figure 22 Cattle and sheep numbers, 1964 to 2050



Source: ABS Yearbooks and State Statistical Summaries; projections as described in text.

Rice cultivation

Rice cultivation accounts for only around 0.15 per cent of Australia's emissions. Output of rice is not expected to expand as much as that of other crops.[88] It is expected that improved rice strains[89] and agricultural practices will completely offset any increase in methane emissions resulting from increased rice production so that there is no increase in total emissions from the rice cultivation sector.

Agricultural soils

Emissions of methane and nitrous oxide from agricultural soils[90] are produced from a number of sources, including soil disturbance, fertiliser use and animal wastes. Each of these is discussed below.

Soil disturbance

Emissions from soil disturbance can be reduced through a range of practices including reduced tillage, changes in rotations and cover crops, fertility management, erosion control and irrigation management (IPCC 2000b, Table 4.1). Improvements in

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[88] As incomes rise in developing countries, demand for rice is expected to plateau (Pinstrup-Andersen *et al.* 1999, p. 14).
[89] New crop breeds are expected to increase the productivity of rice by 50 per cent (Conroy *et al.* 2000, p. 138).
[90] Consistent with NGGI methodology, the emission and sequestration of CO_2 from agricultural soils is included in the LUCF sector, discussed below.

cultivation practices and new crop breeds[91] are expected to fully offset increases in agricultural activity (including expansion of area of crops and pasture, and increased cropping rates). Additional cropping may be necessary for the production of biomass for energy, such as sugar and starch crops for ethanol and oil crops for biodiesel. Accordingly, it is assumed that emissions of N_2O from soil disturbance in 2050 are roughly the same as in 1998-99.

Fertiliser use

Emissions from fertiliser use are related to the total amount of nitrogenous fertiliser applied combined with an emission factor estimating the amount of fertiliser nitrogen converted to N_2O. According to NGGIC (1996b, p. 14), 1.25 per cent[92] of the applied nitrogen is converted to N_2O under most conditions. This is assumed to remain unchanged through to 2050. Continued soil degradation and a desire to increase productivity will sustain growth in fertiliser use – doubling consumption by 2050, and resulting in a similar increase in emissions.

Animal wastes

Most of the emissions from animal wastes are from cattle and sheep. Because cattle and sheep numbers are expected to increase (see Section 12.2.1), the amount of waste is expected to increase proportionally. It is not expected that changes in feed will be able to significantly reduce the amount of nitrogen in animal wastes (and it may increase with high-protein diets).

In the case of feedlots and dairies it is assumed that animal manure can be collected relatively easily. Manure can also be readily collected from poultry operations and piggeries. Much manure is currently used as a fertiliser, and replacing it with synthetic fertilisers is expected to reduce N_2O emissions substantially,[93] as long as the manure was used for a purpose that did not allow the formation of large amounts of N_2O. An obvious application for this manure is energy production.[94]

By improving nitrogen uptake in cattle, anti-methanogen vaccines are expected to reduce N_2O emissions by 16 per cent in beef cattle and 18 per cent in sheep, while at the same time increasing animal weight (Allen Consulting 2000, p. 118).

Burning of savannas

It is assumed that burning of savannas will make no contribution to anthropogenic emissions in 2050. Current greenhouse gas accounting methodology suggests that most of the emissions from savanna burning would occur in the absence of human

[91] New crop breeds are expected to double the productivity of maize and increase productivity of wheat by 50 per cent and oats by 40 per cent (Conroy *et al.* 2000, p. 138).
[92] With an error of +/-1 per cent (NGGIC 1996b, p. 14).
[93] NGGIC (1996, p.14 and Table 6) suggest that the proportion of nitrogen in manure emitted as N_2O is around 40 per cent greater than the proportion from synthetic fertilisers. However, there is a high degree of uncertainty in these estimates.
[94] Depending on energy generation technology used it may be possible to largely avoid N_2O emissions from combustion of fuels derived from animal wastes. However, emissions of NO_x may be substantial and for this reason this fuel may be unsuitable for use in areas where air pollution may be a problem.

activity as a result of wildfires. Accordingly, emissions from burning of savannas are assumed to be zero in both the base year (1998-99) and 2050.

Field burning of agricultural residues

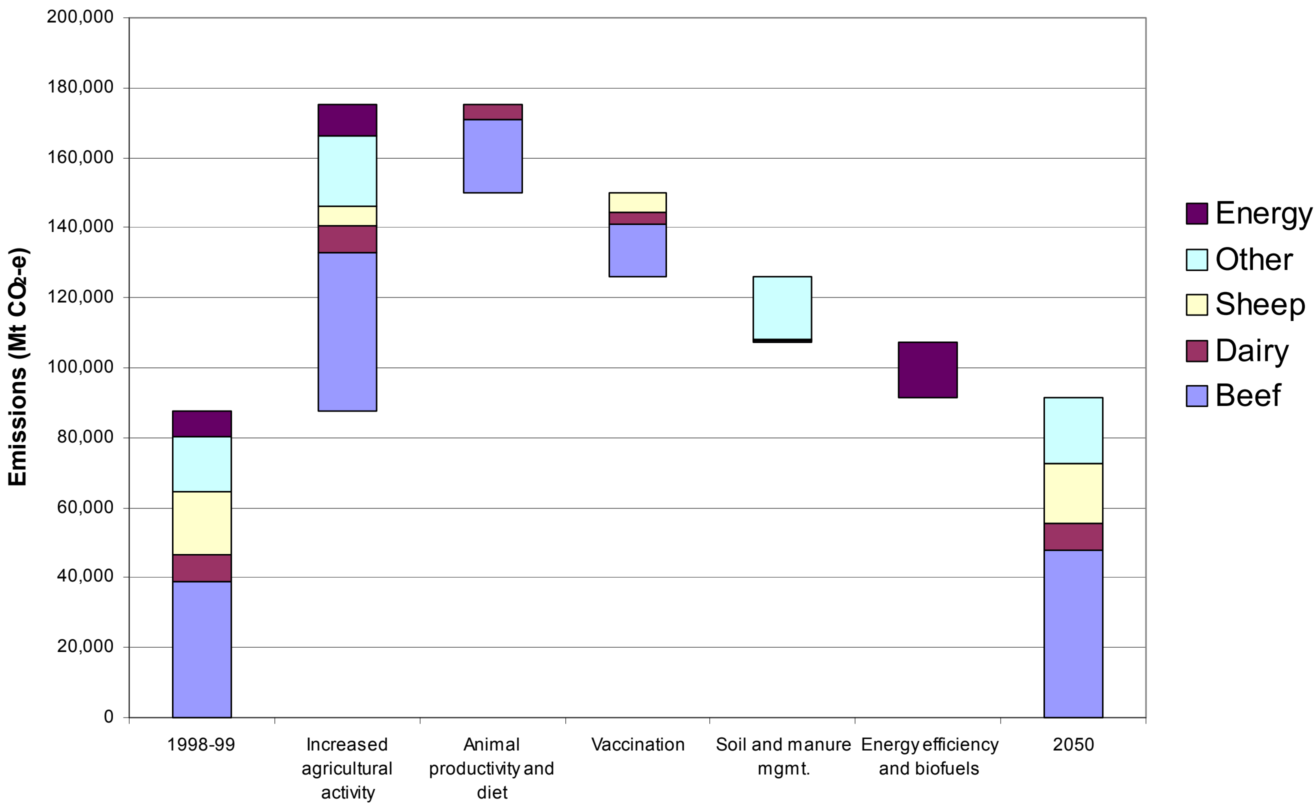
This makes a relatively small contribution to total emissions (0.1 per cent). By 2050 it is assumed that emissions from field burning of agricultural residues will be zero.

Currently, the main residues burnt are wheat stubble and sugar cane prior to harvest. Burning of stubble is becoming less common, and by 2050 it is assumed that it will no longer be in practice. Sugar cane burning is also becoming less common with the use of green harvesting technologies. Annual burning has been replaced with burning every three or four years. In the future, it is expected that sugar cane residues will be collected and burnt at a central location, possibly providing as much biomass energy as is currently obtained from sugar mill waste (bagasse).

Agriculture summary

The impacts of the various influences discussed above are summarised in Figure 23. Productivity improvements, shifting cattle to feedlots, use of methanogen vaccines, improved soil and manure management and the replacement of almost all agricultural energy needs with biofuels almost wholly offset the expected increase in emissions due to higher production in 2050.

Figure 23 Factors affecting emissions from agriculture, 1998-99 to 2050 (excludes land-use change and forestry)



12.3 Land-use change and forestry

In the medium term it is expected that Australia will meet greenhouse gas abatement targets through a combination of measures, including increasing forest and biomass stocks and eliminating land-clearing.[95] However, by 2050 there are likely to be few opportunities to sequester carbon or reduce emissions further (without geological or possibly marine sequestration).

Changes in forest and biomass stocks

It is assumed that by 2050 a majority of suitable sites will have been afforested or reforested, meaning that there will be almost no more forestation beyond 2050.[96] Some of the forests established between now and 2050 will still be relatively young in 2050 and will therefore still be acting as net greenhouse gas sinks. At the same time, forest harvesting will continue to grow with demand for biomass fuels and wood and paper products (and may expand further if forest products replace more energy-intensive materials). Accordingly, it is assumed that by 2050 forests (both old-growth and plantation) are in a carbon equilibrium.[97] Expanding the forest stocks will affect other agricultural activities since some of the sites appropriate for afforestation are currently used for other agricultural purposes.[98] The assumptions for agriculture are consistent with this, i.e., slow increase in fertiliser use and no additional soil disturbance, largest increases in extensive agriculture (cattle and sheep).

Forest and grassland conversion

Emissions from 'forest and grassland conversion' (i.e., land-clearing) accounted for 13.5 per cent of Australia's total emissions in 1998-99 (AGO 2001a, pp. A-5, A-35). Most of the continued clearing occurs in Queensland (AGO 2001b, p. A-13). It is the policy of both State and Federal Governments to end land-clearing in order to protect the land from degradation and to preserve biodiversity (see Hamilton and Vellen 1999). It is expected that net emissions from the clearing of native vegetation will be zero within a decade and remain so through to 2050. Some sequestration of carbon through revegetation of cleared land will occur, but it is assumed that the process of

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[95] Eliminating emissions from land-clearing is likely to be one of the cheapest forms of abatement available to Australia (Ryan 1997). Because Article 3.7 of the Kyoto Protocol (known as the 'Australia clause') permits countries with net emissions from land-use change and forestry in 1990 (comprising changes in forest and biomass stocks, forest and grassland conversion, abandonment of managed lands, CO_2 emissions and removals from soil and some other emissions) to count these emissions in their base year (1990) total on which the Kyoto target (108 per cent in Australia's case) was calculated, Australia is in a relatively unique position to achieve early abatement cheaply.

[96] There may be some small additional afforestation of agricultural land after 2050 or as heavily degraded land is rehabilitated and becomes suitable for afforestation.

[97] If forest harvesting emissions continue to increase at the rate of growth observed from 1990 to 1999, total emissions will be around 105 Mt CO_2-e in 2050. Accordingly, total forest sinks will be 105 Mt CO_2-e also, which is only a little over 30 per cent above current sequestration rates. However, by 2050 there will be an additional large stock of sequestered carbon (in balance) created over the period 2000-2050 to offset emissions from other sources during that period. It should be noted that forest sinks may need to be larger to offset additional emissions from forest harvesting to provide additional biomass for energy and replacements for some energy-intensive products (e.g. concrete, aluminium, plastics and other energy-intensive products).

[98] Although many are being degraded or are affected by salinisation or acidification (Foran and Mardon 1999, Table 2.1).

regrowth will be complete by 2050, so that forest and grassland conversion is neither a source nor a sink.

Soils

The IPCC estimates that improved productivity and conservation tillage can allow increases in soil carbon at an initial rate of around 0.3 t C/ha/yr (IPCC 2000b, p. 204). All unimproved pasture that is appropriate for improvement is assumed to have been converted to improved pasture well before 2050. Similarly, where minimum tillage is expected to increase soil carbon (which is only in Western Australia, see NGGIC 1997, p. 41) this increase is also assumed to occur well before 2050. Accordingly, soils are assumed to be neither a CO_2 source nor a sink in 2050.

Table 11 Current and projected emissions from agriculture, fisheries and forestry, 1998-99 and 2050

Sector (NGGI classification in parentheses)[a]	Emissions 1998-99 (kt CO_2-e)	Emissions 2050 (kt CO_2-e)
Energy used in agriculture	7,018	568
Agriculture (4)		
Enteric fermentation (4A)		
Beef cattle		
Feedlot	820	6,555
Non-feedlot	36,030	37,858
Dairy cattle	7,095	7,212
Sheep	16,087	15,598
Other	228	500
Manure management (4B)	2,364	
Beef cattle		
Feedlot	incl in total	0
Non-feedlot	0	0
Dairy cattle	incl in total	0
Sheep	0	0
Other (mainly pigs and chickens)	incl in total	0
Rice cultivation (4C)	669	669
Agricultural soils (4D)		
Soil disturbance (non-CO_2)	6,510	6,510
Fertilizer	5,422	10,844
Animal waste		
Beef cattle		
Feedlot	85	775
Non-feedlot	2,003	2,475
Dairy cattle	737	630
Sheep	1,564	1,745
Other	600	60
Burning of Savannas (4E)	0[b]	0[b]
Burning of residues (4F)	294	0
Land-use change and forestry (LUCF) (5)		
Changes in forest and biomass stocks (5A)	-23,069	0
Forest and Grassland Conversion (F&GC) (5B)	71,700	0
Abandonmnent of managed lands (5C)	0	0
CO_2 from soils (5D)	-4,224	0
Other (5E)	1,420	0
Total	**133,351**	**91,998**
Total minus F&GC	61,651	91,998
Total minus LUCF	87,524	91,998

a. Classifications used in AGO 2001a.

b. Anthropogenic burning of savannas is assumed to displace natural wildfires (NGGIC 1996b, p. 17). The 1998-99 greenhouse gas inventory estimates that total emissions from savanna burning were 13,343 kt CO_2-e (AGO 2001a, p. A-23).

13. Waste and fugitive emissions

13.1 Waste sector emissions

Greenhouse gas emissions from waste account for a small but significant share of Australia's total greenhouse gas emissions. In 1998-99, total emissions from waste were approximately 16 Mt CO_2-e or 3.5 per cent of national emissions (excluding land-clearing). Table 12 shows current and projected emissions by source. The factors affecting emissions from waste in 2050 are discussed below.

Solid Waste

Table 12 shows that most of the emissions from waste are generated from decomposition of solid waste disposed in landfills. There is significant scope to reduce these emissions, including diverting organic wastes to other uses and increasing the levels of methane capture and energy utilisation from waste.

Based on the information below, it is estimated that it is possible to reduce emissions from solid waste by around 75 per cent, to approximately 3,500 kt CO_2-e by 2050.

Improved landfill and waste management practices could reduce methane (CH_4) emissions from solid waste to approximately 5,300 kt CO_2-e by 2020 (or to around 64 per cent below current levels) (Meinhardt 2001). This would involve flaring of waste CH_4 on a majority of smaller landfills, improved CH_4 recovery efficiency, a high uptake of waste-to-energy technologies and reasonably high diversion rates for organic waste. By 2050 it is reasonable to assume that in addition to these measures, improved diversion rates will have been achieved for 'food' wastes and 'printing and writing paper wastes.'[99] These two waste streams contribute a significant proportion of the greenhouse emissions from the waste sector and hence further improvements from 2020 to 2040 will significantly reduce emissions by 2050.[100] Based on diversion rates of 65 per cent for food and 75 per cent for printing and writing paper, emissions

Table 12 Current and projected waste sector emissions, 1998-99 and 2050

Waste subsector	**Current emissions (1998-99) (kt CO_2-e)**	**Projected emissions (2050) (kt CO_2-e)**
Solid waste on land	14,595	3,500
Wastewater handling	1,386	280
Waste incineration	17	10
Other waste	NA	NA
Total emissions	**15,998**	**3,790**
		(24% of 1999)

Source: AGO 2001a, p. A-31 and derived from analysis below.

[99] For example, Meinhardt's (2001) estimates for 2020 assume only 40 per cent diversion of food wastes and 50 per cent for printing and writing paper wastes.

[100] Reductions in waste tonnage to landfill must occur prior to 2050 to have a significant effect on the 2050 inventory emissions, due to the long time period for decay of organic wastes in landfills.

will be reduced by a further 40 per cent, to around 3,500 kt CO_2-e (based on Meinhardt 2001).

Wastewater

There is also significant scope to reduce greenhouse emissions arising from wastewater treatment processes. The main options involve moving from anaerobic to aerobic digestion (or other treatment technologies), or capturing and utilising CH_4 from treatment plants that continue to rely on anaerobic digestion technology.

Between now and 2050, most existing and all new wastewater treatment systems (both municipal and industrial) will move to aerobic digestion or CH_4 capture. In addition, continued expansion of sewerage systems is likely to reduce the unsewered population by 2050, leading to a decrease in emissions as a result of a larger population being served by systems using CH_4 capture and aerobic digestion.

A 50 per cent increase in CH_4 utilisation (excluding flaring) is predicted to reduce total emissions from wastewater by 25 per cent by 2020 (Meinhardt 2001). A similar increase in capture for flaring or other industrial purposes by 2020 would result in a substantially larger decrease in emissions. Emissions from industrial wastewater treatment could also be expected to decrease due to a possible tighter regulatory regime concerning both water consumption and 'grey water' reuse.

Overall, it is estimated that emissions from wastewater treatment could be reduced by up to 80 per cent, to approximately 280 kt CO_2-e by 2050.

Incineration

It has been assumed that the emissions from waste incineration will fall from approximately 17 kt CO_2-e per annum to 10 kt CO_2-e. Although no formal projections reports have been consulted at this stage, a decrease in these emissions can be expected in response to increasing community concern about local air pollution, in addition to greenhouse issues.

13.2 Fugitive sector emissions

Fugitive emissions arise principally from coal mining and petroleum-related processes, including extraction, distribution and processing. These are dealt with separately below.

Coal-mining emissions

In 1998-99, fugitive emissions from coal mining were approximately 18.3 Mt CO_2-e.[101] Table 13 shows fugitive emissions from coal mining by activity.

There are two key determinates of future fugitive emissions from coal mining – future coal production levels and the uptake of waste coal mine gas (WCMG) capture.

Because most of Australia's coal production is exported, domestic production in 2050 will be heavily influenced by global demand for coal, which will depend largely on greenhouse policies implemented in other countries between now and then. However, as discussed in Section 2, it is assumed that Australia would only seek to cut domestic greenhouse gas emissions by 60 per cent if similar action were being undertaken throughout the world. Accordingly, based on the IPCC global scenario most closely matching a global deep cut in emissions (the B1T-MESSAGE scenario), global coal demand will decrease by almost 55 per cent from 91 EJ in 2000 to 39 EJ in 2050. Assuming that Australia holds a slightly larger share of the global coal market in 2050, this leads to an overall decrease in coal production to approximately 50 per cent of current levels.[102]

It is assumed that there is a significant increase in the quantities of WCMG captured by 2050. However, the potential for this is limited when the decrease in overall coal production is considered, especially when more expensive underground mines (which are most amenable to WCMG capture) are likely to be closed first. It has been

Table 13 Fugitive emissions from coal mining, 1998-99

Coal mining activity	Emissions ($kt\ CH_4$)
Underground mines	605.7
- underground activities	575.8
- post-mining activities	29.9
Surface mines	267.7
- surface activities	267.7
- post-mining activities	NE
Total coal mining	**873.4**

NE: not estimated (from original source)
Source: AGO 2001a, p. B-98

[101] Total CH_4 emissions from coal mining were 873.4 kt. Based on a global warming potential of 21 t CO_2-e/t CH_4, emissions were 18.34 Mt CO_2-e.
[102] This percentage reduction has been applied to all types of coal production, and post production emissions, despite the likelihood that more expensive underground coal mines (which produce most of the emissions) will be closed in preference to open cut mines.

Table 14 Fugitive emissions from coal mining, 2050

Coal mining activity	Emissions (kt CH_4)
Underground mines	52
- underground activities	44
- post-mining activities	8
Surface mines	134
- surface activities	134
- post-mining activities	NE
Total coal mining	**186**

assumed that approximately 250 kt CH_4 will be captured each year by 2050. Emissions could be reduced further if mining of gassy coal seams were phased out.

Table 14 shows the expected emissions in 2050 if the above assumptions are applied. Overall, it is estimated that the potential reduction in fugitive coal-related emissions is in the order of 80 per cent, to approximately 3.9 Mt CO_2-e by 2050.

Petroleum-related emissions

Current petroleum-related fugitive greenhouse emissions are approximately 12.5 Mt CO_2-e (1999). The breakdown of these emissions is shown in Table 15. Emissions arise mainly from venting, flaring and gas distribution, each of which is discussed in turn.

Venting

It is assumed that by 2050 all major natural gas resource projects where the gas contains a high concentration of CO_2, or where a large volume of CO_2 is present, utilise re-injection where appropriate geological storage sites are available. This would apply to all major current projects under consideration, most notably Gorgon (in the Carnarvon Basin), and also to any future domestic or international gas supply projects with a significant emissions profile. It is also assumed that gas fields with a low concentration of CO_2 are developed in preference to those with a high concentration.[103] It is also likely that by 2050 Australia will obtain a substantial share of its gas supply from either PNG or the East Timor Gap, and the emissions associated with these sources will not be the direct responsibility of Australia.[104] Methane emissions associated with acid gas stripping are also assumed to be reduced in proportion with emissions from CO_2 venting, while other venting-related emissions of CH_4 are assumed to remain at 1998-99 levels as a result of efficiency and process improvements offsetting increases in production.[105]

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[103] Consistent with this assumption, it is also assumed that there will be little or no production from the Cooper/Eromanga Basin, currently a basin with high average CO_2 content.
[104] It should be noted that Australia will be responsible for a small proportion of the fugitive emissions from East Timor Gap gas fields.
[105] These emissions of CH_4 are associated with compressor seal gas systems, other process venting and relief venting.

Table 15 Fugitive emissions from petroleum and gas, 1998-99

Activity	Fuel quantity handled (PJ)	Emissions		
		(kt CO_2)	(kt CH_4)	(kt N_2O)
Oil	**NA**	**286.9**	**3.0**	**0.0**
Exploration (for both oil and gas)	NA	56.1	0.6	0.0
Crude oil production	1032.2	NA	0.2	NA
Crude oil transport: domestic	87.5	NA	0.1	NA
Crude oil refining and storage	1669.5	230.8	2.1	0.01
Petroleum product distribution	1121.7	NA	NA	NA
Other	NA	NA	NA	NA
Natural Gas	**NA**	**7.5**	**145.6**	**NA**
Production and processing	1306.1	NE	1.4	NA
Transmission	776.0	0.4	7.2	NA
Distribution	385.7	7.1	137.1	NA
Other	NE	NE	NE	NE
Venting and Flaring	**NA**	**6188.0**	**136.8**	**0.1**
Venting at gas processing plant	1306.1	3148.4	108.7	NA
Distributed venting	880.7	738.4	NA	NA
Flaring	2441.8	2301.3	28.1	0.06
Not included in totals	**NA**	**NA**	**1.3**	**NA**
Crude oil transport: exports	528.5	NA	0.4	NA
Crude oil transport: imports	1150.6	NA	0.9	NA

NA: not applicable (from original source)
NE: not estimated (from original source)
Source: AGO 2001a, p. B-99

Therefore it is expected that CO_2 emissions from venting decrease from approximately 3,100 kt CO_2 to approximately 500 kt CO_2 (an 85 per cent reduction). A corresponding decrease in CH_4 emissions from acid gas stripping and other venting-related activities reduces overall emissions from venting to approximately 1.7 Mt CO_2-e (from 5.4 Mt CO_2-e), equivalent to a 70 per cent reduction.

Flaring

In the short-term, emissions from flaring are expected to decline, continuing the trend of the previous 10 years. Declining domestic production of crude oil and condensate will ensure that emissions from flaring continue to decrease.[106] In addition, the increasing attractiveness of natural gas is assumed to result in a shift away from developing offshore liquids projects without co-development of gas projects.

Based on the above assumptions, emissions from flaring are expected to decrease from 3,188 kt CO_2-e in 1998-99 to approximately 500 kt CO_2-e in 2050, representing almost an 85 per cent reduction.

[106] Production is expected to decline to 60 per cent of current levels by 2015 (at 50 per cent probability) (Geoscience Australia 2001).

Gas distribution

The extent of the natural gas distribution network is expected to continue to increase into the future, particularly considering the likely substitution of more greenhouse gas intensive fuels by natural gas, and the future attractiveness of gas cogeneration. Overall volumes of gas may also increase from current levels. These factors are likely to drive an increase in emissions from gas distribution.

However, the expansion of the network, and demand for increased volumes, may be offset by improvements in the delivery infrastructure. For example, between 1990 and 2000 emissions from gas distribution in NSW and the ACT declined by 70 per cent. This was mostly due to the 'Goldline project' which relined the entire Sydney low-pressure distribution system. It is assumed that further improvements are made to the NSW distribution system, achieving an additional 5 per cent savings on 1999 emissions by 2050. Both the Victorian and SA distribution systems are also assumed to be either retro-fitted or replaced between now and 2050, achieving a 50 per cent reduction in emissions from gas distribution.[107] All other States and Territories are assumed to have identical emissions to the current 1999 levels in 2050.

Overall, major pipe re-lining measures in the next 50 years are projected to constrain emissions by 2050 to approximately 2,200 kt CO_2-e – a 25 per cent decrease on 2,890 kt CO_2-e in 1998-99.

Overall 2050 projected emissions for the petroleum sector

Declining production and consumption of petroleum fuels and the various abatement activities listed above will result in an overall reduction in petroleum-related emissions of approximately 60 per cent from 1998-99 levels by 2050. Total emissions in 2050 are estimated to be around 4.9 Mt CO_2-e or almost a 60 per cent reduction in emissions from 1999 levels.[108]

Total fugitive sector

Based on the information for coal mining and petroleum and gas operations above, fugitive emissions are projected to decline from 30.8 Mt CO_2-e in 1998-99 to approximately 8.8 Mt CO_2-e in 2050.

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[107] This is somewhat lower than the reduction achieved in NSW, owing in part to the relative age of the distribution systems.
[108] Note this assumes no change in other petroleum related fugitive emissions.

14. Energy supply

14.1 Stationary energy

A number of approaches can be applied to determine the mix of energy sources that will supply Australia's stationary energy demand in 2050. However, as discussed in Section 2, the uncertainty over the 50-year time horizon used in this study precludes the application of a least-cost approach (where costs are estimated for each energy source or generation technology according to installed capacity and technologies are then selected with the aim of satisfying energy demand while minimising total energy costs). As an alternative, it is possible to estimate the annual exploitable resource for each energy source (hydro, natural gas, coal, biomass etc.) and then choose the combination that meets energy demand with the lowest greenhouse gas emissions. Unfortunately, without a thorough resource assessment, this approach ignores diseconomies of scale and cost altogether.[109]

The approach taken here is a combination of the above. It accepts there is a large degree of uncertainty about future energy system costs and capacities (and constraints affecting the fuels that can be used by different sectors), but that it is possible to draw some broad conclusions with respect to both (see Section 4 for discussion of trends in electricity generation technology costs). In addition to creating uncertainty, the almost 50-year timeline also allows for considerable flexibility to develop an appropriate energy system.

Balancing demand with supply

After analysing in the previous sections the potential to reduce emissions and energy demand in other sectors, it is possible to determine the maximum allowable emissions from the energy sector that still enable Australia to achieve an overall reduction in emissions of 60 per cent by 2050. It is then possible to work backwards and estimate the maximum amount of fossil fuel that can be combusted without exceeding the allowable emissions from the energy sector.

The next step is to examine whether this amount of fossil fuel is sufficient to supply those energy needs (after energy efficiency improvements) that cannot be met by renewable energy resources because of constraints on capacity, delivery, availability or quality. For example, constraints on the availability of suitable agricultural land (for biomass) and appropriate sites for wind turbines virtually rule out supplying all energy needs with renewable electricity, since this would require mass exploitation of natural resources to ensure a large, continuous and reliable supply. Other constraints arise because some renewable fuels are inappropriate where high quality heat is required (such as in a blast furnace), or their delivery is restricted (such as distributing solid biomass to all commercial and services sector sites).

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[109] For example, there is almost no relevant physical constraint on the installation of solar PV electricity generation capacity to meet Australia's future energy needs. Accordingly, this approach would advocate exploiting PV to meet all energy needs, even though it is almost certain that the cost of electricity generated from PV will remain well above that from other renewables and fossil fuels.

The relevant constraints on fuel use, and the most efficient means of meeting energy demand in each major sector are examined below. An energy balance for 2050, incorporating the various constraints, is presented in Table 17.

Manufacturing and mining

In the manufacturing and mining sector, constraints on fuel switching are determined by which particular process or equipment type is used, and also by individual sub-sectoral constraints. For a number of industrial processes and equipment types it will be necessary to continue to use fossil fuels. In particular, coal will continue to be processed through coke ovens and then used in blast furnaces in the iron and steel industry, and natural gas will continue to be used for metallurgical equipment in the mining, iron and steel and non-ferrous metals industries. In addition, electricity will continue to be necessary for electrolytic equipment and operating motors.

However, throughout the industrial sector there would appear to be little stopping the conversion of a large number of industrial boilers to cogeneration, which will increase fuel consumption but provide a share of each industry's electricity needs. In this study it is conservatively assumed that only half of the steam demand supplied by industrial boilers can be converted to cogeneration, resulting in an average electricity generation efficiency of only 13 per cent across all industrial boilers (both cogeneration and other). Where cogeneration boilers are already used, changes in steam loads and improvements in operation and technology are expected to increase electricity generation efficiency to an average of 20 per cent in 2050 (up from an estimated 9 per cent in 1998-99, see Bush *et al.* 1999, pp. 115-28; ABARE energy data). In addition, it is feasible to convert all boilers to operate on natural gas, solid biomass (where available)[110] or biogas produced from biomass gasification (since this fuel can be used for producing steam just as readily as fossil fuels).

The other major industrial equipment types – kilns (used in the chemicals, cement and non-ferrous metals industries) and dryers – are also amenable to conversion to cogeneration but require higher temperature heat, reducing the electricity that can be generated. However, it is conservatively assumed that the amount of electricity from this source is negligible.[111] Kilns and dryers can be powered by biogas and it is assumed all are converted/replaced to operate on this fuel between now and 2050.

Developing the infrastructure to deliver renewable fuels to satisfy thermal demand at industrial sites may be the largest hurdle to achieving a major fuel switch in the manufacturing sector. For some industries this hurdle may be insurmountable – for example, it may not be feasible to supply biomass fuels (the only suitable thermal fuel) to the power generation turbines used in offshore oil and gas extraction and gas processing operations. On the other hand, some industries already have access to a large supply of biomass, particularly the food, beverages and tobacco manufacturing

[110] That is, in those industries with direct access to solid biomass, including: the food, beverages and tobacco industry; the wood and paper products industry; and the chemicals industry, which is discussed below.

[111] Because of the requirements for higher temperature heat and the unsuitability of some equipment or processes for conversion to cogeneration, it is likely that around only 5 per cent of the energy used in these pieces of equipment can be converted to electricity. Accordingly, it is likely that it will not be cost-effective to install cogeneration equipment in all but a few operations.

industry and the wood and paper products industry. It will be relatively simple for these industries to obtain biomass fuels. For industries that continue to rely on fossil fuels for almost all their energy needs, such as the iron and steel industry, access to biomass fuels is largely irrelevant.[112] However, for some industries, including the chemicals, non-ferrous metals and non-metallic mineral products industries, there is not an obvious existing biomass supply available.

Fortunately, much of the existing gas transmission and distribution infrastructure can be utilised to deliver biogas to these sites. Accordingly, instead of developing infrastructure for solid biomass distribution, it is merely necessary to develop sufficiently large biomass gasification capacity, located within biomass production areas and connected to the existing gas distribution system. Biogas production is also relatively energy efficient, with current gasification technology producing gas containing 70-80 per cent of the energy in the biomass feedstock (OOE 2002) and is the first step in methanol and hydrogen production (Foran and Mardon 1999, p. 32, Figure 1).

In the case of the petroleum and chemicals industry, a shift to bio-liquid fuel production, and some substitution of biological feedstock for petroleum in chemical production, will facilitate decentralisation and relocation of the industry to agricultural areas with improved access to biomass feedstock. One possible scenario is that many small to medium liquid fuel production facilities will be spread throughout energy cropping, waste and forestry regions. These facilities will process a combination of biomass inputs to produce biodiesel, biogas, hydrogen and methanol/ethanol and may be co-located with food, beverages and tobacco or wood and paper industry sites.

Commercial and residential

The commercial and residential sectors will continue to rely on electricity for operating office equipment and domestic appliances, in addition to lighting and some cooling. All other energy requirements could also be met with electricity, but this would be an inefficient way of using limited suitable renewable energy sources.

Accordingly, gas or biogas cogeneration (either fuel cell or microturbine) will supply a large proportion of energy demand in the residential and commercial sectors, including demand for electricity. In the residential sector, the heat from cogeneration will be used for space heating and for water heating requirements not met by solar thermal. In the commercial sector, waste steam will be used to drive heating and absorption chillers. Ventilation equipment, lighting and appliances will continue to operate on electricity, some of which will be produced by cogeneration. Natural gas will be used directly for cooking and for boosting solar hot water systems.

Although solid biomass currently supplies a large share of residential energy demand, substituting gas or biogas avoids problems with large-scale biomass delivery (and can improve efficiency while reducing urban air pollution). This also applies to the commercial sector, where it is infeasible to deliver solid biomass fuel to shops, offices, schools and hospitals. In addition, gas cogeneration systems are simpler to

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[112] Although it is possible for the iron and steel industry to use charcoal instead of coal – for example, the iron and steel industry in Brazil consumed around 165 PJ of biomass in 1999 (IEA 2001a, p. II.63).

operate than solid-fuel boiler-type or gasification-type equipment, ensuring that cogeneration equipment installed in residential or commercial premises operates efficiently.

Agriculture and construction

Agriculture and construction rely almost entirely on transport fuels (which are discussed below). However, their stationary energy requirements also include a small amount of electricity and natural gas. It is assumed that these industries will continue to rely on a similar fuel mix in 2050.

Overall stationary energy sector

The overall impact of the various fuel-switching and cogeneration options discussed above, combined with the various measures outlined in Sections 8, 9 and 10, on greenhouse gas emissions from stationary energy demand is summarised in Table 16. It should be noted that more aggressive energy efficiency would further reduce the amount of renewable electricity required.

The stationary energy supply assumptions above, when combined with energy efficiency potential, suggest that around 60 PJ of black coal and around 1,460 PJ of natural gas will be necessary with the economic structure and energy efficiency technologies discussed in previous sections. Of the natural gas, around 850 PJ will be used in cogeneration across industry, commerce and households. Other thermal fuels include solid biomass, with around 140 PJ used directly in industry, and another 495 PJ used in cogeneration boilers. In addition, almost 350 PJ of biomass will be required for the production of around 240 PJ of biogas that is reformed and purified into hydrogen for use in transport. Additional biomass (around 345 PJ) is required for biodiesel production, also mainly for transport use.

A total of around 880 PJ of electricity will be needed for final consumption, although cogeneration will supply around 310 PJ of this. This leaves around 570 PJ of electricity required to supply remaining stationary energy demands. An additional 30 PJ of electricity is necessary for the production of additional hydrogen for transport. Transmission and distribution losses are also estimated to be around 85 PJ, requiring

Table 16 Factors affecting stationary fuel combustion emissions under the deep cuts scenario, 1998-99 to 2050

	Current stationary energy emissions (1998-99)	**Changes between 1998-99 and 2050**						**Projected stationary energy emissions (2050)**
		Increased activity	**Energy efficiency**	**Cogeneration**	**Fuel switching to gas**	**Fuel switching to biomass/solar thermal**	**Renewable electricity**	
	(kt CO_2-e)	(kt CO_2-e)	(kt CO_2-e)	(kt CO_2-e)	(kt CO_2-e)	(kt CO_2-e)	(kt CO_2-e)	(kt CO_2-e)
Industry	142,823	187,510	-109,799	-29,146	-3,607	-53,887	-76,975	56,919
Commercial	44,924	103,886	-81,337	-41,832	-7,768	0	-9,683	8,191
Residential	57,099	47,194	-32,569	-16,229	1,027	-19,174	-25,713	11,634
Total stationary	**244,846**	**338,590**	**-223,706**	**-87,207**	**-10,348**	**-73,061**	**-112,371**	**76,744**

Note: May not sum, due to rounding.

total generation from renewable electricity of 690 PJ, after the impact of cogeneration is included. In all, total generation of about 1,000 PJ will be required.

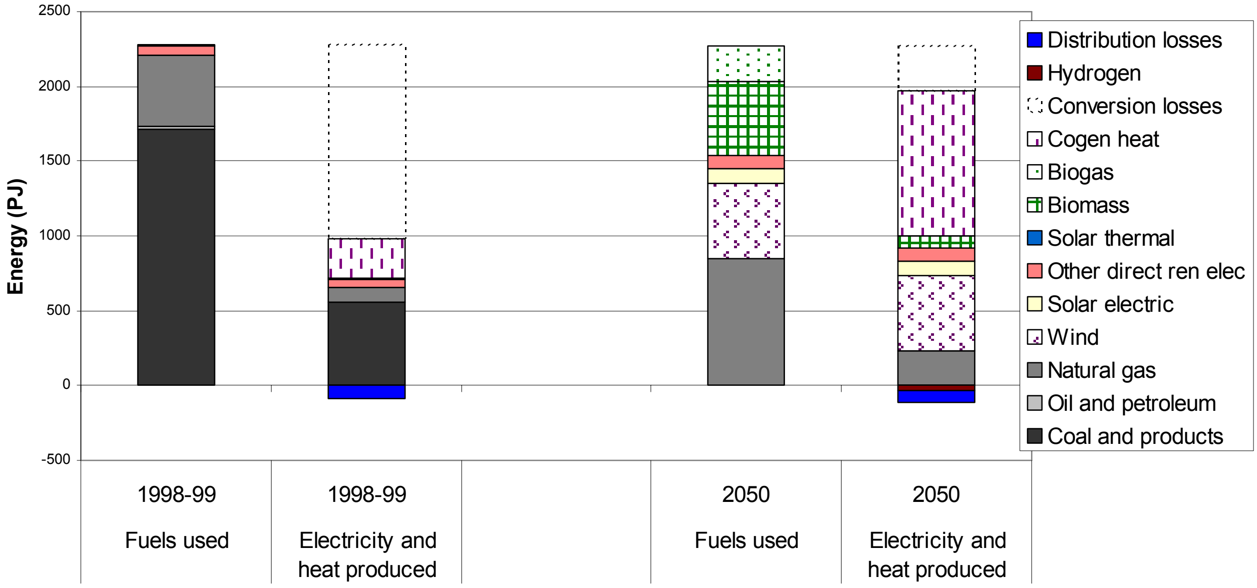
Wind power is expected to supply the majority of this electricity, with around 500 PJ of generation (50 per cent of the total electricity production) supplied from over 11,000 four megawatt turbines mostly spread along the southern coastline, with some located inland and others offshore.

Existing large-scale hydroelectric generation currently supplies around 59 PJ (Dickson *et al.*, p. 65). It is expected that no new large-scale hydroelectric projects will be built, but efficiency improvements and small-scale hydro developments may be able to increase hydro generation. Combined with other small-scale renewable generators not discussed elsewhere, around 90 PJ is expected (around 9 per cent of total generation).

Solar thermal electric and solar PV are optimistically assumed to supply around 100 PJ of electricity (around 28,000 GWh, or 10 per cent of total generation).[113] This is a challenging but feasible target, with solar operating in all niche markets, particularly in attenuating summer peak demand.

Figure 24 shows electricity, heat and hydrogen production in 1998-99 and 2050, including the amount of each fuel used, and the amount of electricity produced from each source.

Figure 24 Electricity, cogeneration heat and hydrogen, 1998-99 and 2050



14.2 Transport energy demand

After accounting for energy efficiency, around 815 PJ of transport fuels is necessary to supply energy requirements in the transport, agriculture and construction sectors.

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113 Amounting to around three times the existing new renewable electricity requirements of the Federal Government's Mandatory Renewable Energy Target (MRET).

In 2050, half of all road vehicles are expected to be powered by fuel cells. These vehicles will require almost 110 PJ of hydrogen (which will be generated through electrolysis of water with 30 PJ of electricity and directly from biomass gasification and shift reaction, requiring around 240 PJ of biogas (see Foran and Mardon 1999, Table 4.3, p. 38)),[114] although this will displace the need for 295 PJ of other transport fuels.[115] Road transport will require another 295 PJ of either petroleum or liquid biofuels (natural gas is not expected to play a major role in transport – see Section 11). Other land-based consumers of transport fuels, comprising agriculture, construction and lawnmowers, will demand around 110 PJ in 2050.

Domestic aircraft will need around 90 PJ and coastal shipping around 25 PJ or transport fuels, while railways are projected to require around 40 PJ of electricity.

After taking into account the 110 PJ of hydrogen used in transport, an additional 520 PJ of transport fuels is required. If it is assumed that around half of all domestic aircraft continue to rely on petroleum fuels, as does a small amount of marine shipping, then at most 470 PJ of liquid biofuels would be required to satisfy all other transport needs. Based on production efficiency for methanol in Foran and Mardon (1999, Table 4.3), this would require around 1,300 PJ of woody biomass.[116] However, the efficiency for biodiesel production is significantly higher, and would require only 590 PJ of biomass inputs for the same amount (assuming all energy inputs come from biomass) (NREL 1998, Section 2.4.1.1). In this scenario it has been assumed that agricultural, construction and most marine vehicles use biodiesel. It is also assumed that biodiesel accounts for half of all the non-hydrogen fuels used by road vehicles (accounting for almost all freight vehicles and some passenger vehicles), requiring a total of 275 PJ of biodiesel. Because of the low conversion efficiency for other liquid biofuels it has been assumed that the remaining 245 PJ of fuel is petroleum-based.[117]

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[114] Overall conversion efficiency of methanol production (excluding plantation, harvesting and transport) is 35 per cent (Foran and Mardon 1999, p. 38). Hydrogen is produced during this process and used as a precursor in the production of methanol, but can be purified and used elsewhere. It has been assumed that when the energy in the other synthesis gases is used, the overall efficiency of hydrogen production from biogas is also 35 per cent. Electrolysis is assumed to be 80 per cent efficient.

[115] In an internal combustion engine, 80-85 per cent of the energy in the fuel is lost in the conversion from chemical to kinetic energy. In contrast, current fuel cells convert 40-65 per cent of hydrogen's energy to electricity (and this is expected to improve with refinements in the technology) (see http://www.rmi.org/sitepages/pid540.php). Assuming 80-90 per cent of electricity generated from fuel cells is converted to kinetic energy, each unit of hydrogen fuel delivers around 2.7-times more kinetic energy than petroleum or biomass used in an internal combustion engine. This improvement also applies relative to hybrid vehicles because they obtain all their energy from an internal combustion engine, although they use no energy while idling and can use regenerative breaking to recycle kinetic energy (both of which can also be done by a fuel cell vehicle).

[116] It should be noted that methanol production is more efficient than ethanol production (Foran and Marden 1999).

[117] The large quantity of biomass required to produce enough methanol or ethanol may limit the availability of biomass for biogas production or direct thermal use, where efficiency is much greater. This would necessitate additional consumption of enough natural gas to more than offset any benefits arising from reduced petroleum consumption.

Military vehicles and lubricants

Emissions from military vehicles are assumed to remain unchanged from 1998-99 levels in 2050. This reflects the impact of increased efficiency offsetting any additional activity. It is also likely that land-based military vehicles will be converted to operate on biofuels, which have the advantage that they can be manufactured from biomass in the field.

Demand for lubricants is expected to drop substantially with the shift to fuel-cell vehicles. In addition, the development of a large-scale biodiesel and ethanol industry may facilitate the production of bio-lubricants. Overall, emissions from lubricants in 2050 are assumed to remain at the 1998-99 level.

14.3 Energy balance for 2050

The information above is summarised in Table 17, which shows the supply, conversion and final consumption of each fuel by each sector. It also includes estimates of exports and imports of fossil fuels in 2050. Figure 25 presents primary supply and energy for final consumption according to fuel type for 1998-99 and 2050.

Figure 25 Energy supply and consumption, 1998-99 and 2050

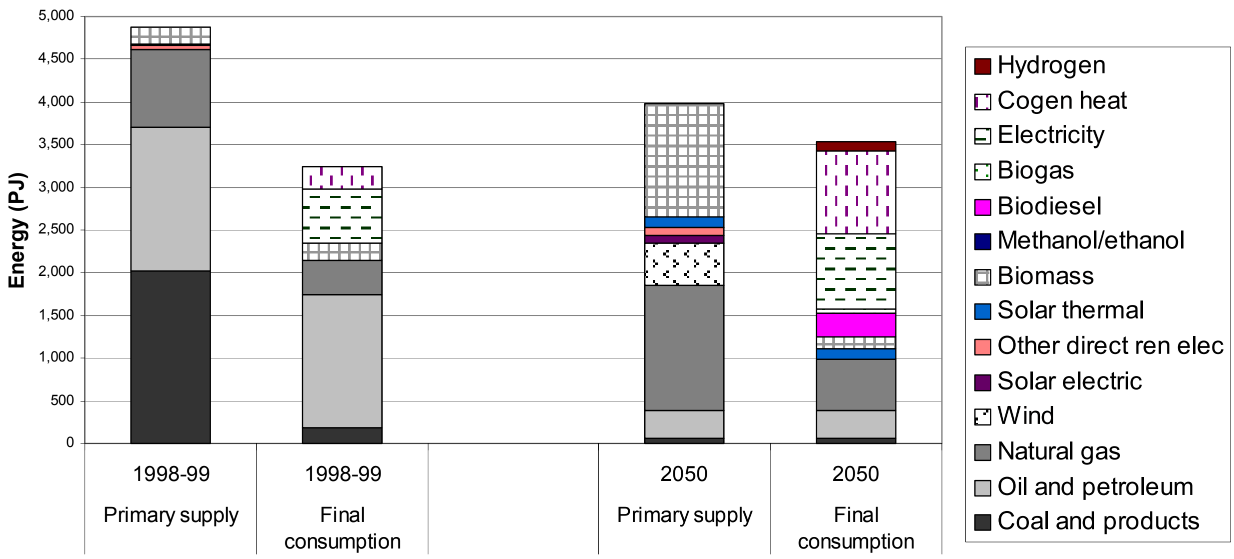

Table 17 Energy supply and disposal, 2050

	Coal and products PJ	Oil and petroleum PJ	Natural gas PJ	Wind PJ	Solar electric PJ	Other direct ren elec PJ	Solar thermal PJ	Biomass PJ	Methanol/ ethanol PJ	Biodiesel PJ	Biogas PJ	Electricity PJ	Cogen heat PJ	Hydrogen PJ	Total PJ
Supply															
Production[a]	2,400.0	0.0	4,000.0	500.0	100.0	90.5	114.8	1,331.3							**8,536.6**
Imports[a]		421.8	0.0					0.0							**421.8**
Exports[a]	-2,341.3	0.0	-2,536.3					0.0							**-4,877.6**
Intl Bunkers[a]		-100.0													**-100.0**
Primary energy supply	**58.7**	**321.8**	**1,463.7**	**500.0**	**100.0**	**90.5**	**114.8**	**1,331.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3,980.8**
Conversion															
Electricity generation				500.0	100.0	90.5		0.0				-690.5			**0.0**
Biomass (solid) cogeneration (FBT, Wood, Chemical)								493.5				-80.5	-409.4		**3.7**
Commercial/residential cogeneration			430.2								0.0	-154.9	-219.5		**55.8**
Biogas production								350.5			-280.4				**70.1**
Cogeneration (other industries)			419.3								0.0	-76.2	-341.6		**1.5**
Bioliquid production								345.5	0.0	-276.4	0.0				**69.1**
Hydrogen production								0.0			241.5	31.2		-109.4	**163.2**
Distribution losses												84.6			**84.6**
Final domestic availability	**58.7**	**321.8**	**614.2**	**0.0**	**0.0**	**0.0**	**114.8**	**141.7**	**0.0**	**276.4**	**38.9**	**886.2**	**970.5**	**109.4**	**3,532.8**
Final demand															
Coal, oil and gas			143.3					0.0				14.5	21.9		**179.7**
Mining (non-energy)			51.5								3.1	88.4	9.2		**152.2**
Gas production and distribution			30.5					0.0				0.3	0.0		**30.8**
Petroleum and coal products			13.1								1.8	0.8	9.2		**24.8**
Iron and steel	58.7		67.5								1.2	7.8	25.1		**160.3**
Food, beverages, tobacco			0.0					7.1				21.7	233.4		**262.3**
Chemicals			0.0					128.4				27.5	62.4		**218.3**
Cement, lime, plaster and concrete			39.7								5.4	5.3	0.6		**51.0**
Other non-metallic mineral products			41.1								5.6	6.0	1.6		**54.3**
Non-ferrous metals			161.5								15.5	232.3	240.9		**650.3**
Wood, paper and printing			0.0					6.2				29.7	113.7		**149.5**
All other manufacturing			22.6								0.6	38.5	32.9		**94.6**
Commercial			25.6								3.5	141.7	141.3		**312.0**
Residential			16.3				114.8				2.2	222.7	78.2		**434.3**
Construction		0.0	1.6					0.0		48.4		0.2	0.0		**50.3**
Agriculture		0.0	0.0					0.0		59.9		10.2	0.0		**70.1**
Road transport		147.7							0.0	147.7				109.4	**404.9**
Rail transport												38.7			**38.7**
Air transport (domestic)		91.4							0.0						**91.4**
Water transport (domestic)		4.6								20.4					**25.0**
Lubricants, greases, bitumen and solvents (oxidised component counted elsewhere)		58.2													**58.2**
Military and recreational vehicles (counted elsewhere)		19.9													**19.9**
Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note: May not sum, due to rounding. a. For coal, oil and gas, these figures are estimates consistent with primary energy supply.

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Appendix

Table A1 Economic growth by sector, 1998-99 to 2050-51

Sector	Gross value-added, 1998-99 ($ million)	Annual growth rate %	Gross value-added, 2050-51 ($ million)
Beef cattle	1,780	1.49	4,617
Forestry and logging	463	2.38	1,571
Other agriculture and fishing	17,183	1.59	39,014
Coal; oil and gas	13,080	-0.82	7,756
Mining (non-energy)	10,864	2.08	31,620
Food	13,415	1.58	30,248
Wood, paper, printing, publishing	12,177	2.08	35,443
Cement, lime etc.	1,224	1.08	2,135
Other non-metallic minerals	2,927	1.08	5,106
Iron and steel	3,938	0.58	5,308
Non-ferrous	3,590	2.08	10,448
Chemicals	8,139	2.08	23,690
Other manufacturing	27,019	1.97	74,468
Petroleum and coal products	1,433	-2.00	501
Electricity	8,423	2.50	30,416
Gas	1,005	2.50	3,629
Water, sewerage and drainage	4,101	1.08	7,154
Trade	62,375	2.08	181,552
Financial, legal, property & business services	134,468	2.08	391,390
Health and education	56,471	2.73	228,649
Govt and defence	22,904	2.08	66,666
Communication services	18,922	2.73	76,614
Scientific research etc	15,062	2.38	51,068
Accommodation, cafes & restaurants	13,204	2.73	53,462
Sport, gambling etc	4,992	2.73	20,211
Community services	3,163	2.38	10,724
Motion picture, radio etc	2,893	2.38	9,808
Libraries, museums, arts	2,618	2.38	8,875
Personal services	3,606	2.32	11,858
Other services	9,125	2.08	26,561
Road transport	9,909	1.50	21,506
Rail, pipeline, other transport	4,710	2.01	13,211
Water transport	706	1.04	1,209
Air and space transport	4,543	2.29	14,735
Services to transport; storage	11,579	1.82	29,524
Construction	34,697	1.08	60,527
Total	**546,707**	2.08	1,591,277

Table A2 Energy supply and disposal under a 70 per cent cut in emissions scenario, 2050

	Coal and products PJ	Oil and petroleum PJ	Natural gas PJ	Wind PJ	Solar electric PJ	Other direct ren elec PJ	Solar thermal PJ	Biomass PJ	Methanol/ ethanol PJ	Biodiesel PJ	Biogas PJ	Electricity PJ	Cogen heat PJ	Hydrogen PJ	Total PJ
Supply															
Production[a]	2,400.0	0.0	4,000.0	500.0	100.0	90.5	114.8	2,610.4							**9,815.7**
Imports[a]		421.8	0.0					0.0							**421.8**
Exports[a]	-2,341.3	0.0	-3,559.6					0.0							**-5,900.9**
Intl Bunkers[a]		-100.0													**-100.0**
Primary energy supply	**58.7**	**321.8**	**440.4**	**500.0**	**100.0**	**90.5**	**114.8**	**2,610.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4,236.7**
Conversion															
Electricity generation				500.0	100.0	90.5		0.0				-690.5			**0.0**
Biomass (solid) cogeneration (FBT, Wood, Chemical)										493.5				-80.5	-409.4
Commercial/residential cogeneration			0.0								430.2	-154.9	-219.5		**55.8**
Biogas production								1,629.6			-1,303.6				**325.9**
Cogeneration (other industries)			25.6								393.7	-76.2	-341.6		**1.5**
Bioliquid production								345.5	0.0	-276.4	0.0				**69.1**
Hydrogen production								0.0			241.5	31.2		-109.4	**163.2**
Distribution losses												84.6			**84.6**
Final domestic availability	**58.7**	**321.8**	**414.8**	**0.0**	**0.0**	**0.0**	**114.8**	**141.7**	**0.0**	**276.4**	**238.3**	**886.2**	**970.5**	**109.4**	**3,532.8**
Final demand															
Coal, oil and gas			143.3					0.0				14.5	21.9		**179.7**
Mining (non-energy)			35.7								18.9	88.4	9.2		**152.2**
Gas production and distribution			30.5					0.0				0.3	0.0		**30.8**
Petroleum and coal products			3.9								10.9	0.8	9.2		**24.8**
Iron and steel	58.7		61.4								7.3	7.8	25.1		**160.3**
Food, beverages, tobacco			0.0					7.1				21.7	233.4		**262.3**
Chemicals			0.0					128.4				27.5	62.4		**218.3**
Cement, lime, plaster and concrete			11.9								33.1	5.3	0.6		**51.0**
Other non-metallic mineral products			12.4								34.3	6.0	1.6		**54.3**
Non-ferrous metals			81.9								95.2	232.3	240.9		**650.3**
Wood, paper and printing			0.0					6.2				29.7	113.7		**149.5**
All other manufacturing			19.5								3.6	38.5	32.9		**94.6**
Commercial			7.7								21.3	141.7	141.3		**312.0**
Residential			4.9				114.8				13.6	222.7	78.2		**434.3**
Construction		0.0	1.6					0.0		48.4		0.2	0.0		**50.3**
Agriculture		0.0	0.0					0.0		59.9		10.2	0.0		**70.1**
Road transport		147.7							0.0	147.7				109.4	**404.9**
Rail transport												38.7			**38.7**
Air transport (domestic)		91.4							0.0						**91.4**
Water transport (domestic)		4.6								20.4					**25.0**
Lubricants, greases, bitumen and solvents (oxidised component counted elsewhere)		58.2													**58.2**
Military and recreational vehicles (counted elsewhere)		19.9													**19.9**
Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note: May not sum due to rounding. a. For coal, oil and gas, these figures are estimates consistent with primary energy supply.

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