The Heat Is On

The Future of Energy In Australia

December 2006

CSIRO Corporate Centre
Limestone Avenue, Campbell ACT 2612, Australia

ISBN-10: 0 643 09414 8
ISBN-13: 978 0 643094 14 7

Disclaimer
The results and analyses contained in this Report are based on a number of technical, circumstantial or otherwise specified assumptions and parameters. The user must make its own assessment of the suitability for its use of the information or material contained in or generated from the Report. To the extent permitted by law, CSIRO excludes all liability to any party for expenses, losses, damages and costs arising directly or indirectly from using this Report. The views expressed in this Report do not necessarily represent the views of any single, or all, organisations or that of the Department of Industry Tourism and Resources.

Acknowledgments
While the Australian Conservation Foundation, ENERGEX, Pacific Hydro and OneSteel withdrew from the Energy Futures Forum prior to the completion of its Report, their contribution is gratefully acknowledged. The Energy Futures Forum also extends its sincere thanks to the Department of Industry Tourism and Resources, for its financial support and active participation, and to John Wright, Director CSIRO Energy Transformed, for his guidance and support throughout the project.

Project Team
Chairman: Oleg Morozow, RPS Ecos
Project Leader: Paul Graham, CSIRO
Social Research: Simon Niemeyer, CSIRO/ANU; Kath Fisher, Southern Cross University; Anna Littleboy, CSIRO; Naomi Boughen, CSIRO
Climate Research: Roger Jones and Ben Preston, CSIRO
Editor: Vanessa Wallace, Savance Communications
Scenario development facilitation: Kate Delaney and John McBride, Delaney and Associates
Economic modelling: ABARE; Paul Graham, CSIRO; Luke Reedman, CSIRO; and Josephine Cheng, CSIRO
Additional facilitation: Mary Maher, Mary Maher and Associates
Communications: Samantha East, CSIRO
Administration: Kim Phillips, CSIRO
Design: Greg Connors, Face Graphics

Energy Futures Forum Delegates
Jim Beckwith, David Bowker, Graham Bunn, Irina Cattalini, Lanie Chopping , Drew Clarke, Marian Cross, Gordon Dean, Thao Doan, Matthew Dodson, Greg Everett, Elissa Freeman, Mark Gell, Steven Gerhardy, Patrick Gibbons, Rick Humphries, Barry Isherwood, Erwin Jackson, Holly Lindsay, Karl Mallon, Lauchlan McIntosh, Greg McLean, Steve Mullins, Jeroen Nanninga, Ian Nethercote, Ray Nias, Fiona Nicholls, Andrew Richards, Roy Rose, Jay Rutovitz, Franco Scalzo, Joanna Scellier, Andrew Stock, Julie Taylor Mills, John Titchen, Julian Turacek, Simon Vanderzalm, Simon Vandestadt, Simon Vardy, Garry Wall, Jim Wellsmore, Gregory Wong, Tony Wood, Alex Zapantis.

Enquiries should be directed to:
Paul Graham
Theme Leader Energy Futures
CSIRO Energy Transformed
PO Box 330, Newcastle, NSW 2300, Australia
Telephone: +61 2 4960 6061
Facsimile: +61 2 4960 6054
E-mail: Paul.Graham@csiro.au

The Heat Is On

The Future of Energy In Australia

A report by the
Energy Futures Forum

December 2006

acoss

bhpbilliton

ACTU

Delta electricity

ALCOA

Eraring energy

Hydro Tasmania
the renewable energy business

AUSTRALIAN AUTOMOBILE ASSOCIATION

LOY YANG power

Macquarie Generation

Westpac

ORICA

WOODSIDE
AUSTRALIAN ENERGY

Origin energy

WWF

PUBLIC INTEREST ADVOCACY CENTRE

RIO TINTO

STANWELL CORPORATION LIMITED

xstrata coal

Foreword

The level of attention currently focussed on the energy sector in Australia is unprecedented.

Access to low cost energy underpins a significant part of Australia's economy and our way of life. Our energy infrastructure requires substantial ongoing investment for it to continue to play its role, and each new investment brings with it implications that last for decades to come. Pressing environmental concerns are driving us to consider whether the fuels and technologies Australians currently use will continue to be appropriate for our future. If we do not, or cannot, continue with our current energy technologies, which portfolio of choices do we choose, and on what basis?

History shows that when acting alone, neither government, industry, community nor an individual has the definitive answer in addressing these challenges. What is required is a process that builds consensus about how Australian society should collectively respond. As representatives from Australia's energy and transport stakeholders, we therefore welcomed the opportunity to participate in the CSIRO-led Energy Futures Forum.

Our goal has been to identify plausible scenarios for energy in 2050 and consider their implications for our nation's future. In doing so, we have not made recommendations for specific investments or government policy; instead we have sought to present a cogent view of the various elements to be considered when assessing the most prospective technological pathways in the stationary energy and transport sectors.

A key focus of our project was conducting a range of research that would provide further insight into the possible outcomes of our postulated scenarios and associated energy technology paths. This included economic modelling, risk-assessment analysis of climate change, and social mapping to gauge potential views of the public towards various energy options. While the views contained in this Report do not necessarily represent the views of any single, or all, organisations participating in the project, we have been immensely pleased by the level of consensus that we have achieved in coming to terms with the subject matter.

As climate change began to emerge as the most significant topic of interest, the potential for divergence seemed much higher than it turned out to be in reality. The challenges are, however, too urgent and the stakes too high to permit the customary passions of sectoral and political debate.

Typically the debate over mitigating climate change only focuses on the costs and rarely addresses the benefits. This Report outlines how, on the basis of risk assessment, it is likely that the global benefits of avoiding those risks in the year 2100 outweigh the global costs of managing those risks to 2050.

We hope the successful conclusion of this somewhat experimental project will assist in moving forward the debate on our future energy needs by stating what is already agreed to and by providing useful input to decision-makers in industry and government on what options will need their careful consideration and further research. We also wish that the process will act as an example of how all Australians can seek to progress their discussions on other critical national challenges.

Prepared jointly by Energy Futures Forum delegates
December 2006

Preface

CSIRO began to consider the need for a forum of energy stakeholders in Australia in 2004 as a result of its commitment to begin a new flagship research program on energy, called Energy Transformed. The goal of Energy Transformed is to facilitate the development and implementation of stationary and transport technologies so as to halve greenhouse gas emissions, double the efficiency of the nation's new energy generation, supply and end use, and to position Australia for a future hydrogen economy.

The process of designing an initial research program for Energy Transformed brought into clear focus both the wide variety of energy related options for reducing greenhouse gas emissions and the lack of objective, broad and reliable evidence-based analyses for guiding research directions. What was missing was access to credible assessment tools and a process by which such tools could be applied to a wide variety of viewpoints led and developed by a cross section of 'energy' stakeholders, made up of industry, government, environmental and public interest groups.

Out of these initial thoughts, and with a lot of encouragement and input from industry and government, the Energy Futures Forum was born. Some two years later it is with great pleasure that I can introduce this public report of the Energy Futures Forum (EFF).

The Report's structure is based on the journey taken by the EFF over the past 21 months.

Section 1 sets the scene for the EFF: its principles, goals and objectives, the selection of the participants, the rationale for the assessment framework, and the key learnings from the process employed by the EFF.

Section 2 outlines energy in Australia in 2006 so as to provide the knowledge of where we are today, from which we can chart pathways to the future.

Section 3 is where the work started in earnest. It reveals the futures exercise the EFF undertook in developing plausible qualitative scenarios for energy in Australia in 2050.

Sections 4, 5 and 6 summarise the way in which we analysed the qualitative scenarios for economic, social and climate impacts. Ultimately all these have to be brought together in order to establish a holistic understanding of the future of energy and that aim is best achieved by looking at the strands separately before weaving them together. Each section is supported by a separate report that contains the technical details of the work constituting each of these approaches.

Finally, Section 7 attempts to fuse these strands in the form of options and their various implications that decisions-makers in industry and government can choose to consider, and potentially research further, when seeking to address our future energy needs.

As with any futures exercise, the Report does not resolve the uncertainties we in the research community, and other energy sector stakeholders, face. However, it clearly articulates the key technological, social and environmental challenges that CSIRO, in partnership with our stationary energy and transport stakeholders, will seek to address on behalf of the Australian community over the next 44 years to 2050 and beyond.

John Wright
Director Energy Transformed Flagship
CSIRO
December 2006

CSIRO

Contents

Figures

Boxes

Tables

Executive Summary

Energy is a basic input into virtually every aspect of personal and business activity.

Energy, in some form, is involved in most household activities, such as heating, cooling, cooking, lighting, transport or simply enjoying products and services that require energy. Firms use energy in virtually all of their activities, whether it is processing and manufacturing materials, transporting goods, heating and cooling premises, providing telecommunication services or powering computers.

Australia's energy sector directly employs some 120,000 Australians through the production and supply of stationary energy (such as electricity and gas), transport energy (mainly petroleum-based fuels) and energy for export. The sector involves massive, long-lived capital items such as electricity plants, transmission lines, coal, oil and gas production facilities, pipelines, refineries, wind farms, as well as a multitude of smaller facilities such as wholesale and retail distribution sites.

Australians spend about $50 billion on energy each year, with energy-related sectors, such as electricity, mining and transport, accounting for some 11 per cent of Australian Gross Domestic Product (GDP) and accounting for around half of the total $190 billion in Australian exports each year (ABARE, 2006b).

As a result, energy is a fundamental part of life in Australia.

Australia's energy future will be created from changes originating outside and within the energy sector, driven by multiple institutions, governments, organisations, businesses and private citizens.

Recognising this, CSIRO created the concept of the Energy Futures Forum (EFF) in 2004 as a means of engaging a wide set of stakeholders from the energy and transport sectors – energy suppliers, generators, distributors, major energy end-users, financiers, researchers, government and community representatives – in developing and assessing pathways for the future of energy in Australia and, in doing so, consider the implications for our nation's future.

The EFF specifically sought to challenge existing thinking on energy by identifying nine qualitative scenarios — Blissful Indifference, Rough Ride, Cultural Revolution, Clean Green Down Under, The Day After Tomorrow, Power to the People, Atomic Odyssey, Centralised Failure, and Technology to the Rescue.

Each scenario is a plausible story about how the future might unfold, but while drawing on both factual information and EFF members' experience and judgment, they are not predictions or models. The scenarios address different ways in which relevant issues outside our organisations might evolve, such as the future natural environment, social attitudes, technology and the strength of the economy. Importantly, they allow us to analyse changes in the environment, take new perspectives and develop new understanding. This improved understanding can then be used to inform better decisions today and in the future.

These plausible futures were then assessed for their economic, social, environmental and technological impacts. Recommendations for specific investments or government policy are not, however, made by this Report; instead it seeks to present a cogent view of the challenges and implications arising from the scenarios investigated.

Embarking on the project, the general view of EFF members was that the greatest impact on the future of energy in Australia would come from geopolitical changes, climate change, innovation and the level of community concern about sustainability. The process of creating the qualitative scenarios, however, identified climate change as '*primus inter pares*'– or a first amongst equals – of these challenges.

A secondary challenge was the need for Australia to secure affordable transport fuels. In addressing both these challenges, it was also important to understand the role of different technologies.

The high level of significance attached to the impacts of, and responses to, climate change influenced the way the EFF discussed the future with ABARE, the project's quantitative modellers, and assisted in identifying the parameters of the economic models that were to be applied when attempting to assess economic and environmental impacts.

The process of creating narratives confirmed the common views of members, notably, that:

- Community attitudes or behaviours may well change suddenly, in surprising directions, and in ways that limit or expand the adoption and use of particular technologies, programs and practices.
- New management measures of some form will be introduced for the international carbon economy.
- A broader suite of technologies will play a role in the future than is current today.

In seeking to conduct a quantitative analysis, many elements within the qualitative scenarios, however, were difficult to formalise as they represented subjective interpretation of facts, shifts in values, new regulations or inventions. In addition, all economic models are limited in the real world detail they are able to accommodate. A limited set of key drivers were therefore determined that would explore elements of the qualitative scenarios. These included:

- Abatement targets and the timing of their introduction

  A target for the stabilisation of atmospheric concentration of carbon dioxide (CO_2) of 575 parts per million (ppm) by 2100 is investigated, based on the A1T scenario from the Special Report on Emission Scenarios (SRES) (IPCC, 2000). In establishing this anchor point, the EFF does not endorse it or suggest that it would represent on acceptable level of emissions or consequent climate change. The choice represents a compromise between the desire to explore significant global emission reduction and the need to work within the constraints of ABARE's economic models. There is, and will continue to be, much debate as to what may be the most appropriate level for the atmospheric concentration of CO_2 by 2100.

- The use of carbon taxes as a mechanism to ensure that the required level of abatement is achieved

  For the purposes of the economic modelling, a price on carbon dioxide and other greenhouse gases was the policy instrument used to deliver the required emissions outcomes, subject to the underlying modelling assumptions. Given that the goal was to focus on energy futures for Australia, it was decided that the development of specific country abatement targets was not a key concern. As a result, the carbon tax was assumed to apply universally in a harmonised way across all countries in all scenarios analysed in this Report. Two scenarios differed from this broad assumption: Australia makes deeper, unilateral cuts in its emissions – 50 per cent below 1990 levels by 2050 (scenario 2d), and only OECD countries, the Russian Federation and other members of the Commonwealth of Independent States (CIS), plus China and India undertake emission abatement (scenario 3).

- Access to, and type of, technologies

  While electing to leave the model relatively unconstrained in the technologies adopted, this Report specifically models the availability of carbon capture and storage (CCS) and nuclear energy on the cost of meeting the abatement task.

- Fuel prices

  To explore the impact of increasing global conflict, a scenario was modelled where an extended interruption to the supply of oil led to a sustained increase in the price of oil.

The drivers were then modelled under eight scenarios, with the projected impacts assessed by economic and climate modelling provided by ABARE and CSIRO respectively.

While it has to be acknowledged that all models, particularly those making long term projections, fail to capture the richness of real life, the economic and climate modelling were key inputs to understanding the potential outcomes of the qualitative scenarios. The research examined the costs to economic growth, the structure of the economy, energy prices, technological change and impacts on species, ecosystems and environmental function.

To augment the discussions of the EFF with social data, a two-year social mapping programme was undertaken to gather insights into public perspectives about Australia's energy future.

Using a 'Citizen's Panel' dialogue process, perceptions of energy technologies were explored with members of the public. While not purporting to represent the entire Australian society, this process provided a valuable window into social dynamics in the energy domain. Specifically, the program acted as a useful check on the plausibility of the scenarios from a public perspective, as well as providing an insight into attitudes to alternative low emission technologies. Quantitative and qualitative methods were used to monitor these changes.

The panels' discussions indicated broad concern about greenhouse gas emissions and climate change, which manifested in different combinations of energy technology and different trajectories for

Scenario	Description
Reference case	Aims to reflect a world scenario in which technological development and government policies progress along their current paths, with the exception that globally all trade barriers are reduced by 70 per cent from their 2001 levels across the board by 2025 (this is maintained in all other scenarios except the 'high oil price' scenario), and no implementation of any significant greenhouse gas emission reduction policies.
High oil price	Characterised by a hypothetical world with an oil supply disruption leading toward a heightened worldwide concern for energy security. It is assumed that, under the scenario, the price of oil will increase from its present level to US$100/bbl (in today's dollar terms) by 2007 and remain at that level until 2014, after which it will approach its long-term much lower level over the remainder of the projection period to 2050.
Scenario 1	A greenhouse gas abatement scenario that targets emission reduction similar to that of the SRES A1T scenario. In this scenario, global carbon dioxide emissions are targeted to begin in 2030 such that the global allowable emissions at 2050 will be 43.1 gigatonnes of carbon dioxide (Gt CO_2) consistent with reaching a CO_2 concentration stabilisation target of 575 ppm at 2100. This target represents a 35 per cent reduction in global carbon dioxide emissions relative to the reference case. The emission abatement target is assumed to be achieved through the introduction of a globally harmonised carbon tax from 2030. Other greenhouse gas emissions including methane and nitrous oxide are assumed to adjust in response to the carbon tax. All global regions (with one exception) have access to all potential abatement technologies. The only exception to this technology option assumption is that Australia has no access to nuclear power.
Scenarios 2a-2d	These are four greenhouse gas abatement scenarios, under different technology options and/or a differentiated abatement target for Australia (scenario 2d). In all four scenarios, global carbon dioxide emissions are targeted to begin in 2010 such that the global emissions at 2050 will be restricted to 39.4 Gt CO_2. Again, this targeted emission path is set so as to be consistent with a CO_2 concentration stabilisation target of 575 ppm at 2100. This emissions target represents a 40 per cent reduction in global CO_2 emissions relative to the reference case. The distinguishing features of the group 2 scenarios are as follows:
Scenario 2a	All regions are assumed to have access to all potential abatement technologies. However, Australia is assumed to have no access to nuclear power. The technology option assumption is similar to scenario 1.
Scenario 2b	Similar to scenario 2a, except it is assumed that no region in the world will implement carbon capture and storage technologies during the projection period. As in scenarios 1 and 2a, Australia is assumed to have no access to nuclear power.
Scenario 2c	Identical to scenario 2b except that Australia is assumed to have access to nuclear energy. It is assumed that one small nuclear power plant begins operation in Australia around 2020, with the expansion of capacity building slowly off this low base.
Scenario 2d	Australia is assumed to reduce its own carbon dioxide equivalent emissions to 50 per cent below its 1990 levels by 2050, while the 2050 global carbon dioxide emissions target remains at 39.4 Gt CO_2. Regarding technology options, the assumption of the global access to carbon capture and storage is maintained. Also, Australia is assumed to have access to nuclear energy. As in scenario 2c, one small nuclear plant is assumed to start operating in Australia around 2020, with potential expansion taking place between 2020 and 2050.
Scenario 3	OECD countries, the Russian Federation and other members of the CIS plus China and India form a coalition to undertake greenhouse gas abatement. By 2050, similar to scenarios 2a-d, global emissions are contained to 39.4 Gt CO_2 consistent with CO_2 stabilisation at 575 ppm at 2100. The members of the coalition, with the exception of China and India, implement a harmonised carbon tax in 2010. China and India join the coalition in 2020 with a view to all countries having a harmonised carbon tax by 2070, when the tax rate will be the same for all coalition members. The scenario 2a technology options are maintained in this scenario.

Table 1: Scenarios modelled

	Reference	High oil price	Mitigation scenarios					
			1	2a	2b	2c	2d	3
Targeted global abatement of CO_2 at 2050 [a] (relative to the reference case)	NA	NA	35%	40%	40%	40%	40%	40%
Introduction of climate change policy action	NA	NA	Late action: global partici-pation com-mencing in 2030	Early action: global partici-pation com-mencing in 2010	Early action: global partici-pation com-mencing in 2010	Early action: global parti-cipation com-mencing in 2010	Early action: global parti-cipation com-mencing in 2010	Early action: for developed /transition countries [b] 2010; delayed action for developing countries [c] 2020
Differentiated abatement target for Australia	NA	NA	No	No	No	No	Yes: 50% below 1990 levels of CO_2 equivalent emissions by 2050	No
Availability of CCS, globally	NA	NA	Yes	Yes	No	No	Yes	Yes
Availability of nuclear power in Australia	NA	NA	No	No	No	Yes	Yes	No
A 70% across the board reduction in trade barriers by 2025, globally	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Temporary oil price peak of $100/bbl	No	Yes	No	No	No	No	No	No

a Excludes CO_2 emissions from bunkers.
b Includes Russian Federation and the remaining economies of the Commonwealth of Independent States (CIS).
c Includes India and china

Table 2: Key scenario assumptions

the future. Concern about risks associated with large-scale technologies and a desire for energy security were the main distinguishing features between public attitudes, as well as concern about the resulting shape of society. A key finding of the program is that a broad range of views exist in regard to potential technology development paths in Australia, and that, for many individuals, their views and opinions were susceptible to change when provided with new information and exposed to group discussion.

MAJOR IMPLICATIONS AND CHALLENGES IDENTIFIED

Comprehensive analysis of the research identified six major implications, which, it is hoped, will be of use to decision-makers at all levels of Australian society in guiding efforts to address the key challenges.

1. Climate change: the cost and benefits of mitigation

Typically the debate over mitigating climate change only focuses on the costs and rarely addresses the benefits. This Report found that, on the basis of risk assessment, it is likely that the global benefits of avoiding those risks in the year 2100 outweigh the global costs of managing those risks to 2050.

Under all scenarios modelled, it is projected that both the Australian and world economies will continue to experience strong economic growth when carrying out greenhouse gas mitigation.

The modelling showed that energy can be expected to remain affordable for households. While retail electricity prices will increase by 2050 by between 7 and 20 per cent, those increases will be below the change in real income per capita in Australia which is expected to rise by over 100 per cent by 2050 as GDP increases. By 2050, the share of average full-time wages spent on electricity is expected to decline from around 1.1 per cent in 2006 to between 0.5 and 0.7 per cent. This is inclusive of carbon prices imposed in the scenarios.

Responding to climate change can be expected to have significant effects on some parts of Australian industry, over the next 44 years, particularly agriculture, iron and steel, and non-ferrous metals (aluminium production). Under the scenarios in which Australia acts in concert with the international community (scenarios 1 and 2a-c), agriculture and iron and steel output by 2050 is reduced by between 1–3 and 4–9 per cent respectively at 2050 compared to the reference scenario but where Australia makes unilateral deep cuts (scenario 2d) or acts as part of a smaller international coalition (scenario 3) iron and steel and agricultural output by 2050 is reduced by between 32–44 per cent and 53–54 per cent respectively compared to the reference scenario.

Under all scenarios the reductions in output by 2050 in non-ferrous metals are more significant – between 22 per cent and 39 per cent compared to the reference scenario in scenarios 1 and 2a–c, and about 75 per cent compared to the reference scenario in the case of scenarios 2d and 3.

In 2006 agriculture comprised about three per cent of GDP and about 16 per cent of exports while aluminium and iron and steel comprised about 4.5 per cent of exports. The minerals sector as a whole – of which aluminium and iron and steel comprise a relatively small proportion comprised about five per cent of Australian GDP in 2006 but was responsible for nearly 50 per cent of the value of Australian exports.

As a result of responding to climate change some regions reliant on trade exposed and carbon intensive industries may be disproportionately impacted compared to the rest of Australia. It is for governments to determine if any actions are required to address such impacts.

In some cases, responding to climate change will also require significant investment in new infrastructure.

2. The role of Australia in addressing climate change

Australia has a strong vested interest in finding solutions to climate change. It is a major energy exporter; the environment sits prominently in the Australian psyche; and as a nation it is vulnerable to the broad economic, social and environmental impacts of climate change.

At present there is an international policy framework that has the sign-on of all countries, that is the United Nations Framework Convention on Climate Change and the associated Kyoto Protocol which makes binding targets on developed countries to 2012. Australia has not ratified the Kyoto Protocol but has undertaken to meet the agreed target. The present international discussions regarding future climate change agreements are primarily influenced by differences of opinion over the framework for arriving at an effective and appropriate level of participation from all countries.

It is difficult to predict the shape of future international agreements or what possible measures that some economic blocs may take to encourage wider participation. However, technology transfer could potentially play a role in bringing the position of developed and developing countries closer together.

3. The nature and timing of government intervention

Addressing climate change will require an enormous transformation of infrastructure and society's use and relationship with, not just energy, but a broad range of products and services. While a range of government programs and legislation already exist both globally and in Australia that target greenhouse gas reduction and adaptation, a much greater level of government intervention is likely to be initially required to achieve the scale of transformation required to address climate change in a meaningful way. The challenge is to determine what combination of policies, what level of ramping up is required, and when.

The modelling has included two scenario families, early action where carbon prices are introduced in 2010, and late action where carbon prices are introduced in 2030.

Although the modelling uses carbon prices as the primary policy instrument, in practice, reducing emissions will be based on a range of policies and measures with important variables being the nature of the policies and measures, time of implementation and rate of change. These include policies and measures that would encourage the adoption of low cost emission abatement opportunities in the short term (such as energy efficiency), allow the orderly deployment of existing technologies and industries (such as renewables), and deliver strategic government and industry frameworks driving the development, commercialisation and deployment at scale of new and emergent low emission technologies.

Without advocating a particular approach, the key advantages of adopting an emission reduction goal that begins early, such as in 2010, include:

- It keeps open the opportunity to further reduce the environmental impact of climate change in the future by making greater emission cuts (this opportunity will be lost if early action is not taken)
- It reduces energy sector investment uncertainty if it means policy is announced sooner
- It could accelerate technological change of the "learning by doing" type if it means faster deployment
- It is generally affordable for Australia though it has some adverse impacts on specific industry sectors.

On the other hand, the key advantages of adopting an emission reduction goal that begins later, such as in 2030, include:

- Arguably, it gives time for the existing (or future) international negotiations to reach an agreement about global and national emission reduction targets
- It could avoid locking in any particular low emission technologies if a new lower cost technology emerges
- It does not mean no action since other policies, such as directing funds at research and development of low emission technologies, could take place in the interim
- It reduces the impacts on some specific industry sectors.

4. Climate change uncertainty affects investment

The energy sector will require several tens of billions of dollars of new investment to replace ageing plant and develop new plant to meet growing demand for energy. Addressing climate change will further increase the level of investment required. Business will need to (and currently does) take into account future carbon prices in assessing the financial viability of each potential project.

The announcement of any long-term national policy framework on climate change would assist in reducing uncertainty. However, future carbon prices, if adopted, cannot be predicted, as they would be dependent on the design and the timing of actions taken within the policy framework. Electricity generation assets are most exposed to carbon price uncertainty with asset lives of between 20 and 50 years, depending on the technology, plus construction lead times of several years. If the financial risks faced by the electricity generation sector are too high due to uncertainty about future carbon prices or other policies, there is the possibility of inefficient or under-investment in this sector in the near term, leading to either higher cost electricity or shortfalls in supply.

5. The low emission technology mix

The cost of addressing climate change is lowest for Australia when it can choose from all available technologies, in partnership with energy efficiency improvements and demand management.

All technologies have varying degrees of advantages and disadvantages from economic, social or environmental perspectives.

Carbon capture and storage may be important for keeping the future cost of greenhouse gas abatement in Australia low, as it can utilise Australia's low-cost coal and gas resource base. Nuclear power is an existing low-emission electricity technology providing around 17 per cent of the present global energy market share but requires further assessment to determine its social acceptability and true cost

Remaining large hydropower sites are limited in Australia, but some smaller sites will be exploited. Hydropower will continue to play an important role as a provider of electricity at peak times due to its ability to quickly ramp up and down following changes in electricity demand.

Non-hydro renewables, and in particular wind and biomass, will play a much more substantial role in energy supply than they currently do if further emission abatement policies are implemented and as their relative costs fall. It is likely that a rich set of non-hydro renewables – including wind, biomass, solar thermal, solar photovoltaic, geothermal and wave technologies - will be taken up in addressing Australia's future energy needs.

With regards to transport, a variety of alternative fuels, including biofuels and hydrogen, are emerging. While hybrid vehicles are increasing in popularity, they will compete more effectively when they achieve the same economies of scale as stand-alone internal combustion engines.

Energy efficiency is also expected to play a role, with improvements in energy conversion in the supply of energy and energy end-use, including transport; indeed, it has been postulated that accelerating energy efficiency improvements alone can reduce the world's energy demand in 2050 by an amount equivalent to almost half of today's global energy consumption. It is anticipated, however, that governments would need to implement measures to encourage investment in energy-efficient technologies.

6. Securing affordable transport fuels

Australian oil prices are determined by international markets that are uncertain and subject to fluctuations. Australia is vulnerable to changes in oil prices as a result of households and businesses being strongly geared to liquid fuel based transportation.

A loss of affordability of transport fuels could be expected to have negative social and economic impacts. The volatility of oil prices tends to retard investment directed to preparatory action that would make Australia more resilient to future price variations.

The challenge of preparing for high oil prices is a short to medium term concern for Australia. In the long run, given the abundance of energy sources in Australia, the transition to an alternative fuel, demand management and higher transport efficiency would mitigate most impacts.

WHERE TO FROM HERE?

It is hoped that this analysis of implications and challenges will provide a base from which a variety of energy stakeholders, including the Energy Futures Forum participants, can further develop their energy policies and investment strategies. At the same time it is recognised that many questions remain unanswered - given no single research project can be entirely comprehensive and because of the inherent uncertainty in the future.

In coming to terms with the project over the course of the two years the Energy Futures Forum participants identified the following key areas of research that would complement the information developed by this Report.

Climate policy design

The EFF has not sought to design policy instruments. The decision to ramp up Australian emission reduction, if taken, would send a strong signal, regardless of the type of policy instrument applied.

The Report has noted the advantages and disadvantages of alternate carbon price signals as demonstrated in the discussions around the impacts of climate policy on investment, the effects of carbon leakage and issues in relation to how the impacts of carbon prices could be influenced by accompanying taxation changes elsewhere.

The Report has also sought to make it clear that a carbon price signal is only one of several policies that could be considered in taking action to address climate change. There may also be a need to clarify legislation impacting the development of new technologies. Australia could potentially benefit from further study of these and other policy design issues.

Energy end-user efficiency, demand management and urban design

While recognised as a general trend over time, the potential for further improvements in end-user energy efficiency over and above the trend is not amenable to close analysis in economic models. Economic models typically assume that any financially viable opportunities for energy savings are always fully taken up. In reality there are likely to be other non-price drivers for adoption, leading economic models to underestimate the potential role for reduced energy consumption in addressing energy sector challenges. More research could establish the potential for accelerated take up of energy end-user efficiency and demand management informed by behavioural theories other than economics. Urban design is a part of this puzzle and also requires a wide set of research skills.

Energy supply technology

Ongoing energy supply and generation technology research is essential to address the risks faced by the Australian energy sector. Research needs to be directed at all levels including fundamental scientific research, engineering studies, strategic assessments (such as this Report), trials and demonstrations.

In terms of strategic assessments, there were several issues that the report noted had a higher level of uncertainty attached to them or due to other limitations could not be fully addressed in this Report. A selection of these issues is listed below and could potentially benefit from more detailed research. This list is not considered to be comprehensive.

- The potential for energy services companies to emerge, which work across present boundaries of electricity generation, distribution and retailing, and the role of distributed generation in the emergence of such a structural shift.
- The potential for, and implications of, the possible future integration of transport and electricity markets, including the hydrogen economy concept.

- Understanding the potential constraints to the role of biomass related energy in electricity generation and transport in Australia.
- The potential role of electric and fuel cell vehicles in Australian transport.

In future strategic assessments of energy scenarios that consider economic growth, it will be important to explore more robust methods to determine the shape of the climate damage curve, including adaptation and subsequent impacts of climate change on world and Australian economic growth.

1 A pressing conversation: the Energy Futures Forum

This section outlines the concept, principles, goals and objectives of the Energy Futures Forum and the framework it adopted in developing plausible scenarios for energy in 2050 and considering their implications for our nation's future.

CSIRO conceived the concept of an energy futures forum in 2003 as a means of engaging the energy and transport sectors in developing and assessing pathways for the future of energy in Australia and, in doing so, considering their implications for our nation's future.

The Energy Futures Forum (EFF) was not conceived as a think-tank or commission of inquiry, or even an expert panel, but as a participatory process involving a wide set of stakeholders including energy suppliers, generators, distributors, major energy end-users, financiers, researchers, government, non-government organisations (NGOs) and community representatives including trade unions and environmental groups.

A major impetus for the project was CSIRO's significant investment in the Energy Transformed Flagship research program.

The Energy Transformed Flagship is part of CSIRO's National Research Flagships program. The National Research Flagships are partnerships of leading Australian scientists, research institutions, commercial companies, CSIRO and selected international partners that target six fields of high national research priority: health, water, energy, food, light metals and oceans.

The goal of the Energy Transformed Flagship is to halve greenhouse gas emissions; double the efficiency of the nation's new energy generation, supply and end use; and to position Australia for a future hydrogen economy.

ENERGY FUTURES FORUM PRINCIPLES

In partnership with industry, government, NGOs and community groups, CSIRO refined the concept of an energy futures forum until agreement was reached on the scope of the project and processes to be employed.

In principle, the EFF would:

- seek to inform, but neither lobby business or government nor advocate specific investments or government policy.

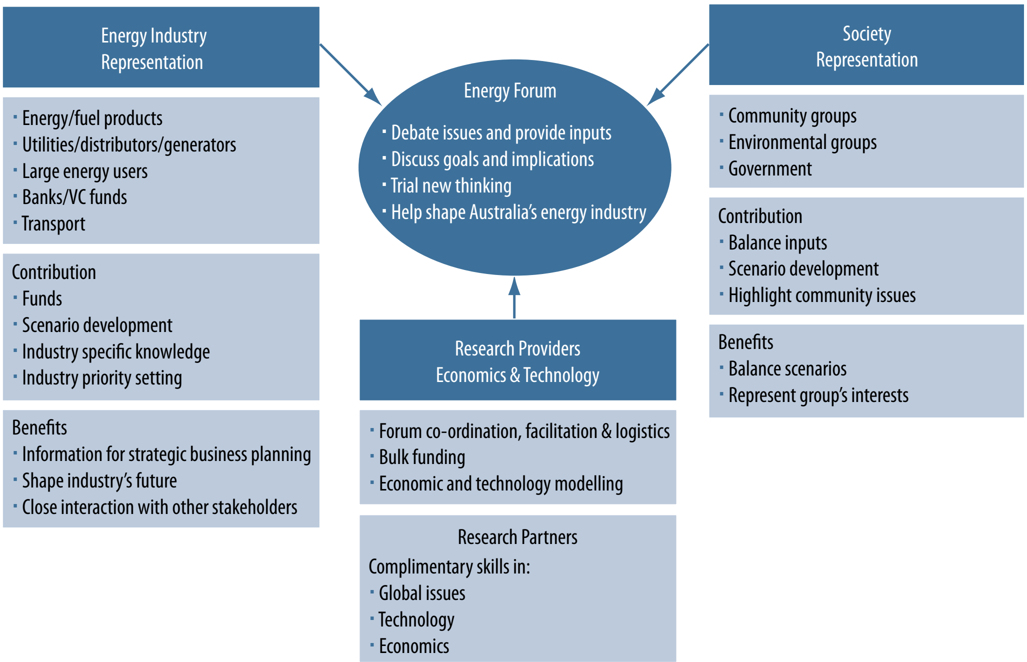


Figure 1: Energy Futures Forum

- include a diverse set of stakeholders from community, industry and government.
- focus on both the short-term and the long-term, to at least 2050.
- be facilitated by CSIRO. As requested, CSIRO would also contribute economic and technology advice; it would not, however, participate in developing or evaluating the scenarios.
- challenge existing thinking by analysing future scenarios, rather than business-as-usual or trend projection.
- assess scenarios for economic, social and environmental impacts.
- seek a financial contribution from all participants, on the basis that all participants should benefit from the process. Community groups and NGOs to be invited to provide in-kind contribution only.
- require up to two years to achieve its goals.
- make its work available through a public report, excluding commercial-in-confidence material, at the conclusion of the project.

GOALS AND OBJECTIVES

The goal of the EFF was to bring together energy sector stakeholders to determine plausible scenarios and their implications for Australia's energy future.

In arriving at that goal, the objectives of the EFF were to:

1. Promote constructive dialogue between a diverse range of stakeholders in the Australian energy industry on its long-term future.
2. Identify a range of plausible scenarios available to Australian society for future energy options by bringing together views from industry, government, NGOs and the community.
3. Use integrated models featuring economic, technological and environmental aspects.
4. Analyse, quantify and discuss the major social, environmental, economic and technological implications of each scenario.
5. Provide information for different organisations to use in meeting their needs; for example:
   - Government to use in energy and environment policy development
   - NGOs to inform policy development
   - Businesses to inform investment strategies
   - CSIRO to use in the development of future research programs.

PARTICIPANTS

Ideally, futures planning should involve a broad range of people from different organisations and backgrounds, as the process of gathering people to reflect on the future and to understand different points of view can be just as important as the final product. For this reason, EFF participants were selected by CSIRO to reflect a balanced representation of key stakeholders to the energy sector.

The general selection criteria were willingness and ability to participate; sector leadership, size or representativeness; and preparedness to contribute financially (community groups and NGOs to contribute in-kind). Many participants had already self-selected by their commitment to a variety of other energy futures-related exercises being conducted around the time the EFF was proposed.

Participants met, on average, every two months, with most meetings lasting for one or two days. Oleg Morozow, RPS Ecos, was appointed as an independent chairperson.

Four organisations (Australian Conservation Foundation, OneSteel, Pacific Hydro and ENERGEX) withdrew from the EFF prior to its completion. These withdrawals resulted from internal restructuring within their respective organisations that precluded the continued financial or in-kind support of the EFF.

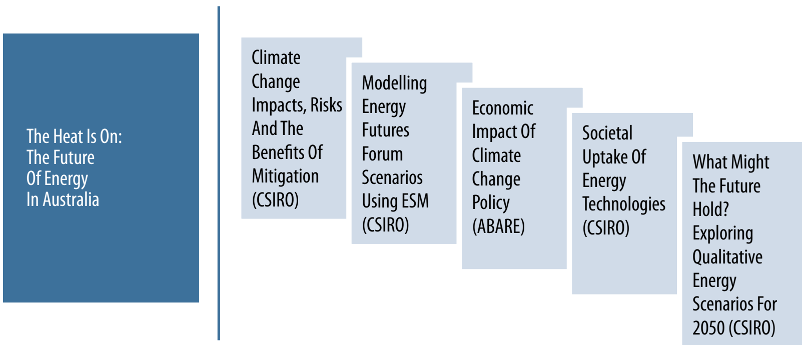


Figure 2: Energy Futures Forum reports

ASSESSMENT FRAMEWORK

The EFF conducted its assessment of our nation's energy future over five phases:

Phase	Task
1	Developing detailed qualitative scenarios about how the future might unfold for the Australian energy sector
2	Social mapping to assess how public reactions to different aspects of Australia's energy future are likely to evolve, and to test the plausibility and comprehensiveness of the qualitative scenarios
3	Quantitative analysis of key scenario assumptions
4	Modelling of climate change impacts, risks and the benefit of mitigation
5	Deliberation of implications

Table 1: EFF assessment phases

Details of the assessment framework are contained in the following sections.

At the conclusion of its deliberations, the EFF is releasing its work via this public report, excluding commercial-in-confidence material. The Report is supported by five separate reports (Figure 2) outlining the major bodies of research undertaken as part of the project:

- qualitative scenarios – *What Might The Future Hold? Exploring Qualitative Energy Scenarios For 2050* (CSIRO)
- social research mapping – *Societal Update of Alternative Energy Futures* (CSIRO)
- economic modelling – *Economic Impact Of Climate Change Policy (ABARE)* and *Modelling Energy Futures Forum Scenarios Using Esm* (CSIRO)
- *Climate Change Impacts, Risks And The Benefits Of Mitigation* (CSIRO).

Australia's Energy Sector at a Glance

- Australia is well endowed with coal, natural gas, solar, wind, biomass, wave, geothermal and uranium resources and moderately endowed with oil
- Largest consumers of primary energy in Australia are electricity generation, transport, and manufacturing processes such as aluminium and iron and steel
- New South Wales, Victoria and Queensland consume 80 per cent of electricity generated
- Road transport accounts for some 75 per cent of total transport energy; two-thirds of road transport energy use is from passenger vehicles
- Three fossil fuels supply 95 per cent of Australia's energy needs: coal (brown and black), oil and natural gas
- Coal is the primary source for 84 per cent of Australian electricity generation
- Australia's greenhouse gas (GHG) emissions per capita is the highest amongst developed countries and ranked fourth overall
- Australia contributes 1.5 per cent of the world's greenhouse emissions (excluding land-use change)
- Relative to the rest of world, the cost of electricity in Australia is low
- Australia is a net energy exporter in volume terms but a net importer in value terms (if coking coal is not included) owing to a recent decline in domestic oil production and an increase in the price of oil
- Any significant reduction in Australia's long-term greenhouse signature must involve changing the way it produces and uses energy
- Demand for energy is relatively price inelastic. However, this is less true for aluminium, iron and steel processing and some industrial energy consumers
- The environmental impact of energy is a concern for some households
- New investment will be required to both replace ageing energy infrastructure and meet growth in demand
- Both state and territory governments and the private sector own electricity generation assets. This has major implications for the way in which replacement and new investment decisions are driven in the resultant market structures, such as the need for market prices to rise or subsidies to be in place before investors will deploy higher cost low-emission technologies

2 Energy in Australia in 2006

This section outlines the features that combine to make Australia's energy sector unique.

Energy is a basic input into virtually every aspect of personal and business activity.

Energy, in some form, is involved in most household activities, such as heating, cooling, cooking, lighting, transport or simply enjoying products and services that require energy. Firms use energy in virtually all of their activities, whether it is processing and manufacturing materials, transporting goods, heating and cooling premises, providing telecommunication services or powering computers.

Australia is well endowed with energy.

Australia's energy sector directly employs some 120,000 Australians through the production and supply of stationary energy (such as electricity and gas), transport energy (mainly petroleum-based fuels) and energy for export. The sector involves massive, long-lived capital items such as electricity plants, transmission lines, coal, oil and gas production facilities, pipelines, refineries, wind farms as well as a multitude of smaller facilities such as wholesale and retail distribution sites.

Australians spend about $50 billion on energy each year, with energy-related sectors, such as electricity, mining and transport, accounting for some 11 per cent of Australian GDP and accounting for around half of the total $190 billion in Australian exports each year (ABARE, 2006b).

As a result, energy is a fundamental part of life in Australia.

AUSTRALIA'S SHARE OF ENERGY RESOURCES

Australia is well endowed with energy (Table 1). Australia has vast reserves of coal that are relatively easy to mine and located close to energy users, making it the world's fourth largest producer and the largest exporter of coal (IEA 2006)[1]. The country's natural gas and uranium resources are substantial, although much of the natural gas is located far from

	AUSTRALIA				WORLD	
Resource	Economic Demonstrated Resources (EDR) a	Total Identified Resources (TIR) b	Years of availability (EDR) c	Years of availability (TIR) c	Percentage of world (EDR)	Economic Demonstrated Resources (EDR)
Black Coal [d]	39 Gt	107 Gt	100	270	5.3	739 Gt
Brown Coal [d]	37 Gt	194 Gt	550	2,900	23.9	155 Gt
Natural Gas	2,587 Bcm	4,069 Bcm	65	100	1.4	180,000 Bcm
Crude Oil	157 GL	238 GL	7	10	0.1	190,500 GL
Uranium [d]	716 kt [e]	1,191 kt	75	125	36.5	1,962 kt
Biomass [f]	NA	330 PJ/y	Renewable	Renewable	NA	NA
Wind [g]	NA	200 TWh/y	Renewable	Renewable	NA	NA
Solar	NA	Very large	Renewable	Renewable	NA	NA
Wave and tidal	NA	Very large	Renewable	Renewable	NA	NA
Hot dry rocks [h]	NA	2500 EJ	NA	800	NA	NA

Gt: gigatonnes; Bcm: billion cubic metres; GL: gigalitres; kt: kilotonnes, PJ/y: petajoules per year, TWh/y: terawatt hours per year, EJ: etajoules, NA: Not available.
a Economic Demonstrated Resources (EDR) are resources judged to be economically extractable and for which the quantity and quality are computed partly from specific measurements, and partly from extrapolation for a reasonable distance on geological evidence.
b Total identified resources (TIR) consist of demonstrated resources (economic and subeconomic) and inferred resources.
c Years of availability based on current rates of Australian production.
d EDR and total identified resources estimates reflect recoverable resources, not in situ resources.
e Recoverable at costs of less than US$80/kg U.
f All biomass crops and residues, without competing with food crops
g On shore sites no more than US8c/kWh
h Includes resources in granite bodies above 5km and more than 165 degrees celcius

Table 1: Energy reserves for Australia and the world (source: Geoscience Australia (2006a and 2006b); Somerville et. al. (1994); Energy Strategies (2004); IEA Greenhouse Gas R&D Program (2000))

large domestic markets and uranium is not used to produce energy in Australia.

The nation's oil resources are significant but reserves are declining in the absence of new discoveries. There is the potential for new discoveries to add to the size of this resource, however, given demand is also rising with economic growth, the 'years of availability' statistic, which indicates the number of years until the resource will deplete at current production rates, is not expected to significantly increase. In general, exploration effort is only expended in time to maintain proven resources for several years (assuming that the exploration is successful). As a result, estimates of years of availability have generally remained at a similar level for many years or increased.

By comparison to the body of knowledge surrounding fossil fuels and uranium, the size of the renewable energy resource is not nearly as well understood. However, for many renewable energy technologies, such as geothermal, wave, solar and wind, the potential is very large. This is based on Australia's availability of land relative to population, general weather patterns (solar), wind speeds (wind power), length of coastline (wave) and the existence of certain geological structures (geothermal). Further details on renewable energies are listed in Box 1.

Large-scale hydropower potential has been largely exploited, as a consequence of present legislative environmental restrictions, while some potential for smaller-scale hydro remains.

AUSTRALIA'S APPETITE FOR ENERGY

Over the past 30 years, energy consumption in Australia has more than doubled to over 5500 petajoules a year (Figure 6).

Until the early 1990s total energy consumption tended to grow at a rate that closely matched the rate of growth in gross domestic product (GDP). Since then, energy consumption has tended to

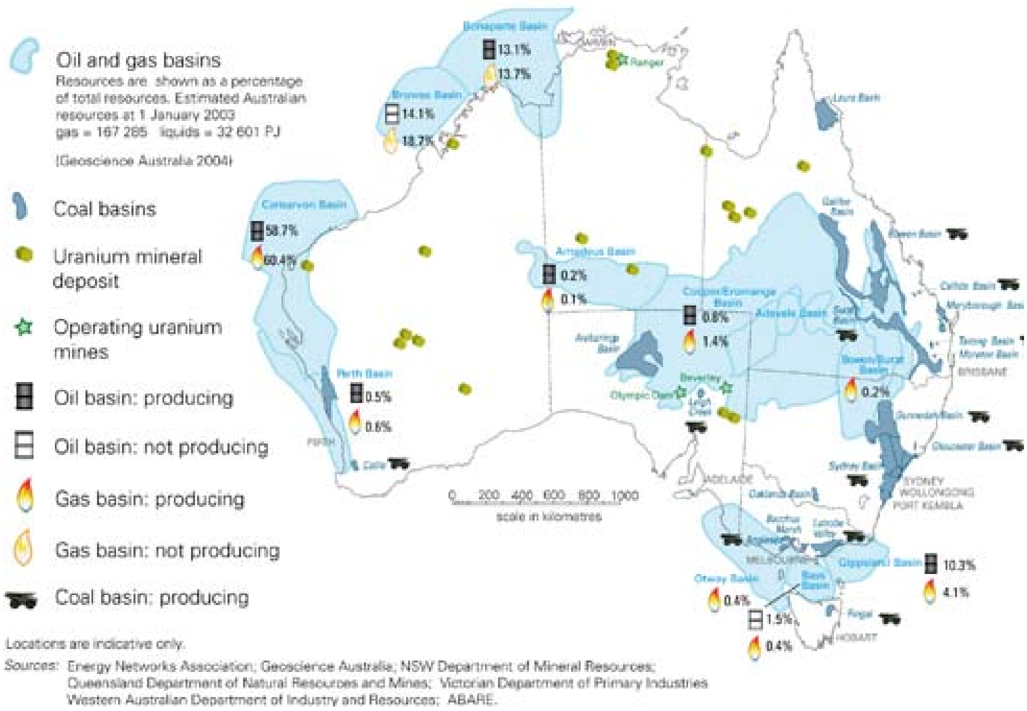


Figure 1: Australia's coal, gas, oil and uranium resources (Reprinted with permission of ABARE)

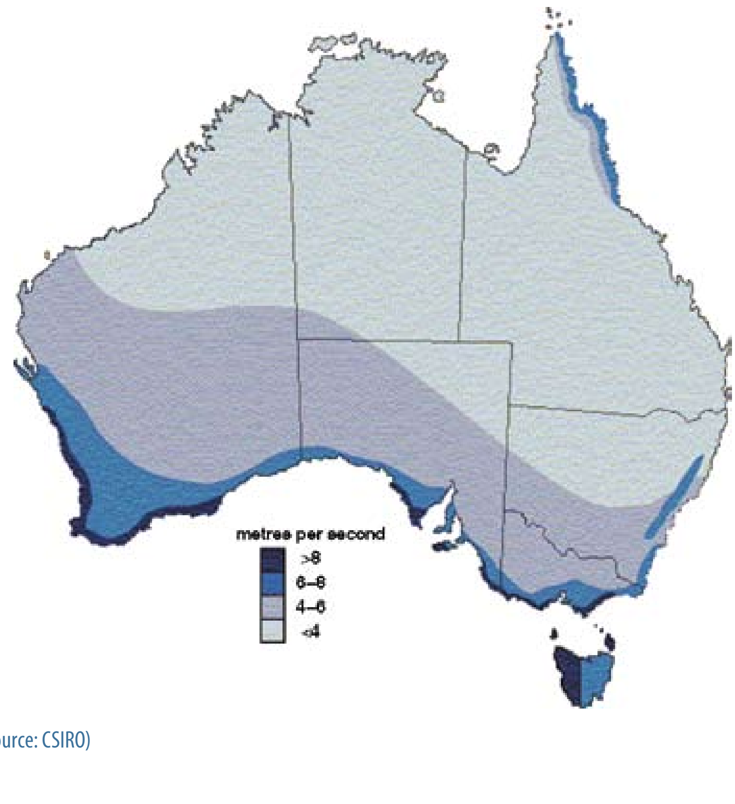


Figure 2: Australia's wind resources (source: CSIRO)

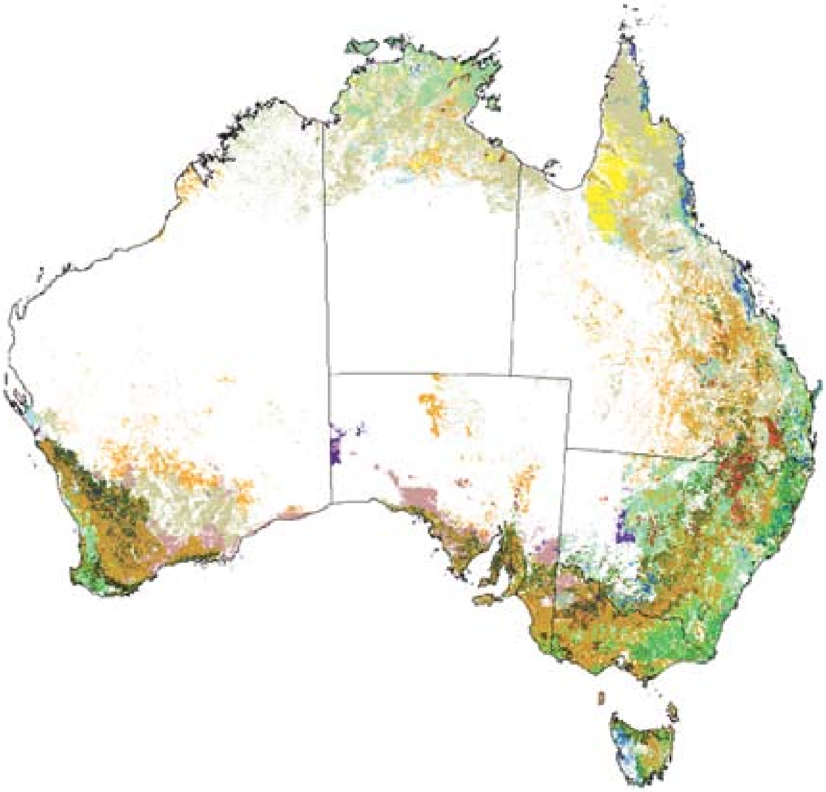


Figure 3: Australia's biomass energy resources. Includes Agricultural in-field resources, agricultural plant oil residue, agricultural trash, forests and plantations (source: Bioenergy Atlas; reproduced with permission from the Australian Greenhouse Office in the Department of the Environment and Heritage)

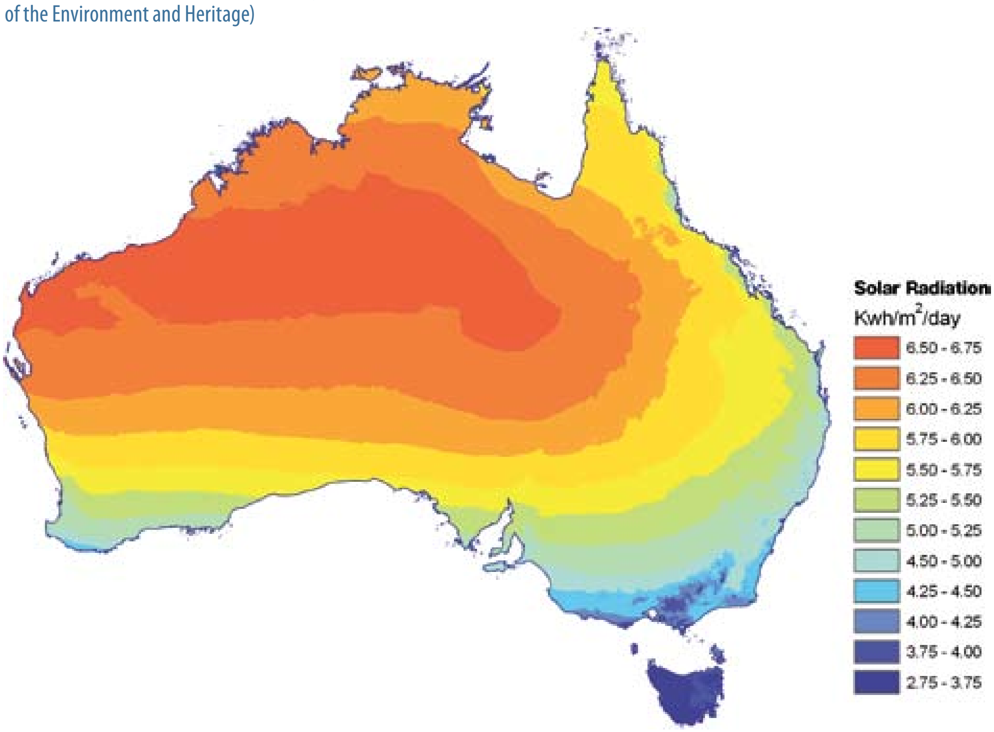


Figure 4: Improved global solar radiation map for Australia, mean annual solar radiation levels, kWh/m2/day (constructed from data supplied in ANUCLIM - data and map supplied by CRES, ANU)

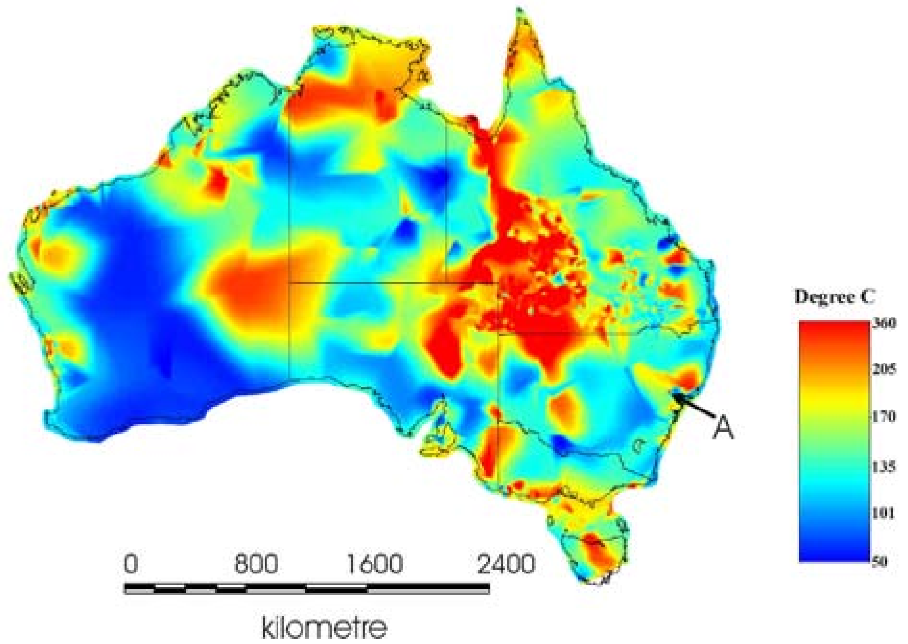


Figure 5: Australia's geothermal resources (Courtesy of Dr. Prame Chopra, Department of Earth & Marine Sciences, Australian National University)

grow more slowly than GDP (Figure 7). This decline in energy intensity of the Australian economy can be attributed to two main factors – greater energy efficiency through technological improvements and fuel switching (for example, by using more gas instead of coal), and the rapid growth of less intensive sectors, such as services, relative to the more moderate growth of more energy intensive sectors such as manufacturing and mining (ABARE Energy Update 2006).

The three largest uses of energy in Australia are electriity generation, transport and manufacturing processes.

There is significant potential for energy efficiency to improve further. It is estimated that energy consumption improvements of between 15 and 35 per cent are achievable under conservative assumptions of only existing technology being available, and that the change must pay for itself within four years. Under more optimistic assumptions of new technology becoming available and longer payback periods being acceptable, energy consumption reductions of up to 70 per cent were economically viable in some sectors (Energy Efficiency and Greenhouse Working Group, 2003).

The three largest uses of energy in Australia are electricity generation, transport and manufacturing processes,

Box 1: Renewable Energy

Renewable energy is energy derived from sources that cannot be depleted or can be replaced such as solar, wind, biomass (waste), wave or hydro. Clean, renewable sources don't produce greenhouse pollution.

What is biomass energy?

Biomass describes the generation of energy from organically based sources. The energy stored in plants or animals can be captured for energy generation by several different methods such as decomposition, combustion or gasification. Current biomass generators include landfill gas, sewage gas and bagasse.

Crops grown specifically to provide biomass compete with traditional land-based food and fibre products for suitable areas of land. The 'energy crops' industry is in its infancy in Australia.

With regard to forestry wastes, utilisation of fuels from existing forestry plantation is likely to be acceptable as 'green' energy. However, utilisation of any materials (including wastes) from high conservation value forests, such as old growth forests, is generally not supported.

What is wind energy?

Wind energy is a form of solar energy and represents 0.25 per cent of the sun's energy reaching the lower atmosphere. Wind comes from the movement of air resulting from thermal gradients and the earth's rotation. Depending on climatic conditions and surface topography, wind can vary significantly in intensity over a day, over a season, or over a year.

The basis of a successful wind energy facility - or wind farm - is to find a site that has a strong and steady wind. A good wind resource is usually characterised by an average wind speed of over 6.5 metres per second (23 km/hr). Issues relate to potential visual impact, noise and intermittency.

What is small hydro energy?

Hydroelectric power is electricity produced from the energy of falling water using dams, turbines and generators. A waterway is suitable for small hydropower generation only if it does not flood severely and if it has an adequate drop in height over a short distance. Stand-alone systems are not always as reliable or cheap as mains electricity and there can be large capital costs. The distance of the turbine from the point of use also needs to be considered, as transmission cables can further increase the cost.

What is solar energy?

Energy from the sun can be categorised in two ways, as heat energy (thermal energy) or as light energy. Photovoltaics are a semiconductor-based technology that converts the sun's light energy directly into an electrical current. Photovoltaic panels are very versatile and can be mounted in a variety of sizes and applications such as on building roofs, roadside emergency phones or in solar powered calculators. Solar thermal systems use the sun's heat to generate electricity, usually by heating a fluid such as water and using it to drive a turbine. Such a system is not common in Australia.

Solar power can be intermittent. Solar panels can still generate some electricity on cloudy days but the supply is variable. Energy storage systems may be necessary for periods when the sun does not shine.

What is geothermal energy?

In geothermal power plants steam, heat or hot water from geothermal reservoirs provides the force that spins the turbine generators and produces electricity. The used geothermal water is then returned down an injection well into the reservoir to be reheated, to maintain pressure, and to sustain the reservoir.

What is hot rocks?

Australia has some of the best reserves of hot dry rocks in the world, offering prospects for a plentiful supply of energy. Australia's hot dry rock resources are found in granite rock layers buried up to several kilometres underground, beneath layers of sedimentary rock.

Extracting the heat occurs by pumping down into the hot granite through a borehole that may be several kilometres deep. This helps to open up existing tiny cracks in the granite, increasing the permeability of the rock. The water is converted to steam by the heat and is channelled to the surface through another borehole, where it can be used to drive a turbine and thereby generate electricity.

What is wave energy?

Waves are ultimately a form of solar energy. The sun heats up the Earth's surface, causing winds that, in turn, drive waves. As the waves travel, the winds continually pump energy into them. By the time the waves hit a coast they contain considerable power.

To convert wave action into useful energy, a power plant must provide a way for the waves to drive something—such as turbine blades or pistons. The apparatus might briefly store the waves' energy, or it might apply the waves' momentum immediately to some mechanism. Issues include getting electricity to land from offshore and also of anchoring in stormy weather. Maintenance can also be problematic if the apparatus is far from the coast.

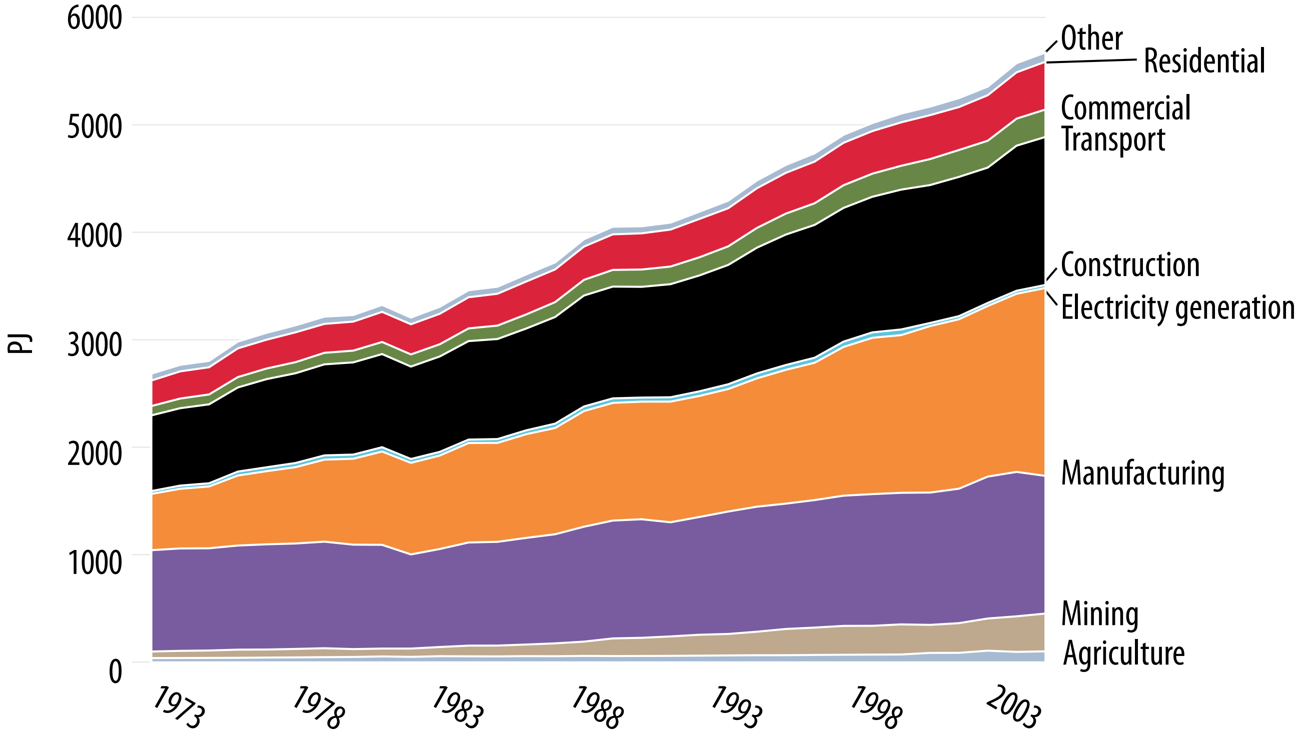


Figure 6: Australian energy consumption by industry (source: ABARE, 2006a)

which together account for some 75 per cent of Australia's energy consumption (Figure 9).

Once energy has been converted into electricity, the residential and commercial services sector each account for around 25 per cent of electricity consumption. The remainder is consumed by industry, with manufacturing, metals and aluminium smelting being the largest groupings of industrial electricity consumers (Figure 10).

Almost 80 per cent of electricity is consumed in New South Wales, Victoria and Queensland. Western Australia's electricity consumption is around 10 per cent, about half the size of Victoria's. Electricity consumption in Tasmania and South Australia is half the size again at around 5 per cent each. Electricity consumption in Northern Territory is around 1 per cent of the Australian total (Figure 11).

Over the past 15 years, energy consumption in both Queensland and Western Australia has risen by an average rate of around four per cent per annum. State population and economic growth, and the expansion of energy-intensive industries in these states have driven this increase. The boom in the mining sector in recent years has also resulted in increased energy demand in northern Australia, where mining and minerals processing contribute significantly to economic output. In the Northern Territory, recent strong growth in energy consumption is expected to continue, with the start-up of liquefied natural gas (LNG) and other natural gas liquids processing facilities.

The economies of Victoria and New South Wales are less energy intensive than those of Queensland and Western Australia. Despite considerable economic growth in New South Wales and Victoria over the past 15 years, the rate of growth in energy consumption in both these states has been relatively subdued. In South Australia and Tasmania, low population and economic growth and a decline in activity in the energy intensive industries have resulted in lower rates of energy consumption growth than in New South Wales and Victoria.

Road transport accounts for some 75 per cent of the total transport use of energy. Reflecting the desire of Australians for personal mobility, two-thirds of road transport energy use is from passenger vehicles, with the remainder representing commercial vehicles (Figure 12).

The transport system is heavily reliant on petroleum-based fuels, which meet more than 97 per cent of Australia's total transport needs. This is in line with world trends. Electricity powers some rail transport, coal powers some water transport, natural gas powers gas pipelines, and biofuels and natural gas play a very minor role in meeting Australia's road transport needs (ABARE 2003).

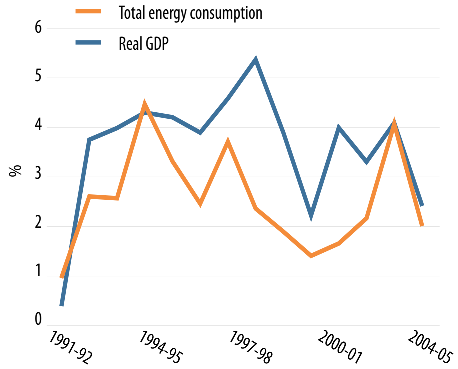


Figure 7: Growth of Australian real GDP and energy consumption (source: ABARE 2005a , 2006a and 2006b)

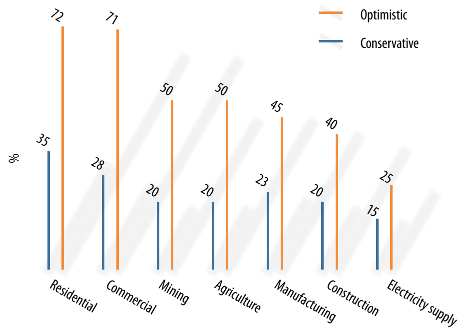


Figure 8: Cost-effective energy consumption reduction potential across sectors (source: Energy Efficiency and Greenhouse Working Group, 2003)

AUSTRALIA'S ENERGY SOURCES

Coal, oil and natural gas supply 95 per cent of Australia's energy needs.

Three fossil fuels – coal (brown and black), oil and natural gas supply 95 per cent of Australia's energy needs (Figure 13).

These fossil fuels cater for different needs in different markets, and also occupy niche roles in many markets.

Australia is fortunate in having large, easily mined deposits of coal close to the major urban centres in the eastern mainland states. It has been possible to site the major power stations close to those coal

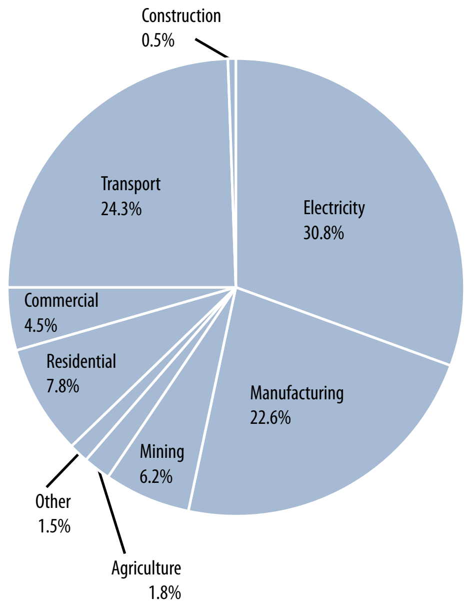


Figure 9: Shares of energy consumption in Australia by end use, 2004–05 (source: ABARE, 2006a)

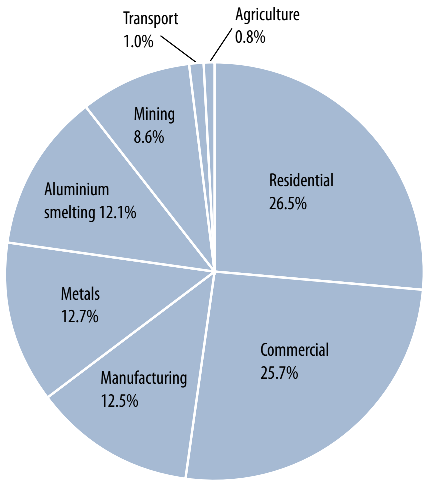


Figure 10: Shares of electricity consumption in Australia by end use categories, 2004–05 (source: ABARE, 2006a)

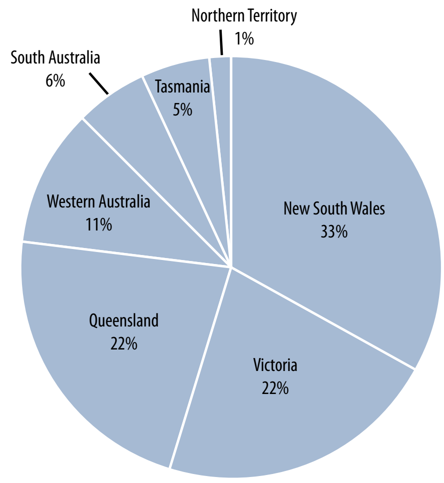


Figure 11: Electricity consumption by state and territory 2004–05 (source: ABARE, 2005b)

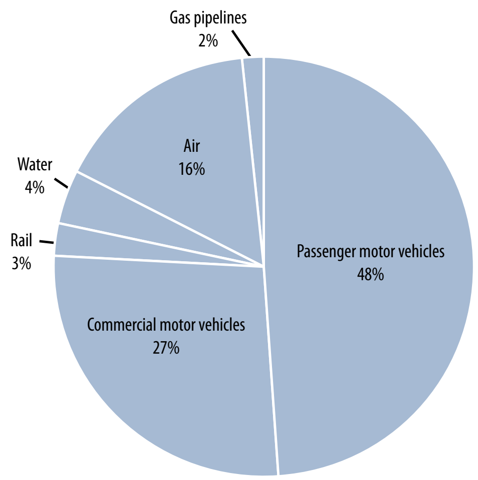


Figure 12: Share of energy consumption in transport by end use category, 2004–05 (source: ABARE, 2005b)

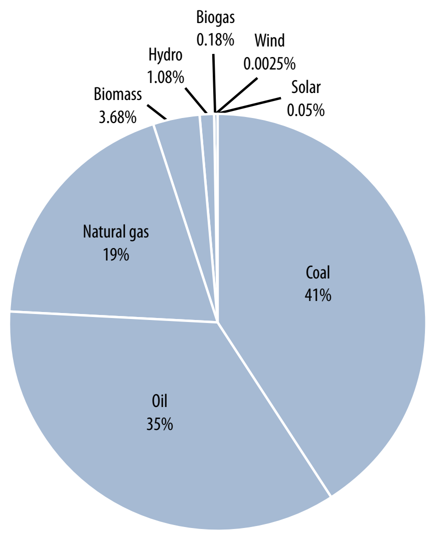


Figure 13: Share of energy consumption by fuels and other energy sources, 2004–05 (source: ABARE, 2005a)

deposits and thus eliminate much of the cost and inconvenience of moving large tonnages of a bulky material. As a result of this relative cost competitiveness (ignoring any cost to the environment; for example, greenhouse gas emissions), coal dominates base load electricity generation in Australia, as reflected in the installed generation capacity by fuel (Figure 14).

Western and South Australia have relatively less coal, but plenty of gas and also lower demand for electricity. More than half of their electricity is derived from burning gas. Development of Tasmania's large hydroelectric resources has put off the day when it needs any large thermal power stations, but hydro potential is now almost fully utilised.

The role of natural gas is greater in South Australia, Northern Territory and Western Australia where access to natural gas and a comparative lack of coal makes it more competitive as a source for base load, as well as mid and peak load, electricity generation. Tasmania is unique in that almost all of its electricity is generated from hydroelectric power stations. These states and territories, however, only consume some 20 per cent of electricity generated in Australia so coal remains dominant, overall, in total Australian electricity generation.

Recent years have seen the development of an increasing network of electricity and gas transmission connections between the states and territories. This has contributed to a more competitive energy market and facilitated the balancing of supply and demand in a smoother fashion than would be the case otherwise.

With the exception of hydropower, low emission technologies are currently not cost-effective, as greenhouse gas emissions are not taken into account throughout the National Electricity Market (NEM), except under mechanisms such as the NSW Government's Greenhouse Gas Abatement Scheme, and the Commonwealth Government's Mandatory Renewable Energy Target.

Low emission technologies are currently not cost-effective, as greenhouse gas emissions are not taken into account.

In recent years, a number of Commonwealth and state based schemes have been introduced to encourage the development of low emission technologies. These schemes have enabled low emission technologies to derive income from the trading of permits and credits in addition to revenue from the sale of electricity. While the majority of electricity is sourced within each state and territory, the eastern Australian states (New South Wales, Victoria, Queensland, South Australia and Tasmania) are interconnected as part of the National Electricity Market (NEM). Snowy Hydro is physically located between New South Wales and Victoria and supplies energy to both regions. Trade between states via the interconnections represents 13.5 per cent of the total elec-

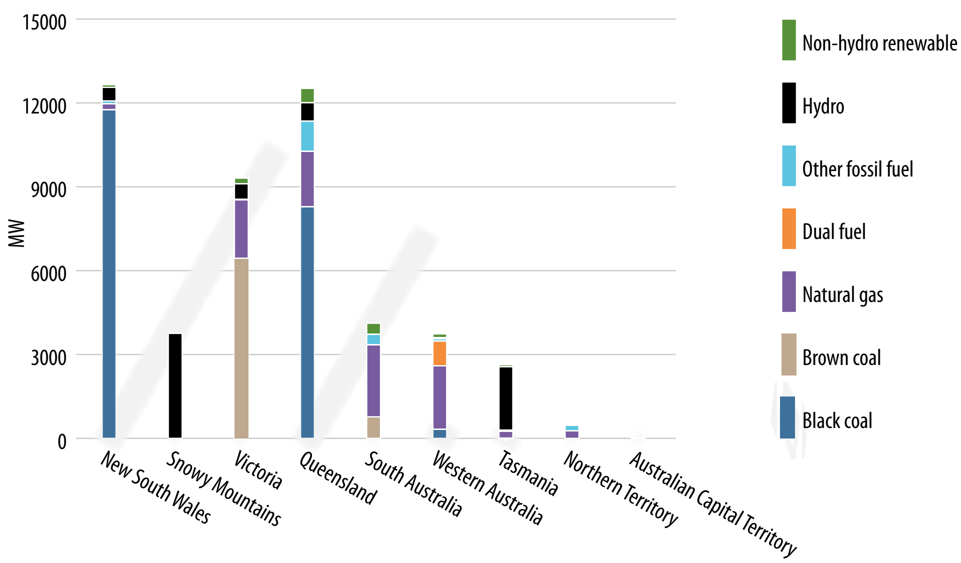


Figure 14: Installed electricity generation capacity by technology category in Australia (Based on ESAA, 2006)

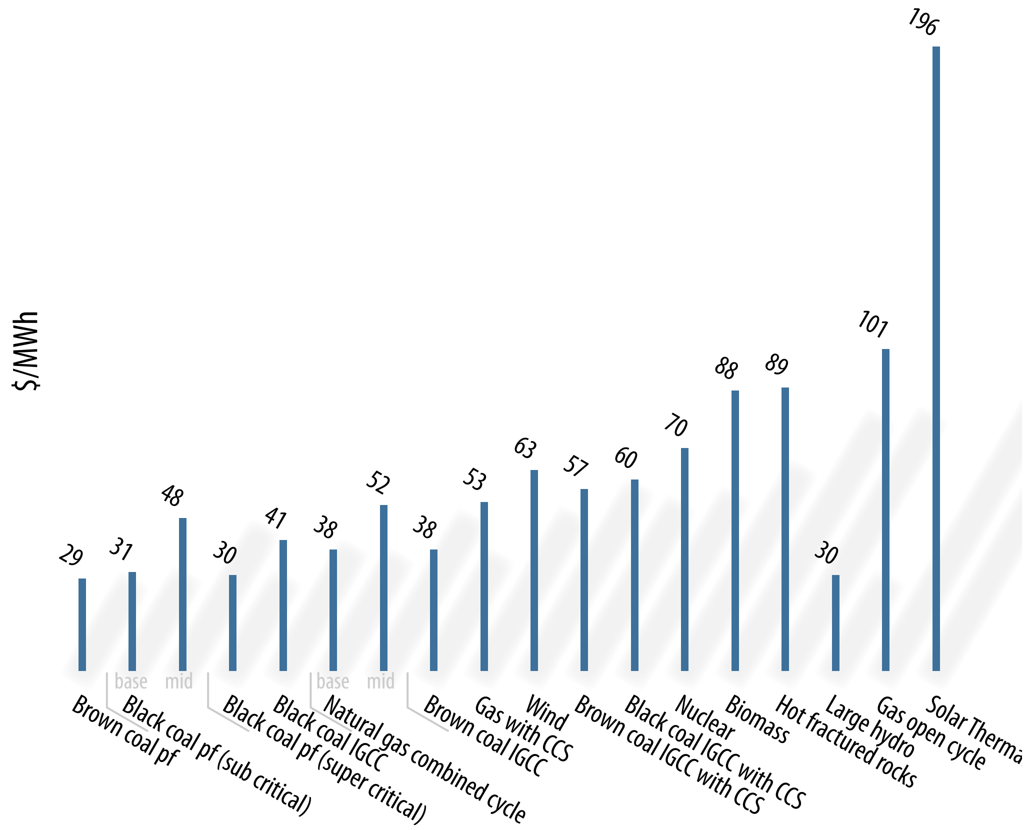


Figure 15: Estimated electricity generation costs of selected centralised electricity generation technologies (source: CSIRO estimates.)

tricity produced in the eastern states in 2004–05. That share is expected to have increased with the interconnection of Tasmania in 2006.

HOW MUCH IS AUSTRALIA PAYING FOR ENERGY?

In 2004–05 Australia had among the lowest electricity prices for large business and industrial users when compared to a host of other developed countries, including Germany, Japan, Italy and the United States. Australia also has one of the lowest residential electricity prices in the Asian region and performs well in comparison with European countries.

Similarly, gas prices in Australia are among the lowest in the world and are substantially lower than in most OECD countries including France, Germany, Japan and the United States of America

Australia's inexpensive electricity has seen substantial investment in resource processing and other energy-intensive industries. The production of alumina and aluminium, paper, cement, chemicals, metals and minerals processing requires large amounts of energy. The international competitiveness of these sectors relies on Australia's abundant mineral resources, low sovereign risk and access to competitively priced, reliable energy.

The National Electricity Market Management Company (NEMMCO) oversees the operation of the wholesale electricity market and the management of power system security in the Australian eastern states. Wholesale electricity costs represent roughly a third of residential retail electricity prices, around a half of large business retail prices, and less than a third of small businesses retail prices.

The retail price that consumers pay for electricity differs from the wholesale price for two reasons. Firstly, the retail price of electricity is significantly higher to cover the costs of transmission and distribution of electricity via the grid, and secondly, the retail price of electricity depends on the type of customer. An example of the prices paid by different customer categories is shown in Table 2.

A consequence of such pricing arrangements is that for any given change in wholesale electricity prices, retail prices are unlikely to change significantly, at least in the short-term. For example, distribution and energy prices to residential customers are usually regulated by the government or subject to contractual arrangements with the retailer. Similarly, commercial and industrial customers protect themselves from wholesale electricity price movements by entering into short, medium and long-term energy contracts with energy retailers.

Across Australia, various segments and jurisdictions are at different points of removing regulated retail prices.

Retail gas prices are also similarly differentiated by end-users with industrial users again having the lowest distribution margin as a component of their retail price. For this reason, industrial consumers may be regarded as more vulnerable to changes in wholesale electricity and gas prices.

Petrol prices are a significant part of the overall Australian energy price picture.

Between 2000 and 2004 retail petrol prices ranged between 80 and 90 cents per litre. In late 2004, average prices reached A$1.00 per litre and remained above that (fluctuating up to A$1.50 per litre) level after March 2005. The fluctuations are largely driven by the international price of oil and the exchange rate since international oil prices are denominated in US dollars. The other components to the petrol price are excise (a constant 38 cents per litre), refining costs, transport costs, retail costs, and goods and services tax (GST).

All fuel excise rates will be incrementally reformed commencing in 2006, and concluding in 2015. Under this system, fuel excise rates will move from a volume-based system to an energy-based system. Excise rates for high, medium and low energy density fuels will be 38, 25 and 17 cents per litre respectively. Alternative fuels such as biodiesel, ethanol, compressed natural

	New South Wales	Victoria	Queens-land	South Australia	Western Australia	Tasmania	Australian Capital Territory	Northern Territory
Residential	9.2	12.2	10.1	12.6	13.3	11.8	10.3	16.0
Small Business	10.4	17.2	13.0	15.4	16.2	12.0	11.9	15.3
Large Business	5.6	5.5	6.5	6.3	8.9	6.6	7.8	9.6
Farming	14.2	17.8	13.0	15.4	15.4	12.0	-	-

Table 2: Indicative retail prices of electricity in cents per kWh by end-user group in 2002–03 (source: Adapted from ESAA, 2004). A specific consumption pattern is used for each general customer type. Prices shown do not necessarily represent customer average prices in the regions presented and comparison between regions can be misleading

gas (CNG) and liquefied petroleum gas (LPG) will remain free of excise until 2011. From 2015 they will attract a discounted excise rate of 19.1, 12.5 and 8.5 cents per litre for high, medium and low energy density fuels respectively.

Petrol prices in Australia are amongst the lowest in the developed world.

Petrol prices in Australia are among the lowest in the developed world.

Recent figures (IEA) show the post-tax retail price of petrol in Australia in the March quarter 2005 was the fourth lowest among OECD countries at A$1.01 per litre. For the same period, average retail petrol prices in the United Kingdom were A$1.95 per litre, Japan A$1.44, Germany A$1.85, and USA A$0.66 per litre. Australia also has the sixth lowest pre-tax petrol prices in the OECD.

AUSTRALIA'S ENERGY TRADE

In contained energy terms, Australia exports significantly more energy than it imports, with thermal coal and uranium as the two largest exports (Figure 16).

In value terms the net trade position is slightly altered (Figure 17). While high in terms of energy content, the value of uranium oxide exports is only around half a billion dollars. While smaller in energy terms, exports of LNG earns around four and half billion dollars.

If coking coal is removed, which is used to make coke for steel making and earned A$17 billion in 2005–06, Australia is a net energy importer in value terms. Australia's status as a net energy importer has only occurred recently as the volume of exports of crude oil fell 17 per cent between 2004-05 and 2005-06, reflecting declining production, at the same time as crude oil prices increased. Imports of crude oil and petroleum products were worth A$21.6 billion in 2005–06.

The minerals sector–of which aluminium and iron and steel are segments (Figure 19)–comprised some five per cent of Australian GDP in 2005–2006 but make an important contribution to Australian exports, accounting for almost half of the A$190 billion estimated total in 2005–06 (ABARE 2006b). The balance consists of agricultural products, and exports of services and other merchandise (Figures 18 and 19).

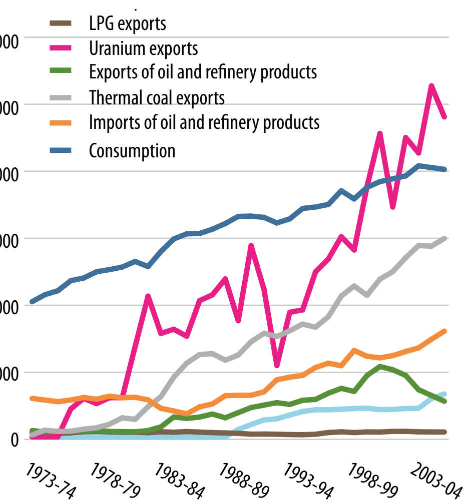


Figure 16: Australia's energy trade (source: ABARE, 2006a and 2006b)

GREENHOUSE GAS EMISSIONS AND ENERGY

Emissions of greenhouse gases come from a variety of sources and locations. While comprehensive and accurate data do not exist on greenhouse gas emissions

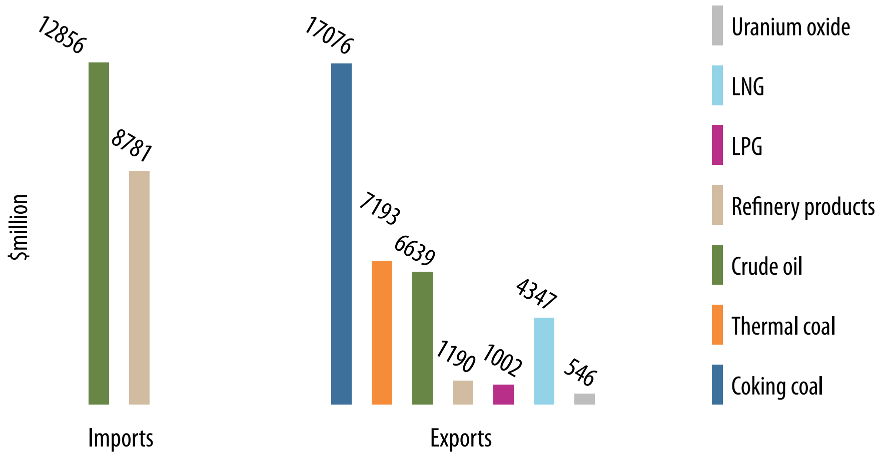


Figure 17: Value of Australian energy and coking coal exports and imports, 2005–06 (source: ABARE, 2006b)

for many nations, some general observations are possible.

The first is that the production and use of energy are large sources of emissions. The World Resources Institute estimates that about 61 per cent of global greenhouse gas emissions in 2000 came from energy use (WRI 2006).

The second is that a small number of nations (or a union of nations, in the case of the European Union) account for a large proportion of global emissions. According to WRI, six nations (United States, European Union, China, Russia, Japan and India) account for nearly half of global emissions and nearly two-thirds of carbon dioxide emissions from energy. The United States accounts for more than one-fifth of global energy-related emissions (Figure 20).

Expected economic growth in less developed countries, such as China and India, will result in emissions from these nations increasing substantially over the next 20 to 30 years. Total emissions from less developed countries are expected to soon overtake those from industrialised countries.

World Resources Institute estimated that Australia contributed 1.5 per cent of world greenhouse emissions in 2000, or 1.2 per cent if land use changes are included. In terms of cumulative emissions from 1950 to 2000, Australia contribution was 1.2 per cent. (The accounting convention in all estimates is to attribute the emissions to the country where the emissions occurred.)

In terms of greenhouse gas emissions per capita, Australia's is ranked 4th as measured in 2000, at around 25.6 tCO_2e per capita (WRI, 2006). Australia's ranking, according to this measure, is the highest among developed countries, followed by the United States and Canada. The average amongst developed countries is 14.1 tCO_2e per capita. Australia's high ranking in emissions per capita reflects our relatively high proportion of fossil fuels in energy consumed, high uptake and relatively less efficient private transport and relatively high production of non-ferrous metals per capita.

Australia's emissions come from a variety of sources (Figure 21). The production and use of energy provides the single largest source, accounting for 69 per cent of total 565 Mt CO_2e emitted in 2004 (with electricity production accounting for 35 per cent, and transport energy 14 per cent of the national

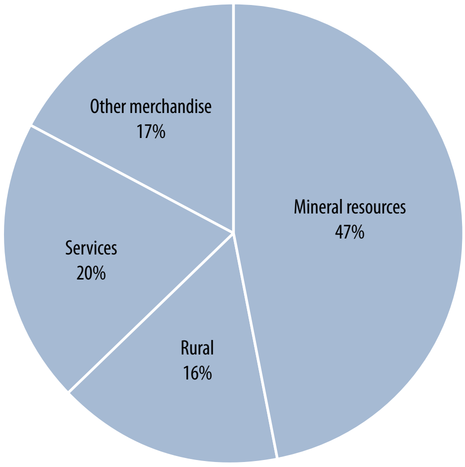


Figure 18: Shares of total exports of goods and services, 2005–06 (source: ABARE, 2006b)

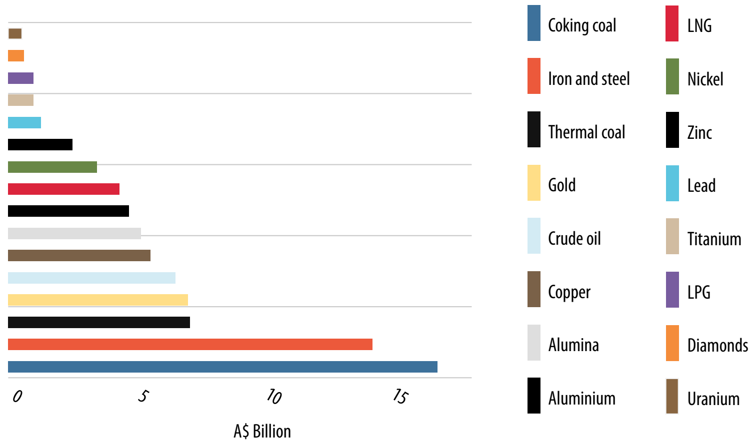


Figure 19: Value of selected Australian mineral and energy exports by type 2005–06

total). Agriculture was the next largest contributor at 16 per cent, with the other 6 per cent of emissions from land use change and forestry, industrial processes and waste.

Emissions from non-energy sectors have generally been declining, with total emissions from these sectors falling by 87 Mt from 1990 to 2004. This is especially due to significant declines in land use, land use change and forestry emissions. By contrast, energy sector emissions rose by 100 Mt over the same period (Australian Greenhouse Office 2006).

Energy sector emissions (including stationary energy, transport and fugitive emissions) are the largest and fastest growing, increasing by almost 35 per cent between 1990 and 2004.

Any significant reduction in Australia's long-term greenhouse signature must involve changing the way it produces and uses energy. Australia's energy sector emissions reflect our fuel mix, economic structure, and lifestyles. Electricity generation is dominated by coal, which has a high CO_2 emission factor (Table 3)and electricity use is growing rapidly. Australian building design has traditionally paid little attention to energy performance and personal transport is largely based on private, medium-to-large vehicles, using petrol or diesel that also have high CO_2 emissions.

Electricity		Road Passenger Transport	
Fuel	**Emission factor**	**Fuel**	**Emission factor**
	(kgCO2e/kWh)		(kgCO2e/km)
Average existing stock:		Average existing fleet:	
Black coal	0.9	Petrol	0.30
Brown coal	1.3	Diesel	0.33
Natural gas	0.6	Liquid Petroleum Gas	0.31
New stock:		New vehicles:	
Black coal	0.8	Large Petrol	0.26
Brown coal	1.0	Medium Diesel	0.17
Natural gas	0.4	Small petrol - hybrid electric	0.11

Table 3: Greenhouse gas emission factors for electricity and transport categories in Australia (source: CSIRO estimates)

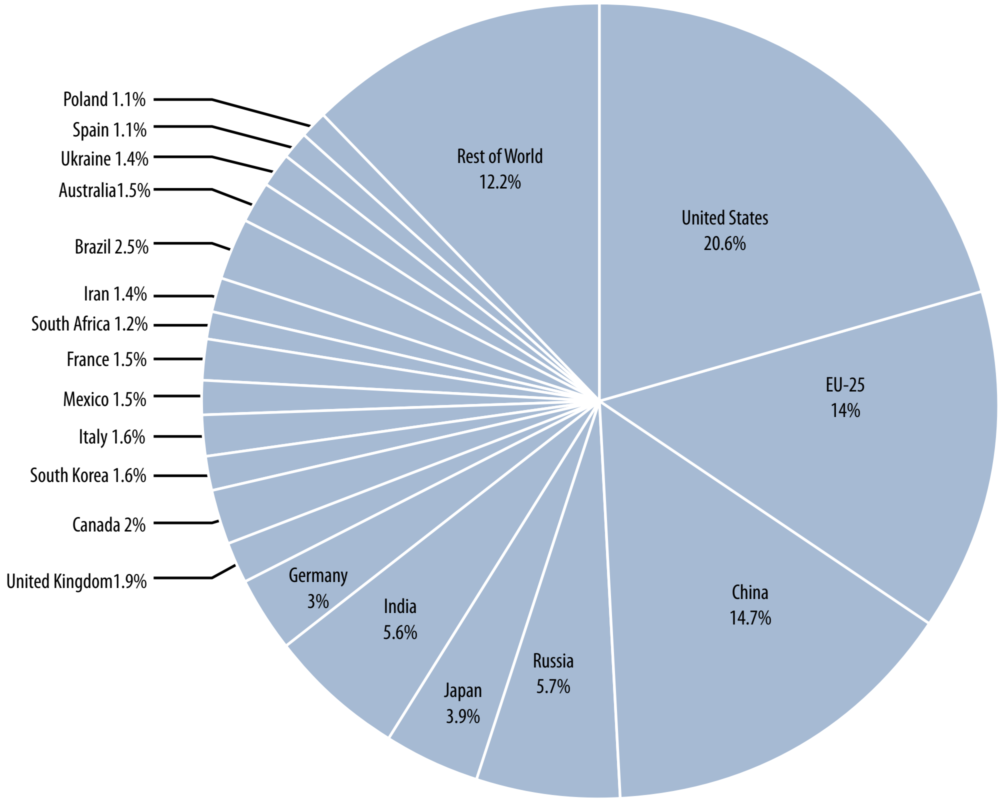


Figure 20: Shares of greenhouse gas emissions (excluding land use change), 2000 (source: WRI, 2006)

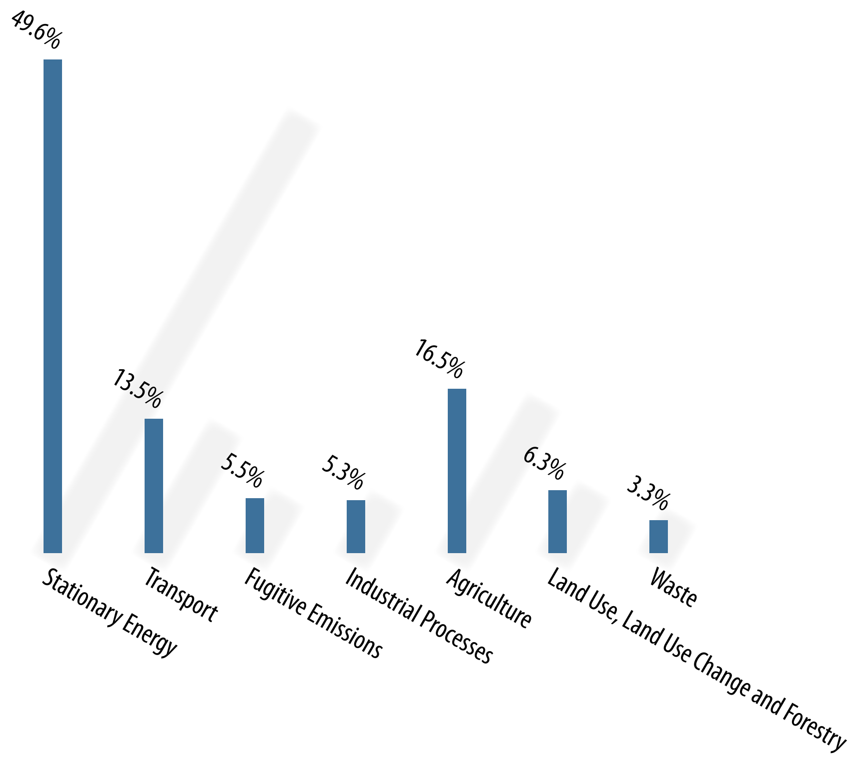


Figure 21: Contribution to total net C02-e emissions by sector (Kyoto accounting), 2004 (source: AGO, 2006)

ENERGY INFRASTRUCTURE

Infrastructure and related services play a crucial role in supporting the economy. Among key sectors in this regard are electricity, transport, telecommunications, financial services and business services. The challenge of infrastructure is that it requires enormous up front investments but once installed provides ongoing benefits, often for many decades. Table 4 shows some indicative infrastructure lifetimes, which are a factor in the rate at which new technologies enter the economy.

Infrastructure	Expected lifetime, years
Hydro station	75 +
Building	45 +
Coal station	45 +
Nuclear station	30-60
Gas turbine	25 +
Motor vehicle	12-20

Table 4: Typical infrastructure lifetimes (source: Adapted from WBCSD, 2004)

While many infrastructure services have been privatised in recent decades (or corporatised where government ownership is maintained but the entity is given the right to behave like a private company), the bulk of Australia's infrastructure development occurred in the 1950s, 60s and 70s in public ownership. As that infrastructure decays, the decisions about the types of new infrastructure required to meet existing and new demand will now in many cases be taken from a commercial point of view. This is particularly so in the National Electricity Market, which is open to any new or existing private investors.

AUSTRALIAN ATTITUDES TO ENERGY

Australians consume energy for a variety of reasons, including entertainment, heating, cooling, industrial processes, information management, mobility and even fashion. Energy, in particular access to electricity and gas, is widely considered an essential service for social wellbeing. Apart from a few industrial processes, the energy costs of these purchasing decisions are often minor when compared to other features of the whole package of goods or services being consumed.

In 2006, average household electricity and petrol costs represented around one and three per cent of average full time earnings assuming the earnings supports one average house and one car (CSIRO estimates).

The general low value of energy relative to income, as well as the key role energy plays in the Australian lifestyle is one reason why demand for energy is often observed as being relatively price inelastic. That is, demand for energy is less price responsive than other goods and services.

Demand for electricity is relatively price inelastic.

A literature review of the price elasticity of demand for electricity (for example ABARE (2003)) indicates that for a 10 per cent increase (decrease) in electricity price, demand for electricity is only expected to decrease (increase) by 2.5 per cent.

Some specific users of electricity, however, would have much higher price elasticity. For example, industries where electricity is a significant share of total costs of production, such as the aluminium sector, would be expected to be more responsive to electricity price changes.

Table 8 shows the contribution of different household activities to energy use and greenhouse gas emissions. In 2005, 43 per cent of households said they considered cost to be the main factor when buying a new whitegood, 44 per cent nominated the energy star rating as a main consideration, and only 11 per cent of households stated an environmental factor as their main consideration. Many households with insulation said their main reason for installing it was to achieve comfort (83 per cent), rather than to save on energy bills (10 per cent) or use less energy (4 per cent).

Household activities	Energy use %	Emissions %
Appliances	30	53
Heating water	27	28
Cooking	4	6
Heating and cooling	39	14
Total	100	100

Table 5: Household energy uses and their contribution to greenhouse gas emissions, 2005 (source: ABS, 2006)

Many Australians are aware of costs to the environment from the consumption of energy.

There are some 300,000 customers of Green Power across Australia - that is electricity certified as coming from new sources of renewable energy such as the solar, wind, biomass (waste), wave or hydro, which do not emit greenhouse gases (Figure 22).

Surveys and research conducted as part of Australian Greenhouse Office National Greenhouse Strategy indicates that the environment has emerged as an issue of concern for large numbers of Australians. Evidence suggests, however, that although people agree more can be done to help protect the environment, adoption of environmentally

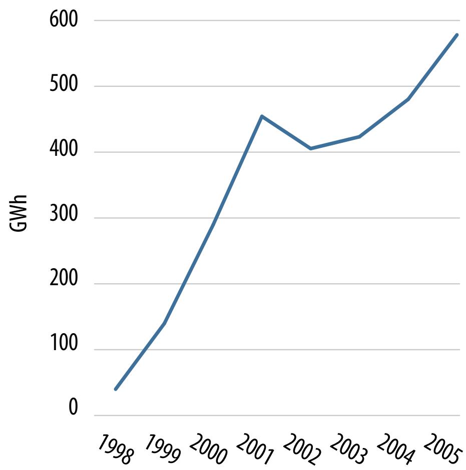


Figure 22: Trend in sales of Green Power in Australia (source: Adapted from Green Power, 2006)

friendly behaviours is greatest where it is convenient and does not require large investments of time or money.

It has also been hypothesised that people may become complacent, feeling that they are 'doing their bit' if they recycle, use unleaded petrol and buy the occasional energy efficient appliance. This complacency may be a barrier to further modifications of behaviour (ABS 2006).

Between 1992 and 2004, the Australian Bureau of Statistics surveyed households every two to three years on their attitudes to environmental issues and concerns.

In 2004, of all Australians surveyed aged 18 years and over, 57 per cent stated they were concerned about environmental problems. The level of concern had decreased considerably since 1992, when 75 per cent of Australians stated they had environmental concerns.

The environment has emerged as an issue of concern for large numbers of Australians.

More recently, the Lowy Institute (2006) in a multination survey found that Australians rated 'global warming' in the top three critical threats to their vital interest, but only Australians ranked 'improving the global environment' as the top foreign policy goal with 87% support; others ranked it in the middle. Australians (68%) are much more likely than Americans (43%) to think we should take steps now to tackle global warming even if they involve costs.

There is some evidence of changes in car vehicle purchasing preferences in response to high petrol prices.

Generally speaking, petrol is considered to be even more price inelastic than electricity. An estimate of the price elasticity of petrol demand shows that for a 10 per cent increase (decrease) in petrol prices, demand for petrol is only expected to decrease (increase) by one per cent (ABARE, 2005b).

Vehicle size is a major determinant of fuel consumption and during the 1970s car vehicle purchasing preferences did change significantly in response to the high oil prices being experienced at the time.

From 1970 to 1980, new vehicles registered in the smaller medium sized car range increased from 14 to 26 per cent. Intermediate medium sized cars also increased from 15 to 30 per cent of new registrations. At the same time the share of new registrations of large and larger medium size cars fell (Monash University Accident Research Centre, 1993). However, the trend levelled out and shares even reversed by a few percentage points when oil (and therefore petrol) prices were still high, but coming off their peak during the 1980s. Some of the purchasing of smaller cars can also be accounted for by improvements in income at the time, which meant second cars were not only affordable for a growing number of households but were expected to deliver better fuel efficiency.

WHAT DOES IT TAKE TO CHANGE ENERGY PREFERENCES?

Historical transitions from one energy source or technology to another suggest that geopolitical stability, political and economic feasibility, environmental impact, and current infrastructure use are all contributing factors to any changes.

Figure 23 shows the growth in the contribution of various energy sources to United States' energy consumption since the 1800s. It shows that some energy sources have been utilised for a long time, energy sources have generally become more diversified over time, and some have experienced differing degrees of volatility in use.

The US Department of Defense (2003) has also studied historical energy transitions. The main issues identified were:

- A de-carbonisation trend: This refers to a gradual decrease in the intensity of carbon in each energy source due to increasing energy efficiency.
- A pre-adaptation trend: Each source of energy has initially substituted for the existing use of another energy source on a smaller scale until a new technology is discovered that better exploits the new energy source. This pre-adaptation phase may ease infrastructure changes that are needed for the new sources of energy.
- Historical energy transitions are tied directly to technology innovation.
- Each new form of energy did not compete directly with predecessor sources since energy consumption was rising at exponential rates (new energy demands) and new sources of energy (allied with new technology) created demand in its own right.
- Government can lead the transition to new energy sources through its acquisition decisions. For example,

the decision by the British and UK naval forces to adopt oil powered ships before World War I.

The convergence of public pressure for 'clean energy' sources, conflict in the Middle East, heightening demand, and strides in science and development might match the pattern of preconditions likely to underpin a transition to a new primary energy source.

The study noted that the convergence of public pressure for 'clean energy' sources, conflict in the Middle East, heightening demand, and strides in science and development might match the pattern of preconditions likely to underpin a transition to a new primary energy source. A study by the International Institute for Applied Systems Analysis gives an indication of the time scales that might be relevant in studying modern society's adoption of new energy technologies.

The cumulative diffusion time (the time required for a new technology to grow from 10 to 90 per cent eventual market share) of a sample of 265 technologies discussed in Grubler et. al. (1999) shows the diffusion times range from very short-term processes of only a few years to processes that extend over two to three centuries. The mean value of the time constant is 41 years, with a standard d eviation of about equal size.

Few diffusion processes extend more than one century. Half of the diffusion processes have diffusion duration of less than 30 years; about three quarters have diffusion duration of less than 50 years; and 93 per cent of the sample exhibits diffusion durations of less than 100 years.

Arguably, a key determinant of the length of the diffusion period is whether the technology fits into an existing cluster of technologies or not. For example, diffusion times for black-and-white TV sets took 30 years in OECD countries, whereas the replacement of black-and-white by colour TV sets took typically only about half that time. This is because colour TVs fitted into an existing cluster or interdependent infrastructure of telecommunications technology.

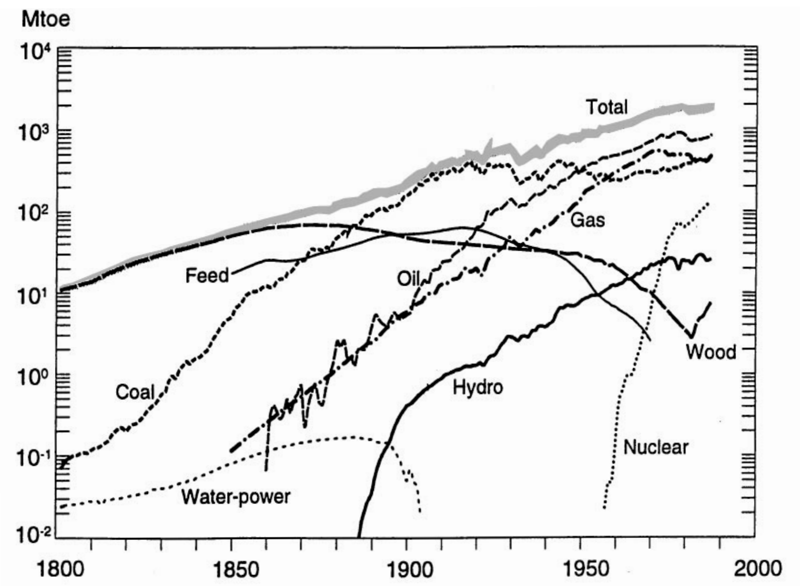


Figure 23: The uptake of selected energy sources in the United States (source: Grubler et. al., 1999 reprinted with permission from Elsevier). Feed refers to the food provided to working livestock.

3 What might the future hold?

Exploring qualitative energy scenarios for 2050

This section outlines how the Energy Futures Forum engaged in scenario thinking in order to explore the shape and nature of energy in Australia in 2050. The result was nine plausible scenarios.

Australia's energy future will be created by forces that originate from a wide variety and number of governments, institutions, organisations, firms and households both within and outside the existing energy sector; some of these changes are able to be altered by people's individual and collective choices, other forces are not controllable, others are perceived to be inevitable. Our ability to quantify and model many of them is limited.

Scenarios are narratives of what the future may be, created by weaving together different strands of what already exists and what may come to exist.

One of the reasons that the Energy Futures Forum (EFF) created qualitative narratives or scenarios is that the Forum did not want to ignore the non-quantifiable forces underpinning and shaping change.

Scenarios are plausible stories about how the future may unfold. Scenarios are not predictions or models. They address different ways in which relevant issues outside our organisations might evolve, such as the future natural environment, social attitudes, technology and the strength of the economy. Because scenarios are not predictions, they are often created and used in sets that are taken to represent the range of plausible developments.

The qualitative scenarios draw on factual information and EFF members' experience and judgment about how the future may come together. The individual scenario narratives are less important than building a better understanding of the environment in which energy organisations and stakeholders will operate. Scenarios allow us to analyse changes in the environment, take new perspectives and develop new understanding. This improved understanding can be used to inform better decisions today and in the future.

Driving forces are the outside forces of change that will shape the future in both foreseeable and unpredictable ways. Driving forces include factors within our working environment, like developments related to communities, and, shifts in the broader environment – social, technological, economic, environmental, and political – that could have an unexpected impact.

Driving forces can be either given or uncertain.

Givens are relatively certain forces of change. Over the next 50 years, changes that were considered to be locked-in included:

- Climate change will affect the natural and built environments[1]
- Some form of carbon constraints will be introduced[2]
- Australia's energy dependence will continue[3]
- Australia's population will grow to reach median projections of 28,000 million[4]

Some driving forces are unpredictable. While all driving forces are important, they are not of equal importance. The priority driving forces identified in this Report were chosen because of their (1) degree of importance to the future of energy in Australia, and (2) the degree of uncertainty surrounding those forces.

The future energy scenarios in this chapter focus on how four forces central and influential to the future of energy in Australia, may intermingle (Table 1). These are:

- the global impact of, and responses to, climate change
- geopolitical stability
- sustainability
- technological innovation.

Climate Change	Climate change refers to the build-up of artificially produced gases in the atmosphere that trap the sun's heat, causing changes in weather patterns on a global scale. The effects include changes in rainfall patterns, sea level rise, potential droughts, habitat loss, and heat stress. The anthropogenic greenhouse gases of most concern are carbon dioxide, methane, and nitrous oxides.
Geopolitical Stability	The term geopolitical stability refers to a situation where nations, commercial entities and other significant global actors are not motivated to unilaterally change their behaviour, and the global political system is at an equilibrium point. Instability occurs when one or more global actor makes unilateral decisions that affect other actors. It is similar to a chess game, when the global system is not stable it becomes progressively more difficult to anticipate other's actions or moves into the future.
Sustainability	Sustainability is an economic, social, and environmental concept. It refers to the ability to provide for the needs of the current global population without damaging the ability of future generations to provide for themselves. When a process is sustainable, it can be carried out over and over without negative consequences or effects or impossibly high costs to environmental and ecosystems health, economic growth, commercial development, and social organisation
Innovation	The Forum used the OECD definition of technological innovation found in the Oslo Manual (1995). Technological product and process innovations comprise: implemented technologically new products and processes and significant technological improvements in products and processes. Technological product and process innovations involve a series of scientific, technological, organisational, financial and commercial activities. Technological product and process innovations have been implemented if they have been introduced to the market (product innovation) or used within a production process (process innovation).

Table 1: Four driving forces for energy futures in Australia

It is important to note that during the discussion about the way in which the drivers of change might combine and evolve, it became clear that the climate change driver was uppermost of the four driving forces (Table 1). Later discussions confirmed the insight – that climate change was '*primus inter pares*' – or a first among equals of the four drivers that had been culled from a much larger selection of driving forces.

The high level of importance about the impacts of, and responses to, climate change influenced the way the Forum discussed the future with the quantitative modellers; and helped the Forum decide the parameters of the models discussed in Section 5.

Some drivers are so unpredictable that they are likely to take us totally unaware: this was a final category of forces for change discussed. These are the types of changes that occur so suddenly that we can neither forestall them nor manage an effective response to them.

These 'wild cards' can create entirely different futures, for example, NASA engineers develop aircraft that can change shape to make them more manoeuvrable. As a result, the next generation of combat aircraft have wings that change shape and use devices within the wing skins to recover or 'harvest" energy as the wings move. This technology is then widely adopted by the largest aircraft and automobile manufacturers, which in turn leads to the collapse of some of the world's largest steel companies.

THE SCENARIOS

The EFF developed nine scenarios, which were created by combining the driving forces to create distinct narratives about what the future could look like. The goal was to develop a set of plausible scenarios that tell very different stories that challenge assumptions and shed light on the strategic issues facing the Australian energy sector.

Developing qualitative scenarios is an art rather than a science. A story should quickly capture a lot of complexity and leave a lasting message with the reader. Scenario narratives need to stretch thinking to challenge conventional wisdom and show futures that could diverge widely, while staying close enough to the present to maintain relevance and credibility in the minds of decision-makers.

The details and reliability of their narrative content are less important than the types of conversations they start. Remember that the narratives are not predictions of the future; in fact, the narratives actually fell into the background of later EFF conversations as the strategic opportunities and challenges facing the energy system in Australia rose to the surface.

Full details of the qualitative scenarios are contained within *What Might the Future Hold? Exploring Qualitative Energy Scenarios for 2050.*

Power to the People

It is 2050 …and a number of key developments over the past 50 years have led to a major restructure in the way Australians are meeting their energy needs. Residents and businesses now generate the majority of their own energy needs locally through a distributed generation network.

	Power to the People	Centralised Failure	Technology to the Rescue
Climate Change	Global management regime, effective	Global management regime, ineffective	Global management regime, effective
Geopolitical Stability	Stable	Stable	Stable
Sustainability	Improved sustainability	Sustainability declines	Improved sustainability
Innovation	Significant technological innovations	Late introduction of technological innovation	Significant technological innovations

	The Day After Tomorrow	Atomic Odyssey	Cultural Revolution
Climate Change	Global management regime	Global management regime, effective	Global management regime, effective
Geopolitical Stability	Stable	Stable	Stable
Sustainability	Improved sustainability	Improved sustainability	Improved sustainability
Innovation	Moderate technological innovations	Significant technological innovations	Significant technological innovations

	Clean Green Down Under	Rough Ride	Blissful Indifference
Climate Change	Global management regime, effective	Global management regime, ineffective	Global management regime, ineffective
Geopolitical Stability	Stable	Instability	Stable
Sustainability	Improved sustainability	Sustainability declines	Sustainability declines
Innovation	Significant technological innovations	Few technological innovations	Few technological innovations

Table 2: How the qualitative scenarios were created to accentuate different futures

The key developments that led Australia down this path were:

- the development of cost-effective solar PV (photovoltaic) and electricity storage technologies around 2030
- the accession of Australia to a global greenhouse gas emission target of 50 per cent below 1990 emission levels by 2050
- a subsequent genuine economic advantage to be gained from installing localised generation relative to paying the retail price for electricity (inclusive of the costs of CO_2 permits)
- the emergence of energy service companies who pay the upfront costs of installing localised generation in return for the opportunity to exploit the generation-retail price gap and thus optimise the financial and energy performance of many thousands of aggregated units across the electricity grid.

The decentralisation of energy is reflected to some extent in the way government and society re-organised itself over the past 50 years. The relatively small 'sea change' trend observed at the start of the century, in time came to offset the then more dominant trend of the population centralising itself in capital cities. Today, more people are living in revitalised mid-sized cities, with a subsequent demand for more decentralised government decision-making.

The greater penetration of distributed generation and greater geographical spread of the population has accelerated energy end-use efficiency improvements in Australia.

Energy service companies have not only provided the incentives for users to shift their loads to non-peak hours of the day, but the act of generating one's own power (much like the installation of rain tanks in the early part of the century saw a lasting reduction in water use per head) has brought about a genuine cultural change toward minimising energy consumption. This attitude also spilled over into transport energy use, following an upward step change in oil prices that was never reversed.

Key technology changes

Distributed generation is dominant where residential and commercial customers use solar photovoltaic (PV) and fuel cell systems to power their homes or premises. Carbon capture and storage (CCS) and geothermal electricity technologies play a role. There is greater use of trains, as well as hybrid and fuel cell vehicles.

Centralised Failure

It is 2050 …and for a variety of reasons, the large-scale roll out of greenhouse gas mitigation technologies have only been in place for some ten years, with actions to address climate change only beginning around 2040.

The lateness of this action has Australia in 2050 questioning whether it would be more cost-effective to focus on climate change adaptation rather than mitigation. Driving this questioning is the failure of the international community to arrive at an enforceable and fully inclusive climate change mitigation agreement and a consequent lack of policy certainty and price signals needed for privatised electricity markets to bankroll new technology deployment.

Nevertheless, Australia and the rest of the world have embarked on an ambitious last-ditch attempt to implement the policy needed to reduce greenhouse gas (GHG) emissions by imposing, from 2040, a very high CO_2 tax rate.

In the transport sector some improvements in energy efficiency have been achieved in the absence of a CO_2 price. Two factors are behind this. Firstly, oil prices increased and have remained moderately high relative to the prices paid in the previous century. Secondly, as employment, and subsequently populations, have become more centralised in Australia's larger cities, the trend away from public transport has been finally reversed. Worsening traffic congestion, and a growth in higher density housing as the only affordable option for most tenants, has seen trains become the most convenient mode for the majority of urban dwellers.

Key technology changes

Relatively modest improvements in energy efficiency have occurred. Electricity storage is cost-effective, with a subsequent focus on electricity generation for base load.

Technology to the Rescue

It is 2050 …and the world, including Australia, has put its faith in technology and the wealth creation of free markets to tackle pressing energy challenges.

This approach had its genesis in 2010 when world leaders agreed that the most painless way of achieving sustainability of energy use was by ensuring that societies' wealth was high enough to pay for necessary structural changes to alter the current technological regime. As a result, after complex negotiations, it was agreed that greenhouse gas emissions would be reduced to 50 per cent below 1990 levels by 2050 and, at the same time, trade would be made free of quotas, subsidies and tariffs by 2020.

This decision was followed by a technology investment boom, which was later followed by 'alternative' energy technology companies being adopted as part of the mainstream energy landscape. With the free market determining the least cost way for Australia to meet its emission reduction target a wide variety of technologies were adopted depending on the unique circumstances of each state and region.

The various spin-offs and long period of stability and growth from this jump in investment activity has been likened to the periods during the two World Wars, the Cold War space race and the 1990s information technology boom in the previous century. However, periods of structural change brought about by reduction in tariff protection did cause a period of domestic political unrest.

Key technology changes

A suite of alternative energy technologies has been introduced.

The Day After Tomorrow

It is 2050 …and so far only a moderate number of greenhouse gas mitigation technologies have been implemented. The seemingly low take-up of such technologies has Australia questioning whether it would be more cost-effective to focus on climate change adaptation rather than mitigation. Behind this question is the failure of the international community to achieve an enforceable and fully inclusive climate change mitigation agreement, and a consequent lack of policy certainty and price signals needed for privatised electricity markets to bankroll new technology deployment.

Nevertheless, in 2050 Australia and the rest of the world have achieved a 10 per cent reduction in greenhouse gas emission compared to 1990 levels.

The moderate CO_2 price has been large enough to convince vehicle manufacturers to roll out more energy efficient hybrid electric vehicles, but it should be noted that the appeal of the cars is due more to their significantly better acceleration performance and high-tech appeal rather than their energy efficiency. Nevertheless, economies of scale make this the new standard.

Key technology changes

High-efficiency trains and cost-effective hybrid and hydrogen vehicles prove to be efficient.

Cultural Revolution

It is 2050 …and greenhouse gas emissions have been reduced to 50 per cent below 1990 levels. This is a direct result of the reassessment in the early years of the 2010s by the United States government of the geopolitical landscape that led to an alliance between the US and China (with many others subsequently joining) to substantially reduce greenhouse gas emissions.

Australia joined the alliance and implemented an emission-trading scheme in Australia which sent the necessary price signals to bring about investment in low-emission infrastructure.

The success of this alliance has had a general calming effect on global political stability. Australia has benefited from such stability and has developed a 'can do' culture around managing and prioritising business activities to achieve sustainable outcomes for the community. As a result, energy end-use efficiency improvements have accelerated well above predicted levels.

Key technology changes

A suite of alternative energy technologies has been introduced. Hydrogen is widely used. Vehicle efficiency levels improve, leading to zero emissions. Trains are cost competitive for freight and some passenger services.

Atomic Odyssey

It is 2050 …and greenhouse gas emissions have been reduced to 50 per cent below 1990 levels, led in large part by a landmark accord in 2010 between the US and China (with many others subsequently joining) to substantially reduce greenhouse gas emissions.

Australia joined the alliance and implemented an emission-trading scheme in Australia which sent the necessary price signals to bring about investment in low-emission infrastructure.

After it became clear in the mid 2010s that carbon capture and storage was not going to be successful and the continued used of fossil fuels would not allow longer-term CO_2 targets to be met, base load power production is now largely provided by nuclear facilities, and supplemented by gas fired and renewables. The early adoption of nuclear technology was eased by a major technological breakthrough that allowed the heat from nuclear reactors to become the economic energy of choice for hydrogen production.

Concerns over the storage of waste material or its potential use in weapons are outweighed by the ability of nuclear power to cut GHG emissions. There have also been some promising technological breakthroughs in fission waste disposal and fusion generation technologies.

Key technology changes

CCS proves unviable; nuclear power is more efficient; hydrogen is co-generated from process, and waste disposal costs fall.

Clean Green Down Under

It is 2050 …and Australia has reduced its GHG emissions to 80 per cent below 1990 levels.

Low emission transport and electricity generation technologies are now de rigueur, as are a consumer preference for energy end-use efficiency throughout the economy.

This dramatic shift was predicated on several major climate events in the early 2010s that effectively removed almost all global opposition to addressing climate change.

While economic damages of these events were minimal, the impact on several sites that had high iconic and tourist amenity value was dramatic. At the same time, oil prices jumped to a level so high that any notion of it being a temporary spike, or having the ability to ride it out until new discoveries were found, was totally abandoned. The post-oil world had begun.

Governments around the world had no difficulties selling a global agreement to reduce emissions from energy to 50 per cent below 1990 levels by 2050 to their constituents; indeed, most governments move to take the necessary actions before even such an agreement is signed.

Australia was, and remains, a signatory to the agreement. In fact, by introducing emissions trading, it has gone a step further to reduce its emission to 80 per cent below 1990 levels by 2050.

Key technology changes

There is a significant improvement in solar and hydrogen technologies, leading to a high adoption rate of zero emission technologies in transport and electricity generation.

Rough Ride

It is 2050 …and fundamental differences between various nations' worldviews remain unresolved, perpetuating a cycle of mid-level conflicts and new Cold Wars. With these geo-political distractions the international community has been unable to make any progress toward addressing the world's energy challenge, except with respect to each bloc's own energy security. In this case, the main response has been an increase in the rate of improvement in energy end-use efficiency driven by government legislation.

In Australia there has been strong growth in public support for energy efficiency and energy savings measures. These increasingly are the focus for governments, planners and for the people of many countries. Technology developments for the military and the 'soldier in the field' involved in inter-regional conflict have led to an increase in military research and development spending. Some of these technologies are suited to, and adopted for, broader civilian purposes; for example, solar powered laptop computers.

Australia's economic environment is less healthy than experienced at the start of the century; indeed, from 2030 global growth stagnated. Major trade initiatives have ultimately failed and been swept away. This has left the global economy more dependent than for many previous decades on bilateral trading agreements and less open commerce.

Prices of fossil fuels have risen dramatically since the start of the century, but investors are wary of bringing new supplies on line in a more volatile economic and diplomatic environment. Coupled with the continuing controversy around claims for anthropogenic climate change, little effort has been directed to developing energy alternatives and Australia remains as dependent as ever on fossil fuels.

Key technology changes

Conventional technologies remain dominant and the international rate of technology transfer is low.

Blissful Indifference

It is 2050 …and in Australia public attitudes to climate change have hardly shifted to those held at the start of the century. Pressure to introduce measures to address climate change never seemed to reach above other political dialogue around economic reform, health and aged care, and education.

On the world scene, relative political stability and strong economic growth has been achieved for an extended period. Greater trade between nations and the development of key, large national economies has combined with technological change to maintain stability in the balance between supply and demand of energy. Free trade was eventually introduced in 2020.

Not all conflict has been resolved, however. Terrorism remains an issue. However, today's threat to energy infrastructure from this source is restricted to a small number of very localised conflicts.

Major new oil supplies from Central Asia were opened up in the 2020s and new supply from these sources drove oil prices down for some years. However, more widespread growth in the 2030s and an eventual reduction in supply from the Middle East put an end to a sustained period of low oil prices from the early 2040s. Technology has also allowed for more complete exploitation of natural resources as previously 'uneconomic' sources now are more easily accessed. There continues to be little public pressure for innovation for energy efficiency and patterns of energy use largely remain the same.

Key technology changes:

Conventional technologies remain dominant.

Learning from the Qualitative Scenarios

Developing the qualitative scenarios provided participants with process and substantive knowledge of the issues.

In terms of process, it was found that having conversations for the purposes of collaboratively developing the scenario narratives:

- Led to an understanding that the process of developing the scenarios was more important than the individual scenario narratives.
- Allowed members to unpack the diversity of viewpoints in the room and, implicitly, the wider community.
- Focussed these, and later, discussions, on what views were held in common, rather than on differences of opinion.
- Deepened participants' knowledge about the energy sector in Australia by sharing members' experiences, interests and their acquaintance with different constituencies.
- Created a richer, more complex picture of what the future could be than that able to be fashioned through quantitative modelling.
- Heightened awareness of the difficulty of conceiving new social, technological, political and economic arrangements and the condition of the natural environment and, at the same time, highlighted the need to do so.

The process of creating narratives also identified and confirmed the common views of members, notably, that:

- Climate change is the *first among equals* of the many processes creating future change that are in train today.
- Community attitudes or behaviours may well change suddenly, in surprising directions, and in ways that limit or expand the adoption and use of particular technologies, programs and practices.
- New management measures of some form will be introduced for the international carbon economy, whether they are managed well or not remains an open question.
- A broader suite of technologies will play a role in the future than is possible to capture in quantitative modelling.

1 Owing to the long lead times between cause and effect, the degree of climate change that will occur between now and 2050 cannot be significantly influenced.

2 Carbon constraints are already implicitly or explicitly in place in many countries through a variety of existing policies, including fuel and technology taxes, subsidies and quotas; businesses also take carbon constraints into account in exercising their commercial judgment and making decisions. It is expected that there will always be a carbon constraint in place in Australia and elsewhere throughout the focus period. However, the degree of carbon constraint is highly uncertain.

3 Australia, as a nation, will remain dependent on energy, as will many major and emerging countries. Energy use is a cornerstone of society. However, the degree of dependence is uncertain.

4 All scenarios adopt the Australian Bureau of Statistics median growth assumptions for population in Australia to 2050. Barring a pandemic, environmental refugees and radical changes to our approach to immigration it is expected that variability around this assumption can be expected to be insignificant for the purposes of this study.

4 What does the average Australian think about Australia's energy future?

This chapter outlines a two-year social mapping program on public perspectives about Australia's energy future that augmented the discussions of the Energy Futures Forum.

To assess how public reactions to different aspects of Australia's energy future are likely to evolve, and to test the plausibility and comprehensiveness of the qualitative scenarios, a two-year social mapping program was conducted by CSIRO on behalf of the Energy Futures Forum (EFF). Full details of the program are contained within *Societal Uptake of Alternative Energy Futures*, CSIRO, 2005.

Attitudinal research is well developed in the energy sector and is used to benchmark public reactions at a particular point in time. This approach, however, does not provide any information regarding the longer-term response to different energy scenarios.

For this Report, the timeframe for consideration is to 2050. Over this timeframe, the societal experience of energy costs, potential climate change and energy security are likely to change dramatically. Hence a deeper understanding of public perspectives and their dynamics was required to contribute to this Report. High-quality and interactive discussion was essential to understand reasons for

Social mapping research will:

- Draw people into the future
- Encourage reflection on issues associated with energy generation and use
- Consider the plausibility and completeness of presented scenarios
- Explore what factors might cause personal views of the future to change
- Provide a window into the views of a group of the Australian population
- Complement economic modelling

Social mapping research will not:

- Pick winners among the scenarios
- Act as a market survey of current public attitudes to energy scenarios and technologies
- Provide a quantitative predictive model of social behaviour under different energy scenarios *per se*

any shifts in position, rather than just their existence (Cooke, 2000; Dryzek, 2000; Mendelberg, 2002). While not purporting to represent the views of the entire Australian society, the process provided a valuable window into the social dynamics around the question of energy supply and use.

RESEARCH METHODOLOGY

The process used by the program was that of the citizens' jury or a 'planning cell' (Lovel et al 2004), where participants were randomly selected to participate in a process that encourages discussion and deliberation, based on information provided both leading up to and during the process. Participants represented a diverse cross-section of the public and many had little prior knowledge about energy. (For this Report, the process was deliberately called a citizens' panel rather than a citizens' jury, as it was not seeking a decision from participants at the end of the process.)

Such an approach is not concerned with examining the methods of 'marketing' technologies in ways that make them more publicly acceptable; rather it projects the aspirations of participants into an uncertain future.

Panels were conducted in Western Australia and New South Wales to ensure perspectives from both east and west coasts of Australia were considered. Later, a panel was held in Victoria to enable a cross comparison to be made between three Australian states. (Social research into energy was already underway in Queensland, Ashworth et al, 2006).

A PARADIGM SHIFT IS NEEDED

All members of the Panels advocated a paradigm shift toward a more synergistic society where goods are shared, wastes are reduced, reused and/or recycled, and services are provided on the basis of life-cycle management.

This paradigm shift was not seen as necessarily being detrimental to the economy if Australians can think differently about how to run our businesses. The Panels were prepared to pay more in taxes to make this happen, but wanted reassurance that the money raised would be used to encourage an immediate change in behaviour to conserve energy and reduce use, to develop education systems to equip the upcoming generation with the knowledge to manage a different energy system, and to establish a mechanism to manage the independent apportioning of research and development funds.

PREVAILING PUBLIC ATTITUDES

Analysis of data from the Panels identified five broad prevailing attitudes in Australia towards energy technologies (Table 1).

The values and beliefs that comprise the five prevailing attitudes are summarised schematically in Figure 1.

Together, these (paraphrased) statements represent the 'story' told by each particular attitude. The numerical scores indicate the strength of agreement or disagreement with a statement for a particular attitude. The size of the spheres varies, reflecting the overall level of agreement with that attitude among all participants. Most of the statements are not unique to any particular atti-

Attitude	Attractive Technologies
A: Broad Scale Reform Associated with 'whole energy system' approach and a belief that all technologies can compete once all externalities are factored in. Attracted to renewable technologies. Willingness to endure some impact on lifestyle.	Renewable / decentralised technologies, such as: • Wind • Solar • Biomass • Geothermal
B: Centralised Energy Generation Most strongly associated with emphasis on centralised generation and distribution of energy, and technologically intensive approaches to greenhouse gas reduction. It is consistent with a high degree of faith in large-scale solutions and the expertise in the policy and regulatory systems that implement them. Although there is sympathy for alternative energy solutions, such as renewable energy, this is tempered by a belief that they are not reliable enough to supply a large proportion of energy needs. While nuclear is not ruled out, it is not seen as the sole solution, just one that can have a fit with the aims of security of supply, large scale generation and low emissions	Centralised technologies such as: • Coal (only if combined with carbon capture and storage) • Natural gas • Nuclear (in some cases)
C: Orderly Reform Concerned about energy policy and how it might drive the system to evolve. Strong enthusiasm for technological possibilities. Technology innovation, rather than demand management, is seen as the primary solution to greenhouse gas emissions.	Wide portfolio of technologies, with emphasis on minimising disruption and costs
D: Technologically Conservative Represents a potentially spirited defence of Australia's energy policy system. It is the most technologically conservative and price-sensitive of the discourses. Evidence of cynicism about the role of experts. Greater emphasis is placed on behaviour and demand to reduce greenhouse gas emissions. Prefers to 'adapt' rather than 'mitigate' climate change.	Averse to (radical) technological change
E: Radically Alternative Concerned regarding many of the large-scale technologies, partly because of the risk involved. Rather than driving change to the energy system, technology should follow the lead, rather than drive the agenda. Mechanisms for achieving solutions are heavily centralist, with a strong role for government.	Low risk technologies (minimum supply disruption): • Natural gas • Solar power • Wind power • Hydro electric power

Table 1: Prevailing attitudes in Australia towards energy technologies

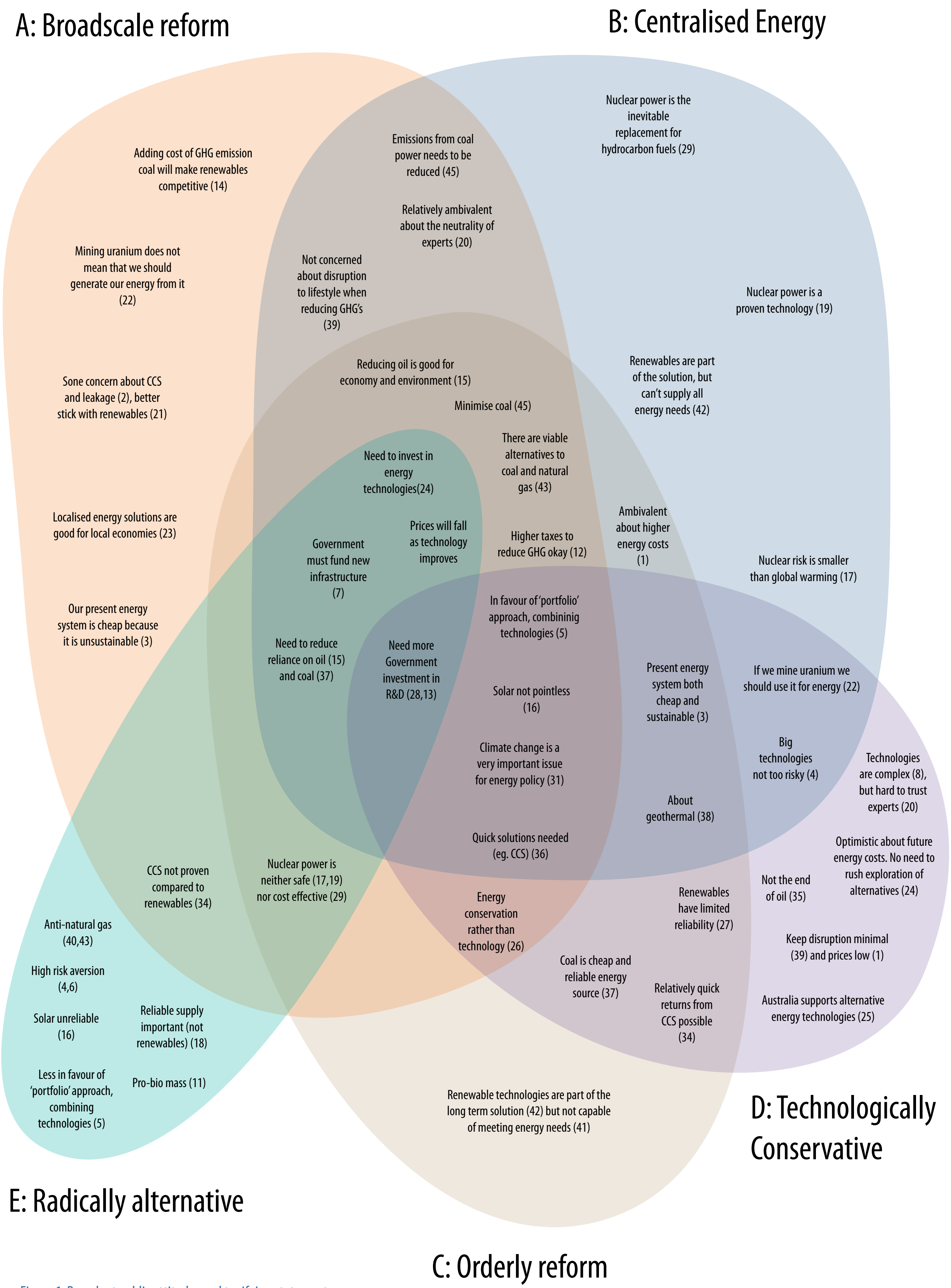


Figure 1: Prevalent public attitudes and typifying statements

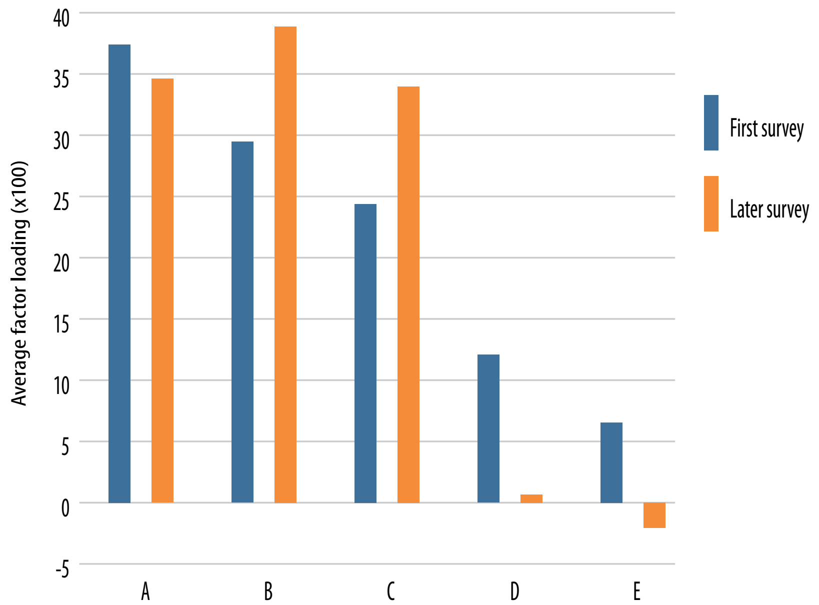


Figure 2: Shifts in perspectives as a result of the panel process

tude; this is witnessed by the overlap of the statements within the spheres.

All three of the large factors – *Broadscale Reform*, *Centralised Energy* and *Orderly Reform* - share serious concern about greenhouse emissions and climate change, which manifests in different combinations of energy technology and different trajectories for the future. Concern about risks associated with large-scale technologies and a desire for energy security are the main distinguishing features between public attitudes, as well as concern about the resulting shape of society.

SHIFTS IN PERSPECTIVE DURING THE PROCESS

Significant shifts in the strength of these attitudes were identified as deliberation progressed (Figure 2).

In relation to *Centralised Energy* (Attitude B), interest in renewable energy was offset by an emphasis on current limitations such as meeting peak energy demand and high costs, thus tending to favour large-scale centralised solutions. Additionally, a shift towards *Orderly Reform* (Attitude C) occurred during the process, mainly in Victoria where there was a greater concern with the short-term viability of renewables. The concept of transition technologies emerged into the discussion (particularly carbon capture and storage). Attitudes D: *Technologically Conservative* and E: *Radically Alternative* both declined during deliberation.

TECHNOLOGY PERSPECTIVES

Participants were asked to identify the important criteria that should be considered in defining a technology mix for the future of energy in Australia (Figure 3).

The ability to reduce greenhouse gas emissions clearly dominated as the

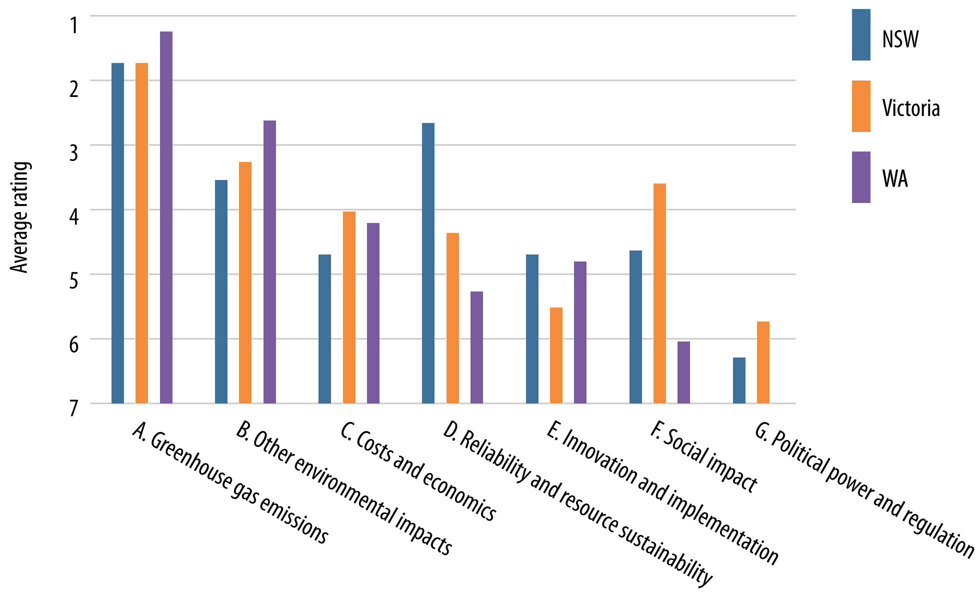


Figure 3: Important criteria for determining the future of energy

preferred attributes of energy technologies, followed by other environmental impacts, and then costs and economics. Other important attributes included reliability, social impact and the ease of implementation, but there were variations between the different panels on the relative importance of these criteria.

Overall, the results indicate a broad acceptance of a range of technologies available to reduce greenhouse gas emissions, with technology preferences being driven by the relative priorities placed on costs, reliability and ease of implementation.

Intensive discussion and debate about energy issues enabled the participants to engage with the complexity of the situation and the many interacting factors that will together define Australia's energy future.

Participants were able to make trade-offs between environmental impacts, and reliability and security of supply, and engaged rapidly with the concept of interim technologies as a means of enabling an orderly transition over the 100-year period as a step towards a desired future.

With respect to the scenarios being considered by the Energy Futures Forum, all were considered plausible although some were considered more credible than others (for example, scenarios involving a late response to climate change). The preferred scenarios were those involving an early response to climate change, although there were differences of view regarding the mix of technologies that should be considered.

The results indicate a broad acceptance of a range of technologies available to reduce greenhouse gas emissions.

5 The economic equation: modelling alternative energy scenarios

This section outlines the quantitative analysis conducted to project macroeconomic and sectoral outcomes under the various qualitative scenarios.

Many groups who come together to explore the future often conclude their process once they have developed a set of plausible scenarios. A goal of the Energy Futures Forum (EFF) was to not only develop a set of plausible scenarios for energy in 2050 but also to determine the implications of these scenarios and, where possible, test their plausibility.

This stage of the project focussed on conducting a quantitative analysis that would project macroeconomic and sectoral outcomes under the various scenarios.

ANALYTICAL FRAMEWORK

CSIRO and the Australian Bureau of Agricultural and Resource Economics (ABARE) formed a partnership to deliver economic modelling services, and economic and technology advice. Neither organisation was involved in the development of the EFF scenarios, with the exception that ABARE developed one scenario (see Scenario 3), and the scenarios modelled in this report do not necessarily reflect their views.

Three models were employed to ensure coverage of inputs and outputs that ranged from a global perspective to an Australian energy sectoral level. Two of the models were existing models provided by ABARE. A third was co-developed by ABARE and CSIRO specifically for the project to provide greater coverage of energy technologies.

1. The global trade and environment model (GTEM) is a dynamic multi-region, multi-sector, general equilibrium model of the world economy developed by ABARE to address policy issues with long term, global dimensions, such as climate change. A dynamic model such as GTEM is beneficial when analysing climate change policies, since both the timing of policy implementation and the adjustment path that economies follow are highly relevant in the climate change policy debate. A detailed description of the model's theoretical structure is contained in Pant (2002).

2. Ausregion is ABARE's dynamic computable general equilibrium model of the Australian economy that depicts the eight states and territories, as well as sub-state regions. Ausregion is designed to take full account of the interactions and interdependencies between sectors and elements of the economy [1].
3. ESM (Energy Sector Model) is an Australian energy sector model co-developed by ABARE and CSIRO for the project to provide additional modelling outputs, specifically the role of individual non-hydro renewable technologies, distributed generation, road transport fuel and engine technologies. GTEM is unable to provide such outputs; for example, it aggregates non-hydro renewable energy technologies under one category of technology.

   Documentation for ESM is contained in "*Modelling Energy Futures Forum Scenarios Using ESM*" (CSIRO and ABARE 2006).

   ESM is described as a partial equilibrium model of the electricity and road transport sectors solved as a mixed integer linear program. The road transport sector is modelled at the national level while the electricity sector is represented at state and territory levels, including trade between the National Electricity Market states. There are 15 and 11 centralised and distributed electricity generation technologies respectively represented. The road transport technology is described by six transport modes, 10 fuels, 20 vintages and two engine types.

Figure 1 shows the relationships between the models and the outputs generated. The diagram shows a downward flow of outputs from the global model to the national model and finally to the energy sector model. The bulk of outputs are derived from GTEM with Ausregion and ESM providing consistent supplementary outputs not available from GTEM.

Given the uncertainties presented by the future, together with the general limitations of modelling, no single approach can provide a complete analysis of the real world.

SOURCES OF DATA

The primary source of data was that already contained within the architecture of the models themselves. Nevertheless there was a concerted effort by the EFF, ABARE and CSIRO to update the models with the latest intelligence on the structure of the global economy, energy prices, technology cost and performance characteristics.

The project was also designed to permit EFF participants – many of who are industry sector leaders – to supply data to the economic modellers on a commercial-in-confidence basis, on the basis that such data could improve the veracity of the model. Some participants exercised this option and, as a result, the modelling data is a mixture of open and confidential sources. All publicly available data is outlined, and referenced where possible, in Ahammad et. al. (2006) and CSIRO and ABARE (2006) .

KEY MODELLING DRIVERS

Numerous independent drivers govern real world events. The qualitative scenarios developed by the EFF sought to describe the future from a wide range of social, political, economic and environmental perspectives. They

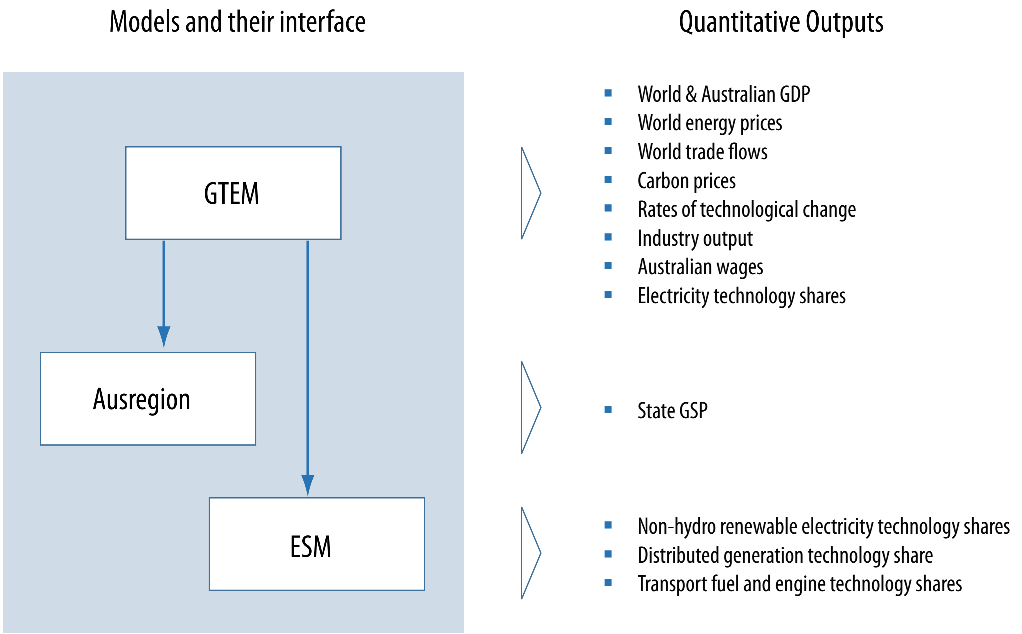


Figure 1: Interfacing GTEM, Ausregion and ESM and their respective outputs*
*Interface: common boundary shared by two devices across which data or information flows

were deliberately designed to differ in substance, and included elaborate and fictional storylines, which were designed to act as a starting point for encouraging divergent thinking.

In seeking to conduct a quantitative analysis, many elements within the qualitative scenarios were difficult to formalise as they represented subjective interpretation of facts, shifts in values, new regulations or inventions. In addition, all economic models are limited in the real world detail they can accommodate.

To make for manageable and consistent model projections, a limited set of key drivers were determined that would specifically examine the economic impacts and associated emission reductions arising from alternative climate change policies, with a particular focus on technology options and carbon taxes. The drivers include:

- Abatement targets
- The use of carbon taxes as a mechanism to ensure that the required level of abatement is achieved
- Access to, and type of, technologies
- The rate of technological change
- The nature of trade barriers
- Fuel prices.

The drivers were then modelled under eight scenarios. All scenarios are equally valid with no assigned probabilities of occurrence. A summary of the scenarios and their key assumptions can be read in Tables 1 and 2. Further details are available in Ahammad et. al. (2006).

Abatement targets

To assess the cost effectiveness of emission reduction it is necessary to establish a target. In all climate change response scenarios analysed in this Report, the target for the stabilisation of atmospheric concentration of carbon dioxide (CO_2) is assumed to be about 575 parts per million (ppm) by 2100. The economic modelling established emissions to 2050 consistent with reaching a target of 575 in 2100; the scenarios were extended to 2100 so that the global warming consequences could be estimated.

In establishing this anchor point, rather than postulating on future greenhouse gas (GHG) abatement targets or schemes, the EFF drew upon the work by the Intergovernmental Panel on Climate Change's Special Report on Emission Scenarios (SRES), (IPCC, 2000), and in particular the A1T scenario. The choice of drawing on A1T was a compromise between the desire to explore significant global emission reduction and the need to work within the constraints of what was feasible to explore with the economic models available.

A1T is one of the lowest global emission reduction paths to 2100 of the scenarios explored by SRES. It is acknowledged, however, that it remains conservative relative to other emission reduction scenarios discussed elsewhere. The A1T storyline describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies, with an emphasis on non-fossil energy sources. This approach is similar to the emission path for the EFF's Scenario 1 in that it represents a 'late action' style scenario where emissions do not begin to significantly move away from business as usual until after 2030.

To explore 'early action' scenarios the EFF modified the A1T so the world would diverge more rapidly from business-as-usual, while still reaching a similar anchor point for CO_2 concentration in the atmosphere by 2100. The concentration of CO_2 in the atmosphere is a function of cumulative emissions over time.

For both late and early action scenarios to stabilise at similar CO_2 concentrations in 2100, cumulative total emissions must be roughly equivalent to 2100. It follows then that the EFF 'late' action scenario demands that the world make deeper emission cuts than the early action scenarios in the period 2050 to 2100, because cumulative emissions are higher before 2050 (Figure 2). Even if cumulative emissions are exactly the same to 2100, due to the lags presented by the life of emissions in the atmosphere, both late and early action scenarios do not precisely reach a concentration of 575 ppm of CO_2 by 2100. The early action scenario is about 25 ppm of CO_2 less.

The economic modelling does not determine the cost of emission abatement beyond 2050. As a result the relative GHG emission abatement costs of either early or late action in the period 2050 to 2100 remain unknown. Prior to 2050, the cost of GHG abatement in late action will, by design, always be lower since total cumulative GHG abatement is less.

Is it CO_2 or CO_2-e?

The targets expressed in this Report are CO_2 – or carbon dioxide – only and do not allow for the additional radiative forcing of methane, nitrous oxides and other greenhouse gases. When all gases are allowed for, they are measured in CO_2-equivalent (CO_2-e) concentrations that are higher than CO_2 only concentrations. For example, all target concentrations in the recently released Stern Report (October 2006) are expressed in CO_2-e.

The EFF does not endorse any particular stabilisation target. There is, and will continue to be, much debate as to what may be the most appropriate level for the atmospheric concentration of CO_2 by 2100 that would represent an acceptable level of emissions or consequent climate change. If the world begins to reduce GHG emissions in the first half of the 21st century, the global community is expected to continue to adjust its target, based on the observed costs of abatement and climate impacts. It acknowledges that there would be nothing to prevent the world deciding to change the target, for example, to achieve stabilisation of less than 575 ppm of CO_2 by 2100. For a more detailed discussion of the issues involved in designing global emissions scenarios for assessment purposes see Jones and Preston (2006).

Use of carbon tax as a carbon price

For the purposes of the economic modelling, a price on carbon dioxide and other greenhouse gases was the policy instrument used to deliver the required emissions outcomes, subject to the underlying modelling assumptions. With the exception of two scenarios, the carbon tax is considered to be globally harmonised. Greenhouse gas emissions other than CO_2, including methane and nitrous oxide, are assumed to adjust in response to the carbon tax. The modelling also does not take into account tax policy design issues or issues relating to compliance costs and revenue constraints.

This approach was the simplest to apply for modelling purposes, as via the modelling process, the carbon tax adjusts automatically to ensure that the world economy achieves the designated emission paths. This automatic adjusting is an important feature of a dynamic model, such as GTEM, as in other modelling contexts a carbon tax may be set to achieve an unknown level of emission reduction.

Because the carbon tax applied in GTEM automatically adjusts to ensure the emission path is achieved, it can also be interpreted as closely approximating the price of a permit (for an equivalent amount of emissions) under a tradeable emissions permit scheme (see Ahammad et. al. (2006) for more details). In other words, the carbon tax is equivalent to emissions trading for the purposes of economic modelling..

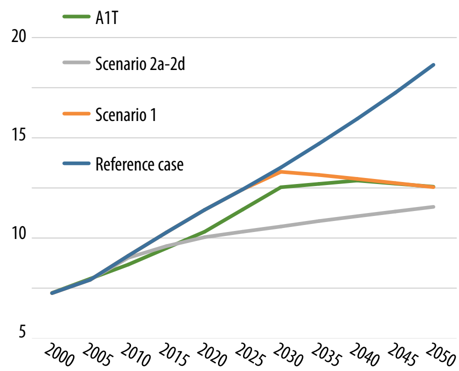


Figure 2: Emission paths: AIT and EFF Scenarios 1-2d

Sharing the abatement task

Given that the goal of the EFF was to focus on energy futures for Australia, the development of specific country abatement targets was not a key concern. As a result, the carbon tax was assumed to apply universally in a harmonised way across all countries in all scenarios analysed in this Report, with two exceptions:

- Australia makes deeper cuts in its emissions – 50 per cent below 1990 levels by 2050. Scenarios 1 and 2a to 2c only result in emission cuts in Australia of between zero and 9 per cent below 1990 levels at 2050). In 2d, the world still follows an emission path that is consistent with achieving CO_2 concentrations of 575 ppm by 2100; Australia, however, has a higher, differentiated carbon tax level to drive emissions lower than other countries.
- only OECD countries, the Russian Federation and other members of the Commonwealth of Independent States (CIS), plus China and India undertake emission abatement (Scenario 3). Other developing countries do not take part and, as a result, a higher carbon tax must be applied to a smaller set of countries

to achieve an emission path that remains consistent with the CO_2 concentration stabilisation target of 575 ppm by 2100. This scenario was developed by ABARE.

Trade barriers

For modelling purposes, all trade barriers are reduced globally by 70 per cent from their 2001 levels by 2025 in all scenarios except the 'high oil price' scenario. It was expected that such changes would not have a major impact on global economic growth (although important to the agricultural sector).

REFERENCE CASE

Projection models typically provide outputs for a reference case – often referred to as a business-as-usual case – as a starting point to confirm the functionality of the model and also as a point of comparison from which the impacts of changes in drivers of other scenarios may be compared.

A reference case has been adopted where technological development, government policies and other factors, such as fuel prices and population growth, progress along their current paths, and with no implementation of any significant new greenhouse gas emission reduction policies. The only major event is all trade barriers are reduced globally by 70 per cent from their 2001 levels by 2025.

It is also important to note that the reference case remains a scenario and should not be interpreted as the most likely outcome.

The reference case, or any of the economic modelling does not include calculation of the economic impact of climate change. This is considered in the next section.

IMPACT OF INCREASING GLOBAL CONFLICT

An increase in global conflict is likely to see world trade interrupted or restricted for extended periods, and the world community turn its attention away from responding to climate change.

To explore such impacts, a scenario was modelled where an extended interruption to the supply of oil led to an extended increase in the price of oil. Other effects of global conflict were not modelled but would be interesting to consider in other contexts.

The price of oil under the high oil price scenario is assumed to increase from its 2006 level to US $100/bbl (in today's dollar terms) by 2007 and remain at that level until 2014, after which it will approach its long-term much lower level over the remainder of the projection period to 2050. Gas prices are modelled to closely follow the oil price path.

In assuming a period of relatively low oil prices between 2014 and 2050, it is projected that given a period of high oil prices, alternative liquid fuels would enter the energy market in large volumes. The market penetration of alternative liquid fuels is projected to occur once their production infrastructure, relying on readily available fuels such as coal and gas as their primary energy source, have sufficient time to be built and the industry enjoys the economies of scale.

THE ROLE OF TECHNOLOGY

All economic models have the capability to 'force' the uptake of a particular technology, for example, by adjusting technological change assumptions in favour of a particular technology.

While electing to leave the model relatively unconstrained in the technologies adopted, the EFF specifically sought to model the importance of the availability of carbon capture and storage (CCS) and nuclear energy on the cost of meeting the abatement task.

Distributed generation technology is assumed to be available in all scenarios, and the model (ESM) is free to determine its future role in Australia, subject to the technology assumptions applied.

Changes in energy efficiency are assumed to occur equally across all scenarios; it does not vary.

Energy efficiency improvements in the reference case have been developed through extensive literature reviews, industry consultations and input from the Forum. Sectors such as electricity, iron and steel and transport, can respond to price changes by switching to those technologies that minimise costs subject to constraints. For other industries, as fuel prices rise, only movement along the "technology frontier" can occur whereby industries substitute away from emission intensive fuels toward less emission intensive fuels and primary factors.

The economic modelling, for practical reasons, was limited in the total number of technologies included. For this reason, the scenarios modelled are less technologically rich than the qualitative scenarios and what would be reasonably expected for the future.

SUMMARY OF SELECTED ECONOMIC MODELLING RESULTS

The key results for the reference case and scenarios 1, 2a to 2d are summarised in Table 3. A summary of results for the *Rough Ride* high oil price scenario follows separately, since the focus of

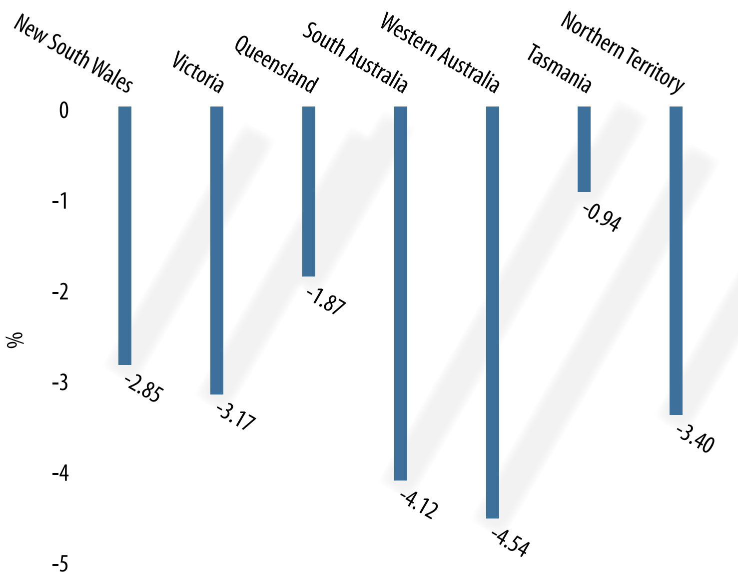


Figure 3: GSP impacts under the high oil scenario at 2010 (per cent change relative to the reference case)

Scenario	Description
Reference case	Aims to reflect a world scenario in which technological development and government policies progress along their current paths, with the exception that globally all trade barriers are reduced by 70 per cent from their 2001 levels across the board by 2025 (this is maintained in all other scenarios except the 'high oil price' scenario), and no implementation of any significant greenhouse gas emission reduction policies.
High oil price	Characterised by a hypothetical world with an oil supply disruption leading toward a heightened worldwide concern for energy security. It is assumed that, under the scenario, the price of oil will increase from its present level to US$100/bbl (in today's dollar terms) by 2007 and remain at that level until 2014, after which it will approach its long-term much lower level over the remainder of the projection period to 2050.
Scenario 1	A greenhouse gas abatement scenario that targets emission reduction similar to that of the SRES A1T scenario. In this scenario, global carbon dioxide emissions are targeted to begin in 2030 such that the global allowable emissions at 2050 will be 43.1 gigatonnes of carbon dioxide (Gt CO_2) consistent with reaching a CO_2 concentration stabilisation target of 575 ppm at 2100. This target represents a 35 per cent reduction in global carbon dioxide emissions relative to the reference case. The emission abatement target is assumed to be achieved through the introduction of a globally harmonised carbon tax from 2030. Other greenhouse gas emissions including methane and nitrous oxide are assumed to adjust in response to the carbon tax. All global regions (with one exception) have access to all potential abatement technologies. The only exception to this technology option assumption is that Australia has no access to nuclear power.
Scenarios 2a-2d	These are four greenhouse gas abatement scenarios, under different technology options and/or a differentiated abatement target for Australia (scenario 2d). In all four scenarios, global carbon dioxide emissions are targeted to begin in 2010 such that the global emissions at 2050 will be restricted to 39.4 Gt CO_2. Again, this targeted emission path is set so as to be consistent with a CO_2 concentration stabilisation target of 575 ppm at 2100. This emissions target represents a 40 per cent reduction in global CO_2 emissions relative to the reference case. The distinguishing features of the group 2 scenarios are as follows:
Scenario 2a	All regions are assumed to have access to all potential abatement technologies. However, Australia is assumed to have no access to nuclear power. The technology option assumption is similar to scenario 1.
Scenario 2b	Similar to scenario 2a, except it is assumed that no region in the world will implement carbon capture and storage technologies during the projection period. As in scenarios 1 and 2a, Australia is assumed to have no access to nuclear power.
Scenario 2c	Identical to scenario 2b except that Australia is assumed to have access to nuclear energy. It is assumed that one small nuclear power plant begins operation in Australia around 2020, with the expansion of capacity building slowly off this low base.
Scenario 2d	Australia is assumed to reduce its own carbon dioxide equivalent emissions to 50 per cent below its 1990 levels by 2050, while the 2050 global carbon dioxide emissions target remains at 39.4 Gt CO_2. Regarding technology options, the assumption of the global access to carbon capture and storage is maintained. Also, Australia is assumed to have access to nuclear energy. As in scenario 2c, one small nuclear plant is assumed to start operating in Australia around 2020, with potential expansion taking place between 2020 and 2050.
Scenario 3	OECD countries, the Russian Federation and other members of the CIS plus China and India form a coalition to undertake greenhouse gas abatement. By 2050, similar to scenarios 2a-d, global emissions are contained to 39.4 Gt CO_2 consistent with CO_2 stabilisation at 575 ppm at 2100. The members of the coalition, with the exception of China and India, implement a harmonised carbon tax in 2010. China and India join the coalition in 2020 with a view to all countries having a harmonised carbon tax by 2070, when the tax rate will be the same for all coalition members. The scenario 2a technology options are maintained in this scenario.

Table 1: Scenarios modelled

	Reference	High oil price	Mitigation scenarios					
			1	2a	2b	2c	2d	3
Targeted global abatement of CO_2 at 2050 [a] (relative to the reference case)	NA	NA	35%	40%	40%	40%	40%	40%
Introduction of climate change policy action	NA	NA	Late action: global partici-pation com-mencing in 2030	Early action: global partici-pation com-mencing in 2010	Early action: global partici-pation com-mencing in 2010	Early action: global parti-cipation com-mencing in 2010	Early action: global parti-cipation com-mencing in 2010	Early action: for developed /transition countries [b] 2010; delayed action for developing countries [c] 2020
Differentiated abatement target for Australia	NA	NA	No	No	No	No	Yes: 50% below 1990 levels of CO_2 equivalent emissions by 2050	No
Availability of CCS, globally	NA	NA	Yes	Yes	No	No	Yes	Yes
Availability of nuclear power in Australia	NA	NA	No	No	No	Yes	Yes	No
A 70% across the board reduction in trade barriers by 2025, globally	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Temporary oil price peak of $100/bbl	No	Yes	No	No	No	No	No	No

a Excludes CO_2 emissions from bunkers.
b Includes Russian Federation and the remaining economies of the Commonwealth of Independent States (CIS).
c Includes India and china

Table 2: Key scenario assumptions

			Scenario					
	Units	Reference case	1	2a	2b	2c	2d	3
Global greenhouse gas emissions	Mt CO2e	84,051	55,112	51,292	50,919	50,920	51,280	53,194
Global abatement	% change relative to reference case	0	34	39	39	39	39	37
Australian greenhouse gas emissions	Mt CO2e	846	540	484	516	513	273	308
	Relative to 1990	160	102	91	98	97	52	58
Australian abatement	% change relative to reference case	0	36	43	39	39	68	64
Growth in global GDP a	Average % growth	2.95	2.92	2.90	2.88	2.88	2.90	2.86
Global GDP level a	2005 US$b	164,209	161,337	160,004	158,662	158,666	159,889	157,219
Growth in GDP Australia a	Average % growth	2.46	2.43	2.41	2.40	2.40	2.23	2.28
Australian GDP level a	2005 A$b	2,674	2,629	2,609	2,591	2,593	2,389	2,454
New South Wales GSP level	2005 A$b	904	889	880	870	871	816	NA
Victoria GSP level	2005 A$b	628	621	619	613	612	581	NA
Queensland GSP level	2005 A$b	580	567	560	550	552	495	NA
South Australia GSP level	2005 A$b	155	155	154	154	154	142	NA
Western Australia GSP level	2005 A$b	340	335	333	328	328	276	NA
Tasmania GSP level	2005 A$b	40	41	41	42	41	47	NA
Northern Territory GSP level	2005 A$b	27	27	26	26	26	22	NA
Agricultural output	% change relative to reference case	0	-1	-2	-3	-3	-44	-32
Iron & steel output	% change relative to reference case	0	-4	-5	-9	-8	-53	-54
Non-ferrous metals output	% change relative to reference case	0	-22	-24	-39	-37	-75	-74
Global carbon price b	2005 US$/tCO2e	0	59	75	119	119	74	347/ 399
Australian carbon price	2005 A$/tCO2e	0	77	99	157	157	623	525
Residential electricity prices c	c/kWh	9.33	10.9	10.8	12.1	11.9	11.6	11.5
Change in residential electricity prices d	% change relative to 2005	0	7.9	7.2	19.5	18.1	14.7	13.9
Cost of petrol, 15,000km/yr consumer e	$/week	24	28	29	33	33	59	53

Table 3: Summary of economic modelling results in 2050

% Share of technology in output market (TWh or kilometres travelled)	Scenarios						
	Reference case	1	2a	2b	2c	2d	3
Black coal with no CCS	48	11	3	10	7	0	NA
Brown coal with no CCS	17	8	6	19	20	1	NA
Total coal with no CCS	65	19	9	28	27	1	1
Black coal with CCS	0	19	25	0	0	16	NA
Brown coal with CCS	0	7	12	0	0	14	NA
Total coal with CCS	0	26	37	0	0	29	33
Diesel internal combustion	1	1	1	1	0	1	NA
Total Oil	1	1	1	1	0	0	0
Gas combined cycle cogeneration	16	9	6	7	7	2	NA
Total Gas with no CCS	21	14	7	25	24	2	2
Gas with CCS	0	12	19	0	0	19	21
Nuclear	0	0	0	0	4	2	0
Hydro	4	5	5	5	5	5	5
Biomass	4	5	5	22	20	21	NA
Wind	5	18	17	19	19	20	NA
Total Non-hydro renewables	10	23	23	41	39	41	37
Total distributed generation	16	9	7	7	7	2	NA
Total centralised generation	84	91	93	93	93	98	NA
CNG	0	0	0	2	2	13	NA
Biodiesel in high blend	0	0	0	0	0	5	NA
Ethanol in high blend	0	0	0	0	0	1	NA
Hydrogen (derived from renewable source)	0	0	0	0	0	4	NA
Petrol	85	85	85	85	85	72	NA
Diesel	12	12	12	9	9	1	NA
LPG	3	3	3	4	4	4	NA
Biodiesel in B20	0	0	0	0	0	0	NA
Ethanol in E10	0	0	0	0	0	1	NA
Gas to liquids diesel	0	0	0	0	0	0	NA
Internal combustion engines	85	61	48	27	27	7	NA
Hybrid electric internal combustion engines	15	39	52	73	73	93	NA

A$1=US$0.76
a GDP projections do not include cost of climate change impacts
b For Scenario 3 former number refers to china and India, the latter to other participating countries
c Based on model output of cost of electricity generation and post modelling calculation of transmission, distribution and other costs which make up the balance of residential retail prices
d Assuming 10.1 c/KWh is representative of average Australian residential electricity prices in 2005
e Post modelling calculation. Based on a single passenger vehicle travel of 15,000 km/yr in internal combustion engine. Carbon prices passed directly to fuel cost. Excise is increased to maintain its present level in real terms

Table 3 continued

those results is on the year 2010 during the period of the oil price peak.

IMPACT OF ROUGH RIDE: HIGH OIL PRICE

Given the assumption that the high oil price of US$100/bbl is sustained during the period from 2007 to 2014, the projected impacts are reported for the year 2010.

At 2010, under the high oil scenario, Australia's GDP is projected to decline to some 3.14 per cent below the level projected in reference case. At the state level, all states and territories are projected to experience a fall in GSP relative to the reference case at 2010 (Figure 3). The most affected state is Western Australia, followed by South Australia, Northern Territory, Victoria, NSW, Queensland and Tasmania. The size of the potential GSP loss is highly correlated to the contribution of oil and petroleum products and gas to the state economies as well as the significance of gas in electricity generation.

Relative to the reference case, the high oil prices (and correlated high gas price) is expected to reduce the output of most sectors of the Australian economy (Figure 4); for example, as a result of the relative high proportion of energy costs to overall operating costs, the Australian production of non-ferrous materials is projected to decline by 23 per cent. Other industries that are projected to undergo significant production cuts, relative to the reference case, include air transport, and iron and steel.

The increase in oil price leads to the uptake of several alternative fuels relative to the reference case (Figure 5).

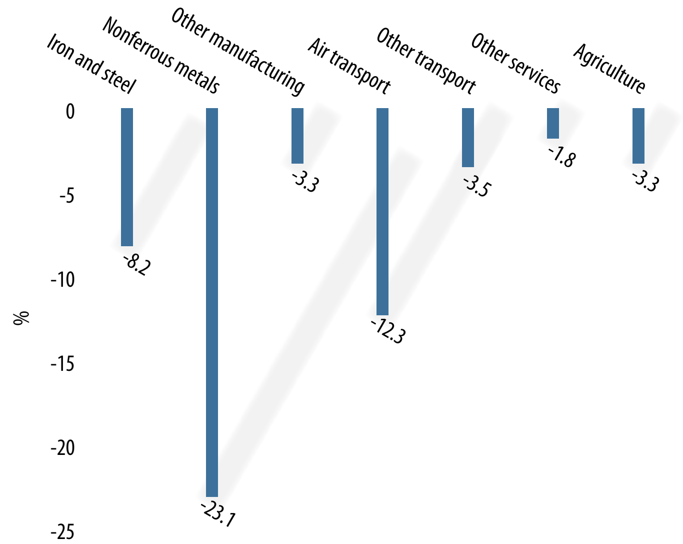


Figure 4: Change in sectoral outputs in Australia at 2010 in the high oil price scenario relative to the reference case

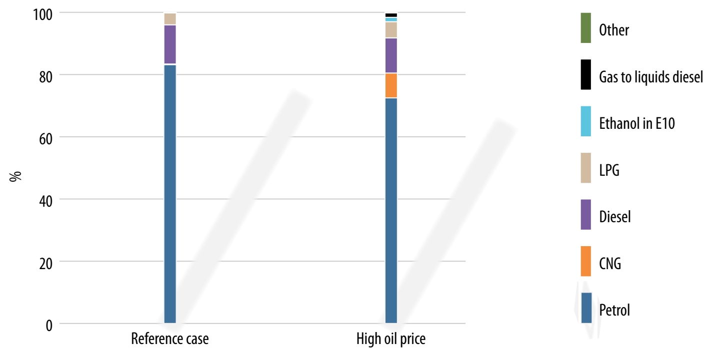


Figure 5: Share of road transport fuels in 2010 under thew high oil price scenario

1 A full description of the model's theoretical structure can be read at: http://www.abareconomics.com/publications_html/models/models/models.html#region

6 Addressing climate change: the benefits add up

This section outlines the range of climate change impacts projected from the EFF scenarios, and the risks and benefits of mitigation.

Assessments of the costs of mitigating climate change rarely address the benefits of avoided damages, because doing so is a very difficult task.

The costs associated with reducing greenhouse gas (abatement and sequestration) are incurred in the relatively near future, whereas the benefits of avoided damage are experienced much later because of delays in the climate system. Furthermore, precise estimates of both climate damages and the benefits of avoided damages are highly uncertain. Because of this, the debate surrounding climate change mitigation compares the costs of moving from the familiar and understood situation of abundant supply of cheap fossil-fuel energy, to one where the outcomes are very unclear.

The successful management of climate risks through the reduction of greenhouse gases can be achieved when the benefits of avoided damages outweigh the costs of mitigation. The costs of greenhouse gas abatement to 2050 are compared with the benefits of avoided climate damages in 2100. This is done by comparing the climate damages associated with a reference greenhouse gas emission scenario with those from a set of mitigation scenarios. Damages are assessed using both monetary and non-monetary measures. The benefit of avoided damages is the difference between the reference case damages – the so-called "costs of inaction" – and mitigation scenario damages. The major scientific uncertainties affecting the assessment of climate change and its impacts are accounted for by calculating risk-weighted damages.

Based on the results from these particular scenarios, when contrasted with the costs of acting, the risks of not acting on climate change clearly outweigh those associated with acting.

ADAPTATION VERSUS MITIGATION

Risks associated with climate change can be managed either by reducing greenhouse gas emissions (mitigation) or adapting to climate change impacts.

Extreme weather events

Severe weather events differ in various parts of the world, and depend on the latitude, the altitude and the topography of a region. They can be weather-based or weather events leading to extreme conditions for a particular region. It is their unusual and unexpected nature that makes these events significant to society.

Extreme weather can include heavy rain, strong wind/ wind gusts, hail, lightning, tornadoes, flash floods, extreme temperature, snow storms, dust and sand storms, sea swell/ tsunamis/ storm surge, and extended areas of fog affecting transport (aviation especially).

Global insurance losses have been rising steadily from such weather events. Since the IPCC published the chart below (IPCC 2003), one of the world's largest insurance companies, Swiss Re, has reported that the financial losses from natural disasters rose to US$120 billion in 2004 (insured property damage US$83 billion) and US$220 billion in 2005 (insured property damage US$49 billion) (Swiss Re, Sigma 1/2005).

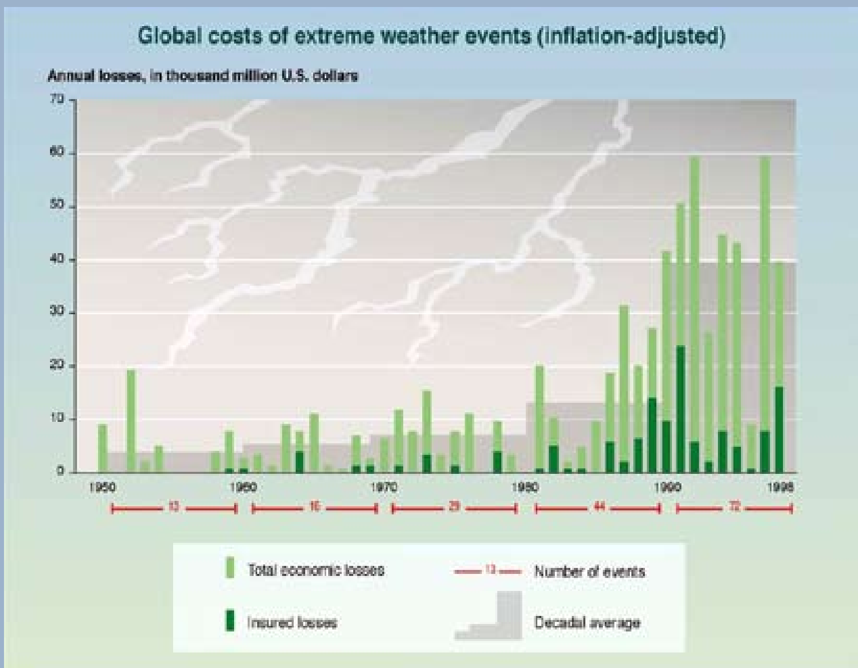


Figure 1: Global costs of extreme weather events (inflation-adjusted). (source: IPCC 2003)

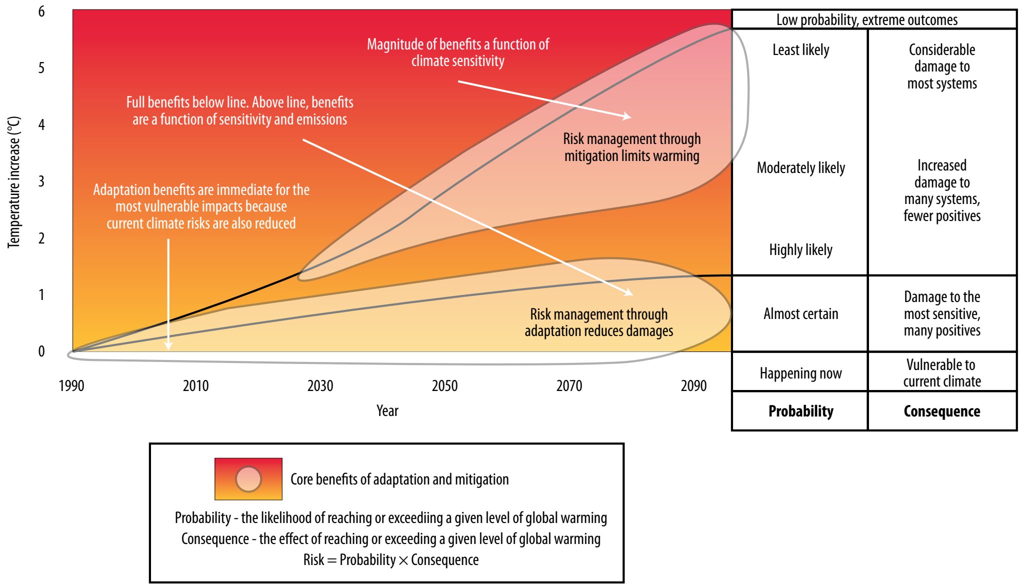


Figure 2: Synthesis of risk assessment approach to global warming. The left part of the figure shows global warming based on the six SRES greenhouse gas emission marker scenarios with the zones of maximum benefit for adaptation and mitigation. The right side shows likelihood based on threshold exceedance as a function of global warming and the consequences of global warming (Jones, 2004a).

Mitigation reduces climate change impacts by reducing the rate and magnitude of global warming. This increases the chance that the remaining risks can be adapted to. Adaptation increases the ability of a system to cope with a changing climate, including variability and extreme events.

Adaptation and mitigation reduce risks from opposite extremes of the projected range of climate change (Figure 2). The range of mean global warming under the Special Report on Emission Scenarios (SRES) is shown in the chart, while likelihood and consequences are shown on its right.

Adaptation will be required to manage climate change risks that are already committed to by historical emissions and those expected in the near future. Adaptation is most urgent for risks that are already being experienced and those that are sensitive to only small changes. Adaptation to higher levels of warming will be difficult and costly, requiring a great deal of accepted loss. Mitigation reduces the uppermost possibilities of climate change by reducing the potential volume of accumulated future emissions. Where the limits of adaptation are exceeded; for example, because adaptation is too expensive, impractical, or unfeasible, mitigation may be the only realistic risk treatment.

The right hand side of Figure 2 relates the consequences of climate change to the likelihood of exceeding a specific level of global warming. High levels of warming are less likely to be exceeded, but the negative consequences are very likely to be widespread and severe. The risk-weighted damages mentioned above are calculated from this combination of probability and consequence.

Adaptation and mitigation can be related in the following ways:

1. They manage different parts of risk: mitigation reduces the likelihood and matgnitude of climate-related hazards and their resultant impacts; adaptation reduces the consequences of those impacts.
2. They manage risk in different parts of the potential climate change envelope: mitigation reduces the likelihood of climate change at the

Figure 3: An illustration of risk neutral weighting of costs and benefits emphasising impacts known with greatest certainty and risk averse weighting of costs and benefits with opposing precautionary approaches to uncertainty.

upper defined limit of the plausible range; adaptation manages the experienced or more probable changes occurring at the lower limit of the plausible range.

3. They are effective over different timescales: most adaptations will have benefits in the short to medium term, especially if designed to manage current climate risks; mitigation benefits are long-term because of the delayed response of climate change.
4. They are effective at different scales: mitigation reduces climate change at the global scale because greenhouse gases are well mixed in the atmosphere; adaptation is specific to local conditions.

UNBALANCED RISKS

Weighing anticipated economic losses in the short term against uncertain gains in the long term creates an unbalanced debate on whether to act, or to not act, on climate change. For example, an aversion to economic loss focuses on the damage that action on climate change may cause to the economy in the short term. This may include the perceived risk of growing the economy at anything less than the optimal rate. Those averse to environmental loss are highly sensitive to long-term threats to natural and human systems, believing that significant economic intervention is warranted to prevent such losses.

These views are difficult to balance because of their asymmetrical nature (Figure 3).

By framing the issue differently with respect to which side of the issue the notion of loss and gain is attached, proponents of either view have different burdens of proof. The economically risk averse prefer quantified economic estimates, most often based on cost-benefit analysis (CBA), which aims to show whether the benefits outweigh the costs. The loss side of the ledger is attached to the economy.

By contrast, the environmentally risk averse will rely most on scientific advice that assesses the possibility of critical environmental or socio-economic thresholds being exceeded at some time in the future. The loss side of the ledger is attached to the environment.

Cost-benefit analysis is not well suited to decision-making on climate change because:

- CBA requires both cost and benefits to be quantified using a single (monetary) measure. However, because damages such as loss of life and loss of species do not have a single market value they cannot easily be monetised. Overlooking such impacts or reducing them to a single value (for example, the statistical value of a human life, which is different between a developed and a developing country) is generally considered unsatisfactory.

- The long delay between emissions and response (and thus, to the costs and the benefits) makes conventional discounting controversial because of varying rate-of-time preferences and risk-aversion.
- The large uncertainties make the possibility of damages being non-marginal (i.e. by producing negative growth or critical outcomes, which are both infinite in a CBA analysis).

Because of different risk-averse attitudes to perceived damages to the economy and to the environment, it is concluded that the questions, "*Can we afford to act on climate change?*" and "*Can we afford to not act on climate change?*" are not the same, and must be treated separately within a risk management framework before being addressed together.

TURNING UP THE HEAT

The first step in such an assessment is to assess the climate changes and impacts resulting from a reference case and set of mitigation greenhouse gas emission scenarios (EFF scenarios 1 and 2a–d). Impacts are expressed in both economic and biophysical terms, allowing the comparison of market and non-market damages.

The EFF reference case represents a world in which technological development and government policies progress along their known paths, with significantly reduced trade barriers, and no implementation of any significant greenhouse gas emission reduction policies (Ahammad et al., 2006).

The EFF scenarios (1 and 2a–d) represent a set of technologies and policies that reduce emissions from the reference case by 35 per cent and 39 per cent by 2050, ultimately stabilising at around 575 ppm CO_2.

The EFF reference case and scenarios 1 and 2a–d as modelled by ABARE were extended to 2100 and loaded into a simple climate model. The EFF scenarios were extended in two ways: constant emissions from 2050 and reducing along the lines of the IPCC A1T marker scenario. The latter stabilises CO_2 in the range 550–575 ppm CO_2. Mean global warming to 2100 was then estimated for both the reference case and scenarios 1 and 2a–d.

For the reference scenario, mean global warming in 2100 is in the range of 2.6 to 5.7 degrees Celsius (°C) with a mid-range warming of 4.0 °C

The small differences between the reference case and scenarios 1 and 2a–d beyond 2050 show that most of the reduction in 2100 is due to relative changes in greenhouse gases and sulphate aerosols (which produce warming and cooling, respectively), cancelling each other out. Much of the reduction in warming by 2100 is due to the reductions in emission before 2050. This is due to the inertia of the Earth's climate system, where most greenhouse gases remain for many years in the atmosphere and radiative changes take some time to warm the atmosphere and especially, the oceans.

AUSTRALIAN IMPACTS

A number of Australian sectors were assessed for the impact of varying levels of global warming. The sectors assessed were natural ecosystems, cropping, forestry, livestock, water resources, public health, settlements and infrastructure and extreme weather events (Table 1).

The risks to natural systems and water resources are generally rated as high, whereas most systems with a strong socio-economic component face more moderate risks due to capacity to adapt (Table 2). Risks to food and fibre production, however, depend greatly on changes to rainfall patterns in different regions. With favourable rainfall, higher atmospheric CO_2 could also lead to net improvements in yield, if temperature increases can be constrained.

Although few studies have extensively surveyed the climate change impacts at higher levels of global warming, warming in the range of 2.6°C to 5.7°C by 2100 would severely damage Australia's ecosystems, exceed adaptive capacity in a range of primary industries, lead to substantial sea level rise along the coast and greatly increase the magnitude and frequency of extreme events. Unfortunately, due to the paucity of national studies, it is difficult to provide more than a qualitative assessment.

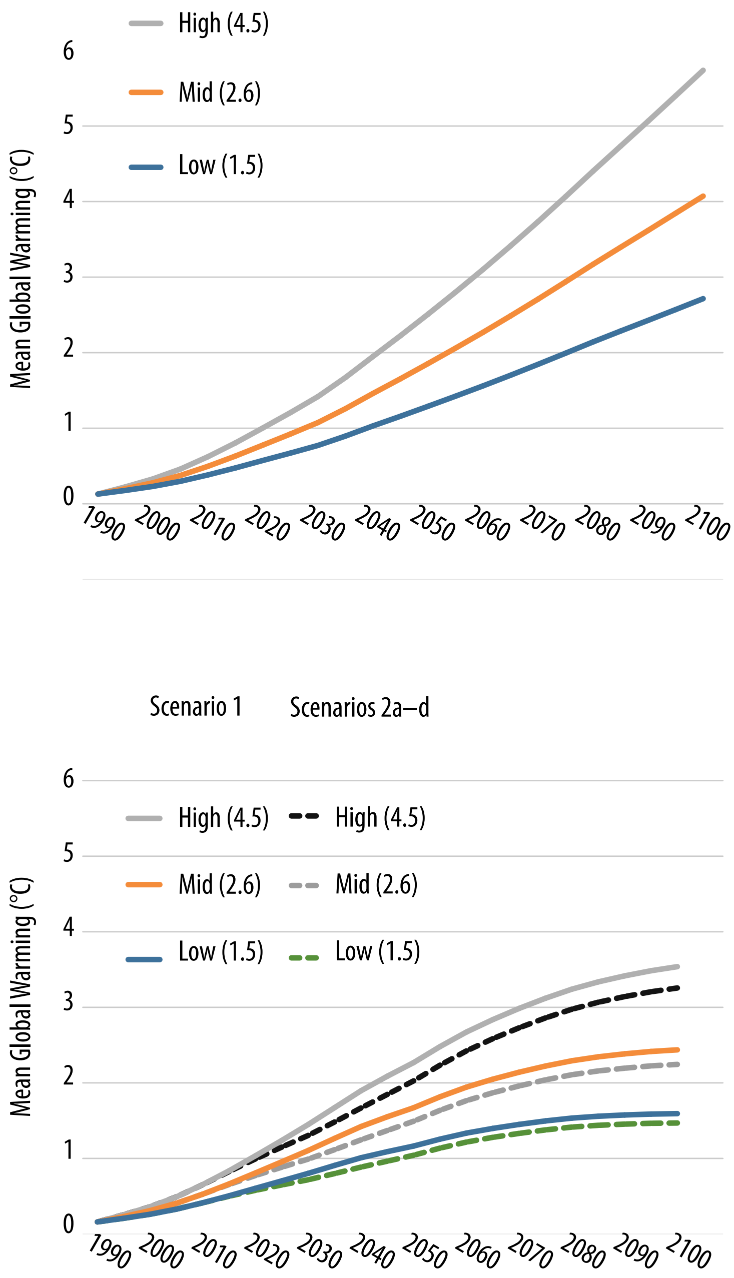


Figure 4: Mean global warming projected for the EFF reference scenario (upper) and scenarios 2a-d (lower) for climate sensitivities of 1.5, 2.6 and 4.5°C.

GLOBAL IMPACTS

To further assess the non-monetary benefits of climate change mitigation on a global scale, four key biophysical indicators were chosen: coral reefs, species extinction risk, North Atlantic thermohaline circulation (THC) and melting of the Greenland ice sheet. Each are valued natural resources with a limited adaptive capacity, and are thus largely dependent on mitigation. Damage curves for each of these impacts, relating levels of damage or the likelihood of exceeding a "tipping point" to global warming have been constructed.

The impacts of large-scale damage to these four indicators are:

- Coral reefs: critical rates of bleaching and coral mortality, resulting in replacement by seaweeds, with a cascade of subsequent changes in

System	Sensitivity	Adaptive Capacity	Risk
Natural systems			
Coral reefs	High	Low	High
Alpine ecosystems	High	Low	High
Endemic species	Moderate to high	Unknown (limited?)	Moderate to high
Cropping, forestry and livestock			
Cropping	Low to high	High	Moderate
Livestock	Moderate to high	Moderate	Moderate to high
Forestry	Low to moderate	Moderate	Moderate
Water Resources			
Urban water supply	High	High	Moderate to high
Irrigated agriculture	High	Moderate	Moderate to high
Industry (inc hydro)	Moderate	High	Moderate
Wetlands	High	Moderate	High
Public Health			
Heat stress	Moderate	High	Low to moderate
Disease vectors	Moderate	High	Low
Indigenous health	High	Low to moderate	High
Settlements and infrastructure			
Energy	Low to moderate	Moderate to high	Low to moderate
Coastal settlements	Low to high	Moderate to high	Moderate to high
Extreme weather events			
Floods	Moderate	Moderate to high	Moderate
Fire	High	Moderate	Moderate to high
Tropical cyclones	Moderate	Moderate	Moderate
Extreme hot days	Moderate to high	Moderate	Moderate

Table 1: Summary of risks to a range of sectors in Australia, rated low, moderate or high. The risks are judged subjectively based on a broad literature (summarised at the end of this section) associated with the range of mean global warming of 2.6°C and 5.7°C in 2100, associated with the reference scenario. Low risks imply that damages are relatively minor after adaptation, moderate risks imply significant damages after adaptation and high risks imply severe damages after adaptation.

fish and other populations. Changes in appearance affect tourism.

- Species extinction risk: endemic species and those with limited ranges and/or high specialisation are most at risk. Although the exact relationship between the risk and extinction rates is unknown, high rates will result in extinction rates unprecedented in human history and the highest for millions of years.
- North Atlantic thermohaline circulation: northern Europe cools or ceases to warm by as much, more severe winters, long-term lack of oxygen in ocean depths, detailed impacts unknown. Large-scale dislocation of regional environments possible.
- Greenland ice sheet: most or all of Greenland ice sheet melts taking hundreds to thousands of years depending on the subsequent rate of warming and ice sheet stability, producing a rise in sea level of up to 7 metres.

There are large uncertainties in estimating global economic damages. A recent review (Downing et al., 2005) showed that existing estimates of economic damages addressed a limited range of climate change phenomena and largely omitted indirect and non-market

Box 1: Key biophysical vulnerabilities

Species extinction risk

Evolutionary changes are inevitable, and every year some species thrive, others decline, and a few disappear forever. Current extinction rates are, however at least 100 times higher than natural background rates. At the same time, more animals and plants are known to be at risk of being lost.

For more than 40 years, the International Union for the Conservation of Nature (IUCN) has been assessing the conservation status of species, subspecies, varieties and selected subpopulations on a global scale in order to highlight those threatened with extinction. Every four years, the IUCN produces the Red List of Threatened Species, which classifies species according to their extinction risk.

The most recent assessment (2004) revealed that of the 40,177 species assessed, 16,119 are listed as threatened with extinction. This translates to one in three amphibians and a quarter of the world's coniferous trees, in addition to one in eight birds and one in four mammals. The assessment also reveals that the numbers of threatened species are increasing.

Most threatened birds, mammals and amphibians are located on the tropical continents. Australia, Brazil, China and Mexico hold particularly large numbers of threatened species. The vast majority of extinctions since 1500AD have occurred on oceanic islands, but over the last 20 years, continental extinctions have become as common as island extinctions.

Reasons for species' declines include habitat destruction and degradation; introduced invasive species; unsustainable harvesting; over-hunting; pollution, and disease. Climate change is increasingly recognized as a serious additional threat.

Coral reef bleaching

Corals host tiny algae (called zooxanthellae) that give them their colour and a food source. When stressed by excessive heat or cold, many corals expel their algae and "bleach." Corals are very sensitive to temperature changes and thrive within a narrow band of heat and cold: a temperature increase of one degree Celsius (1.8 degree F) can trigger them to bleach. After severe bleaching, they often die.

Melting of Greenland ice sheet

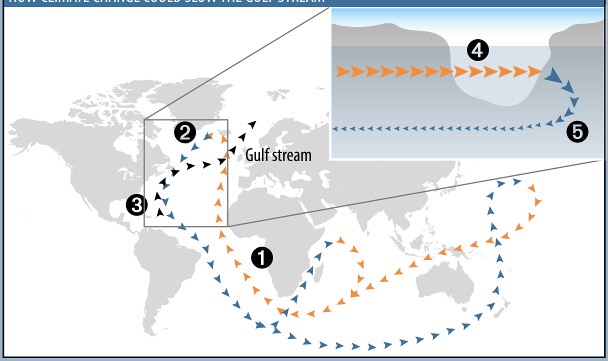
The Greenland ice sheet is the world's largest ice cap, covering 1.7 million square kilometres and up to three kilometres thick.

In the recent present, snowfall onto the ice cap was balanced by meltwater and icebergs draining away into the Atlantic Ocean. Over the past 20 years, however, the air temperature in south-east Greenland has risen by 3 degrees Celsius. In 1996, Greenland was losing about 100 cubic kilometres per year in mass from its ice sheet. In 2005, this had increased to about 220 cubic kilometres. By comparison, the city of Los Angeles uses about one cubic kilometre of water per year.

If the Greenland ice sheet melted completely, it would raise global sea levels by about seven metres, though it is predicted it would take up to 1,000 years to see the full predicted rise.

Once underway, the melting would be almost impossible to stop. As the ice melts, the cap's surface will sink to lower altitudes, warming the surface further, reducing snowfall and accelerating melting. The melting of Greenland would also make the North Atlantic less salty, perhaps triggering a collapse of the Gulf Stream.

HOW CLIMATE CHANGE COULD SLOW THE GULF STREAM



North Atlantic thermohaline circulation

The Gulf Stream is driven both by the rotation of the Earth and by a deep-water current called the Thermohaline Circulation (THC). (1) The THC pulls warm salty water from the tropics northward. (2) It gradually loses heat as it does so and, as it approaches the Artic, begins to sink because it is saltier, and therefore heavier, than the surrounding water. As it sinks, it pulls in more warm water from the tropics. (3) The cold water flows back to the equator, driving the "ocean conveyor" which in turn contributes to the Gulf Stream that warms northern Europe. (4) As ice melts, freshwater dilutes the warm salty water from the tropics. (5) The water becomes less dense so does not sink as fast, weakening the "conveyor" and therefore possibly disrupting the Gulf Stream.

Valuation uncertainties

Increasing costs →

Climate uncertainties (Increasing costs ↓)	Market (direct) value	Non-market (indirect use and options)	Existence and b bequest value
Mean climate	Global studies	Some global studies (as WTP)	None
Variability & extremes	Regional studies some allowance in global studies	Some local and regional studies	None
Thresholds & singularities	Few sensitivity studies	None	None

— Quantified economic costs

Table 2: Major uncertainties in estimating the costs of climate change (Downing et al., 2005), showing the breadth of most integrated assessment studies. The orange boundary and background represents how well costs have been quantified in economic terms. WTP stands for willingness to pay methods of valuation.

values. There is a great deal of evidence from individual studies to show that the costs in Table 3 increase along both axes, but most of the estimates of global costs are restricted to the part of the matrix bounded by the red line.

On balance, the literature probably under-estimates the costs of climate change (Stern et al., 2006). Some guided sensitivity analyses of economic damages informed by estimates from the literature were therefore developed. The biophysical curves also relate to Table 3 because Greenland and THC represent thresholds and singularities, and the coral reef and species at risk curves represent damages to indirect use and options, and to existence and bequest values. This provides a framework within which both monetary and non-monetary damages can be examined.

Four exploratory economic damage curves expressed as a reduction in gross domestic product (GDP) were assessed: a straight line representing one per cent decrease in GDP per °C of global warming, two lines of differing curvature and a line representing a global economic response to a large-scale tipping point or major event.

These curves allow us to show the response to different rates of economic damages. Although temperatures above 5°C are possible but unlikely, the likely costs associated with this magnitude of climate change are unknown. What if a large-scale biophysical system ceased to function adequately? The shape of the resulting economic damage curve is likely to be highly non-linear, but its magnitude and degree of non-linearity is unknown. Both the biophysical and monetary damage curves are shown in Figures 5 and 6.

THE COST OF INACTION

For the reference case, mean global warming in 2100 ranges between 2.6 and 5.7°C with a mid-range warming of 4.0°C. These levels of warming are in the higher part of the IPCC (2001) range of 1.5 to 5.8°C and are projected to result in significant impacts. Clearly, warming in the range projected by the reference case by 2100 would critically impair coral reefs, commence irreversible melting of the Greenland ice sheet, substantially slow the THC and place a great proportion of species at

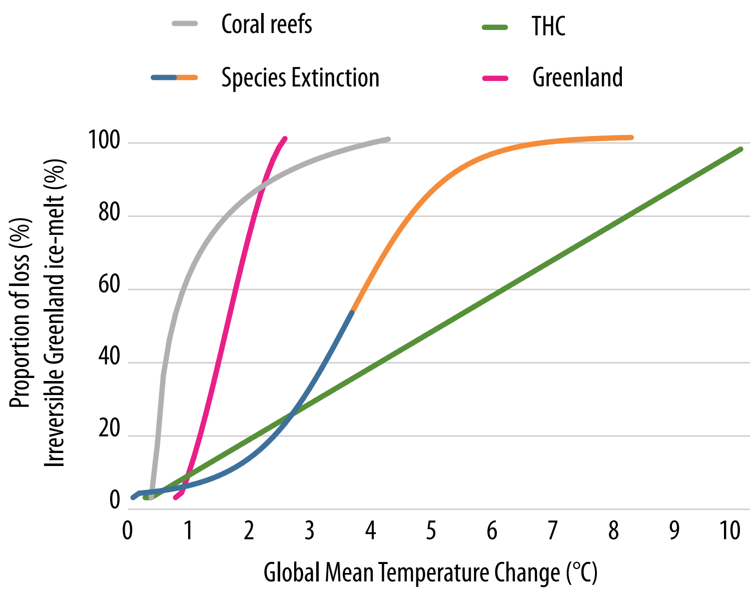


Figure 5: Damage curves for four key biophysical vulnerabilities (left): risk of species extinction, proportion of loss of coral reefs due to thermal bleaching, slowdown in North Atlantic thermohaline circulation and the probability of commencement of irreversible melting of the Greenland ice-sheet

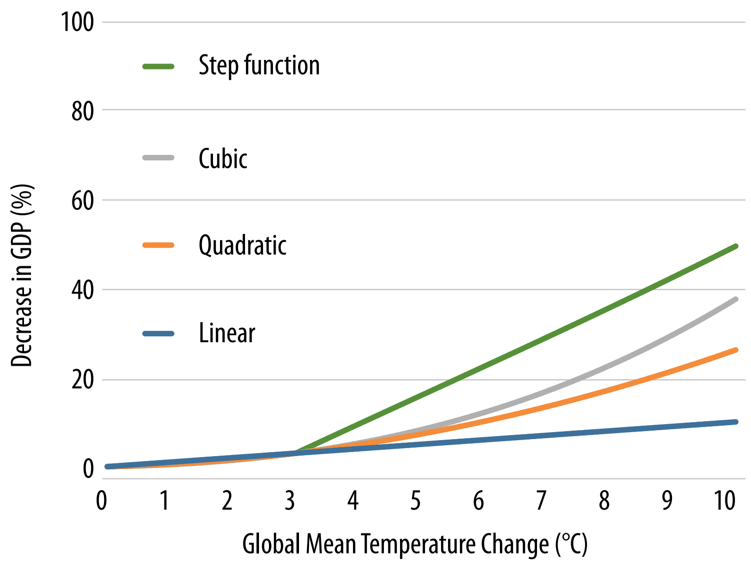


Figure 6: Different conceptual damage curves for global impacts expressed as percentage decrease in global Gross Domestic Product (GDP). Note that economic damage curve is positive, going against economic convention – this is to allow comparisons between the economic and biophysical damage curves.

risk. Economic damages would likely be above three per cent of GDP for the linear damage curve and be higher for all the others.[1] These changes would exceed the capacity of many systems to adapt, including some of these rated as having moderate to high capacity in Table 2.

[1] These findings are consistent with the wider literature such as the studies reviewed by Stern et al. (2006), for increases in temperature to around 4°C. However, this literature does not generally analyse increases at the higher end of the current estimated range of climate change.

THE BENEFITS OF MITIGATION

The benefits of avoiding climate-related damage through the application of risk-weighted damages to both the reference case and scenarios 1 and 2a–d were estimated for 2100. Risk-weighted damages were calculated by multiplying the likelihood of a given level of warming multiplied by the consequence level of damage. The benefits of mitigation actions in 2100 are measured as the difference in risk-weighted damages associated with the reference case and the mitigation scenarios (1 and 2a–d). The risk-weighted estimates for the biophysical damages are shown in Figure 7 while the risk-weighted estimates for the economic damages are shown in Figure 8.

The benefits of avoided damage for both biophysical and economic damages are substantial.

For both THC and species at risk, the benefits are greater than half, as are all the non-linear economic damage functions. The benefits for coral reefs and the Greenland ice sheet are less as they are likely to be critically damaged with temperature even lower than those projected from the scenarios 1 and 2a–d. However, consistent with the discussion about targets for atmospheric concentration of CO_2 in Section 5, significant impacts still remain under these scenarios, so the levels set by these emission scenarios are not endorsed as mitigation targets.

MINIMUM ECONOMIC BENEFITS OF MITIGATION

The above analysis shows there are significant benefits to be gained by 2100 in moving from the reference to the mitigation scenarios for all four types of biophysical damages assessed, with slightly larger gross benefits for the mitigation 2a–d scenarios. There are greater economic benefits the more non-linear the economic damage curve becomes.

However, because the economic damage curves described above only allowed sensitivity analyses to be carried out, the minimum economic damage curves required to balance avoided damage costs (that is, benefits) in 2100 with mitigation costs to 2050 were assessed.

Both costs and benefits were assessed in Net Present Value using UK Treasury Greenbook discount rates, which occupy the mid-range of long-term discount rate estimates from the literature.

The analysis showed that the minimum damage curves required to balance the costs to 2050 for Scenario 1 are lower than three out of four well-known cost curves from the literature. The minimum damage curve for Scenario 2a is in the middle of the range from the literature and is slightly higher for Scenarios 2b–d. Furthermore, this "minimum economic benefit" analysis does not account for economic benefits after 2100, or for social and environmental benefits not included in the economic cost curves.

If the risk-weighted outcomes are disaggregated into individual scenarios explicitly allowing for scientific uncertainties in estimating global warming, using this "minimum economic benefit" approach, about two-thirds show a positive economic benefit and one-third are negative (based on Net Present Value in 2100). Thus, the risk-weighting approach also leads to positive benefits for the larger part of the range of possible outcomes. The optimised solutions for the scenarios 1 and 2a compared with those used in the assessment of economic damages are shown in Figure 9.

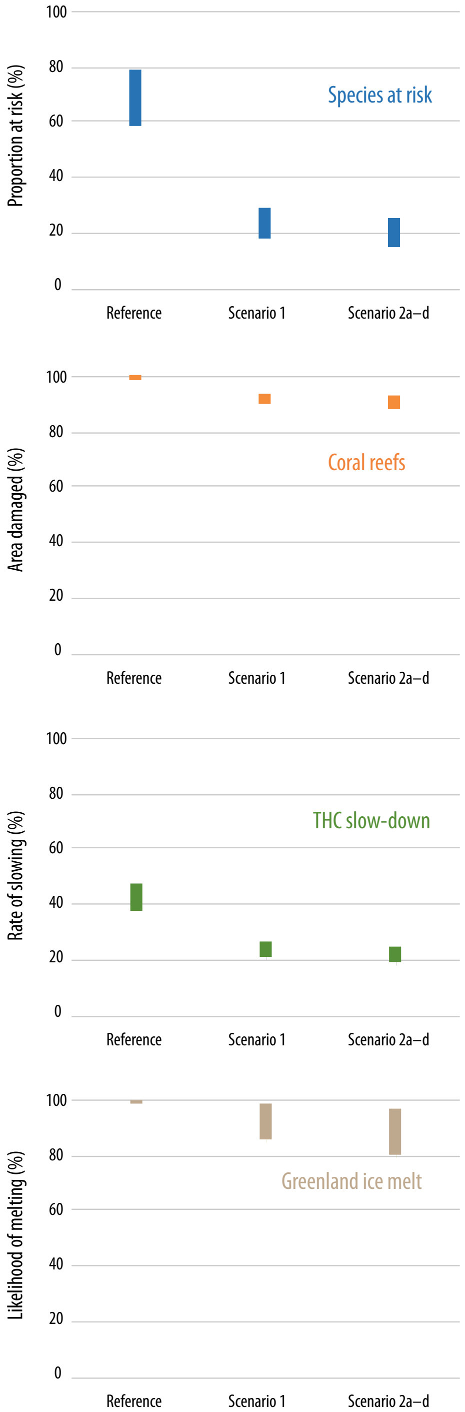


Figure 7: Risk-weighted damages for four key biophysical measures: species at risk, area of coral reefs critically damaged, THC slowdown and melting of the Greenland ice sheet showing the benefits of mitigation. The reference scenario represents no policy action, scenario 1 represents a 35% reduction in greenhouse gases by 2050 and scenario 2 represents a 39% reduction in greenhouse gases by 2050. The spread of damages represented by the bars allows for different estimates of climate sensitivity in estimating the risk-weighted damage.

Therefore, in conclusion:

- The "minimum economic benefit" for Scenario 1 in 2100 is at the low end of estimates from the literature showing that, even after allowing for uncertainty, most outcomes are very likely [2] to be positive. In other words, regrets due to over-expenditure on mitigation are very unlikely for this scenario. A high value placed on accompanying environmental and social benefits will strengthen this conclusion.
- The "minimum economic benefit" for Scenarios 2a–d in 2100 is near the middle of the range of estimates from the literature showing that, even after allowing for uncertainty, most outcomes are *likely* to be positive. In other words, regrets due to over-expenditure on mitigation are *unlikely* for this scenario (less than one-third probability). A high value placed on accompanying environmental and social benefits will strengthen this conclusion.

The analytic framework used here will apply to any set of reference and mitigation scenarios. The likelihood of ensuring there is a positive benefit due to mitigation depends on the cost of mitigation, damages associated with the reference scenario and how likely the minimum benefit required will fall below the real, but difficult to assess, damage curve. The successful management of climate risks through the reduction of greenhouse gases can be achieved when the benefits of avoided damages outweigh the costs of mitigation. For this set of scenarios, success is rated as being *likely* to *very likely*.

[2] Here, terms used to communicate uncertainty are consistent with those used in the IPCC Third Assessment Report (IPCC, 2001), where likely is >66% probability and very likely is >90% probability. Very unlikely is <10% and unlikely is <33%.

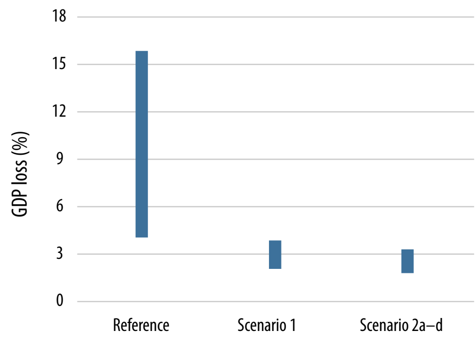


Figure 8: The range of risk-weighted damages for four different postulated economic damage curves expressed in percentage loss in global gross domestic product (GDP).

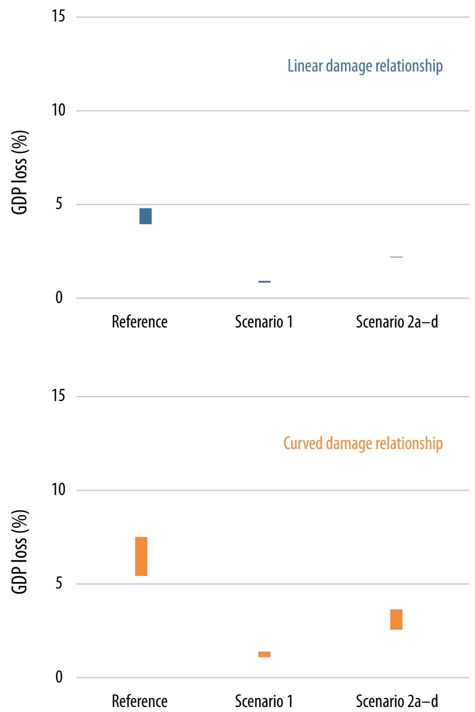


Figure 9: Optimised risk-weighted damages (scenario 1 and scenario 2) representing the minimum damage in 2100 required to balance the costs of mitigation incurred to 2050 for linear and non-linear damage functions expressed in percentage loss in global GDP. These are compared with the reference linear and quadratic damage curves in Figure 6. The spread of damages represented by the bars allows for different estimates of climate sensitivity in estimating the risk-weighted average damage.

ΔT (°C)	Projected impacts to Australian ecosystems	Projected impacts to Australian agriculture, forestry, livestock	Projected impacts to Australian water resources	Projected impacts to Australian public health	Projected impacts to Australian settlements	Climate change and extreme weather events
<1	10–40% shrinkage of snow-covered area in the Australian Alps[1]	$4.4 million/year to manage with southward spread of Queensland fruit fly[1]	0–15% likely decrease in flow in Macquarie River Basin (NSW)[1,2]	1185–1385 more deaths in 65-year age group in temperate Australian cities[1]	3% decreases in thermal efficiency of electricity transmission infrastructure[1]	70% increase in droughts in NSW[1]
	18–60% decline in 60-day snow cover in the Australian Alps[1]	$1.1 million/year benefit with contraction in range of Light Brown Apple Moth[2]	3–11% decrease in Melbourne's water supply[3]	4–12 more deaths in 65-year age group in N tropical cities[1]	Decrease in demand for natural gas for heating in Melbourne[2]	10–20% increase in the intensity of extreme daily rainfall in NSW[1]
	Damage to the Great Barrier Reef equivalent to 1998 and 2002 in up to 50% of years[2]	Increase in 'generic' timber yields (under wet scenarios)[3]		No increase in population at risk of dengue[1]	Peak electricity demand in Melbourne and Sydney decreases up to 1%[3]	18% increase in annual days above 35°C in SA[2]
	60% of the Great Barrier Reef is regularly bleached[3]	Decrease in "generic" timber yields (under dry scenarios)[3]			Peak electricity demand in Adelaide and Brisbane increases 2–5%[3]	25% increase in annual days above 35oC in Northern Territory[3]
	Habitat is lost for 14% of Victoria's marine invertebrates[4]	25% of core habitat lost for total Eucalyptus species numbers[4]				6% decrease in extreme daily rainfall in Victoria[4]
	50% decrease in habitat for vertebrates in northern Australia tropics[5,6]	250–310 litre annual decline in milk production per cow in Hunter Valley[5]				
	<5% loss of core habitat for Victorian and montane tropical vertebrate species[5,7]	8% reduction in pasture growth (11% precipitation decrease)[6]				
	28% of Dryandra species' core habitat is significantly reduced in SW Australia[8]	13% reduction in livestock carrying capacity (11% precipitation decrease)[6]				
	4% of Acacia species' core habitat is significantly reduced in SW Australia[8]					
	63% decrease in Golden Bowerbird habitat in N Australia[9]					
	Habitat for 3 frog and 15 threatened /endangered mammals in SW Australia is lost or restricted[8]					
	50% decrease in montane tropical rainforest area in N Australia[10]					

Table 3: Climate change and project Australian impacts

ΔT (°C)	Projected impacts to Australian ecosystems	Projected impacts to Australian agriculture, forestry, livestock	Projected impacts to Australian water resources	Projected impacts to Australian public health	Projected impacts to Australian settlements	Climate change and extreme weather events
1–2	Up to 58–81% of the Great Barrier Reef is bleached every year[2]	12% chance of decreased wheat production (without adaptation)[7]	0–25% decrease in flow in the Murray Darling Basin[4,5]	Southward spread of malaria receptive zones[1]	100 year storm surge height around Cairns increases 22%; area flooded doubles[4]	100 year storm surge height around Cairns increases 22%; area flooded doubles[5]
	Hard coral reef communities are widely replaced by algal communities[11]	32% chance of wheat crop value below current level (without adaptation)[7]	7–35% decrease in Melbourne's water supply[3]	Population at risk of dengue increases from 0.17 million to 0.75-1.6 million[1]	Peak electricity demand in Melbourne and Sydney decreases 1%[3]	25% increase in 100-year storm tides along eastern Victoria coast[6]
	90% decrease in core habitat for vertebrates in northern Australia tropics[5, 6]	91% chance of wheat exports being below current level (without adaptation)[7]	5–30% decrease in runoff in SW WA[5]	10% increase in diarrhoeal diseases among Aboriginal children in central Australia[1]	Peak electricity demand in Adelaide and Brisbane increases 4–10%[3]	
	5–10% loss of core habitat for Victorian and montane tropical vertebrate species[5, 7]	$12.4 million/year to manage with southward spread of Queensland fruit fly[1]		100% increase in number of people exposed to flooding in Australia and New Zealand[1]		
	88% of butterfly species' core habitat decreases[12]	$5.7 million/year benefit due to reduction of Light brown apple moth[2]		Increased influx of refugees from Pacific Islands[1]		
	66% of core habitat for Dryandra species is significantly reduced in SW Australia[8]	40% of core habitat lost for total Eucalyptus species numbers[4]				
	100% of core habitat for Acacia species eliminated in SW Australia[8]	38% increase in tick-related losses in net cattle production weight[8]				
2–3	97% of the Great Barrier Reef is bleached every year[3]	31% reduction in pasture growth (32% precipitation decrease)[6]	5–35% likely decrease in flow in Macquarie River Basin (NSW)[2]	Further southward spread of malaria receptive zones[1]	17% increase in road maintenance costs over most of Australia[5]	5-10% increase in tropical cyclone wind speeds[5]
	10–40% loss of core habitat for Victoria and montane tropical vertebrate species[5, 7]	40% reduction in livestock carrying capacity of pastures (for 32% precipitation decrease)[6]		Temperature related mortality among people 65+ years in capital cities increases by 89-123%[1]	Decreases in road maintenance costs in SA[5]	20–30% increase in tropical cyclone rainfall[5]
	92% of butterfly species' core habitat decreases[12]			Southward expansion of dengue transmission zone as far as Mackay[1]	Peak electricity demand in Adelaide, Brisbane and Melbourne increases 3–15%[3]	12-16% increase in 100-year storm tides along eastern Victoria's coast[6]
	98% decrease in Bowerbird habitat in N Australia[9]				Peak electricity demand in Sydney decreases 1%[3]	10% increase in forest fire danger index in N, SW, and W Australia[7,8]
	80% loss of freshwater wetlands in Kakadu (30 cm sea level rise)[13]					More than 10% increase in forest fire danger index in S, central, and NE Australia[7, 8]

ΔT (°C)	Projected impacts to Australian ecosystems	Projected impacts to Australian agriculture, forestry, livestock	Projected impacts to Australian water resources	Projected impacts to Australian public health	Projected impacts to Australian settlements	Climate change and extreme weather events
3–4	Catastrophic mortality of coral species annually[2,3] 95% decrease in distribution of Great Barrier Reef species[3] 65% loss of Great Barrier Reef species in the Cairns region[14] 20–85% shrinkage of total snow-covered area in the Australian Alps[1] 38–96% decline in 60-day snow cover in the Australian Alps[1] 30–70% loss of core habitat for Victoria and montane tropical vertebrate species[5,7]	32% chance of decreased wheat production (without adaptation)[7] 45% chance of wheat crop value being below current level (without adaptation)[7] 55% of core habitat lost for total Eucalyptus species numbers[4] 25-50% increase in "generic" timber yield in S Australia[3] 25-50% decrease in "generic" timber yield in N Queensland and Top End[3] 6% decline in Australian net primary production (20% precipitation decrease)[6]	50% chance critical bird breeding threshold exceeded in Macquarie Marshes[2] 16–48% decrease in flow in the Murray Darling Basin[4]	Temperature related mortality among people 65+ years in capital cities increases by 144-200%[2] Southward expansion of dengue transmission zone as far as Brisbane[2]	Oceania experiences net loss of GDP[6] Peak electricity demand in Adelaide, Brisbane and Melbourne increases 5–20%[3] Peak electricity demand in Sydney decreases 1%[3]	
4–5	60–90% loss of core habitat for Victoria and montane tropical vertebrate species[5,7]	128% increase in tick-related losses in net cattle production weight[8]			Peak electricity demand in Adelaide, Brisbane and Melbourne increases 9–25%[3] Peak electricity demand in Sydney decreases 0.5%[3]	
>5	90–100% of core habitat lost for most endemic Australian vertebrates[5,7]				Peak electricity demand in Sydney decreases 0%[3] Peak electricity demand in Adelaide, Brisbane and Melbourne increases 10–25%[3]	30% increase in 100-year storm tides along eastern Victoria coast[6] 25% increase in extreme rainfall in Victoria[4] 173% increase in annual days above 35oC in Northern Territory[3] 150% increase in annual days above 35oC in South Australia[2]

References

	Ecosystems	Agriculture, forestry, livestock	Water resources	Public health	Settlements	Climate change and extreme weather events
	[1]Hennessy et al., 2003 [2]Berkelmans et al., 2004 [3]Jones, 2004b [4]O'Hara, 2002 [5]Williams et al., 2003 [6]Williams and Hilbert, 2004 [7]Brereton et al., 2005 [8]Pouliquen-Young & Newman, 2000 [9]Hilbert et al., 2004 [10]Hilbert et al., 2001 [11]Wooldridge et al., 2005 [12]Beaumont & Hughes, 2002 [13]Hare, 2003 [14]Crimp et al., 2004	[1]Sutherst et al., 2000 [2]Sutherst, 2000 [3]Kirschbaum, 1999 [4]Hughes et al., 1996 [5]Jones and Hennessy 2000 [6]Crimp et al., 2002 [7]Howden and Jones 2001 [8]White et al., 2003	[1]Hassall & Associates, 1998 [2]Jones & Page, 2001 [3]CSIRO & Melbourne Water, 2005 [4]Beare and Heaney, 2002 [5]Jones, pers. comm.	[1]McMichael et al., 2003 [2]Hales et al., 2002	[1]Thomas, 2002 [2]Suppiah et al., 2001 [3]Howden & Crimp, 2001 [4]McInnes et al., 2003 [5]Austroads, 2004 [6]Mendelsohn & Williams, 2004	[1]Hennessy et al., 2004a [2]McInnes et al., 2002 [3]Hennessy et al., 2004b [4]Suppiah et al., 2004 [5]McInnes et al., 2003 [6]McInnes et al., 2005 [7]Williams et al., 2001 [8]Cary, 2002

7 Tough challenges lie ahead

This section outlines the deliberations by the EFF on the Implications of the scenario assessment data.

Embarking on the project, the general view of EFF members was that the greatest impact on the future of energy in Australia would come from geopolitical changes, climate change, innovation and the level of community concern about sustainability. The process of creating the qualitative scenarios, however, identified climate change as 'primus inter pares'– or a *first among equals* – of these challenges.

A secondary challenge was the need for Australia to secure affordable transport fuels.

In addressing both these challenges, there is also a need to understand the role of different technologies.

Following comprehensive analysis and debate, the six major implications have been identified, which, it is hoped, will be of use to decision-makers at all levels of Australian society in guiding efforts to address the key challenges of climate change.

Reference Case	Technological development and government policies progress along known paths; no implementation of significant greenhouse gas emission reduction policies
High oil price	The price of oil increase to US$100/bbl by 2007 and remains at that level until 2014, after which it declines; no implementation of significant greenhouse gas emission reduction policies
Scenario 1	Late action including all countries with a full range of abatement technologies except no nuclear power generation in Australia
Scenario 2a	Early action including all countries with a full range of abatement technologies except no access to nuclear power generation in Australia
Scenario 2b	Early action including all countries without CCS globally and no nuclear power generation in Australia
Scenario 2c	Early action including all countries without CCS globally but Australia can access nuclear power generation
Scenario 2d	Early action including all countries with a unilateral deep cut in Australia's emissions and all technologies available
Scenario 3	Early Action including only an international coalition of developed countries, China and India with all technologies available except no nuclear power generation in Australia

Table 1: Summary of scenarios

CLIMATE CHANGE: THE COST AND BENEFITS OF MITIGATION

Human activity is widely accepted as the primary contributor to climate change. The real issue is how to balance the costs and benefits of climate change mitigation (mitigation means activities that reduce greenhouse gas emissions, thereby reducing CO_2 concentrations in the atmosphere). This is largely because the costs of mitigation must be incurred long before the benefits of avoided climate damages can be realised.

The long timeframe over which the various technology drivers and climate change impacts unfold introduces an enormous amount of uncertainty in all modelling, which is compounded by the complexity of the social and biophysical sciences upon which the projection techniques rely.

The concentration of CO_2 in the atmosphere in 2006 is 380 parts per million (ppm). The scenarios modelled are based on greenhouse gas emission reduction paths that are consistent with achieving stabilisation at 575 ppm CO_2 concentration by 2100.

The stabilisation level of 575 ppm CO_2 concentration by 2100 was chosen on the basis that it was within the limits of the economic models available and was broadly consistent with a well-known international scenario – the A1T path outlined in the Intergovernmental Panel on Climate Change's Special Report on Emission Scenarios (IPCC, 2000).

The cost of mitigating climate change

The costs of mitigation examined are generally a function of four factors:

- the extent to which energy demand can be reduced by improvements in energy efficiency at the end-user, changes in lifestyles and structural change in the economy towards a lower share of the more energy intensive industries.
- the rate at which the cost of low emission technologies fall in price
- the rate at which emissions are required to diverge from a business-as-usual case
- the extent and nature of participation of countries in coordinated global emission abatement.

There are a number of different ways in which costs can be measured. This section examines the standard costs, such as costs to the economy via GDP and direct costs of energy. It also examines costs to the biophysical environment, sometimes called non-market costs. While not reported, intangible costs to society, such as social cohesiveness, are also valid in any discussion on climate policy.

Each of the mitigation scenarios imposes a carbon price (see Box) to reduce emissions to achieve the stabilisation of CO_2 concentration at 575 ppm.

Emission reduction is driven by investment in generally higher-cost technologies in the sectors most responsible for greenhouse gas emissions, namely electricity generation, agriculture and transport. Such investment is underpinned by research, diffusion of information, and other efforts aimed at improving the competitiveness of these technologies.

Mitigation can also be achieved via structural change within the Australian economy, away from high-energy intensive industries to low-energy intensive industries. Such change would bring with it fundamental changes in industry employment. Some communities would be expected to benefit – at least in terms

What is meant by carbon price?

While recognising there are significant differences in the impacts of alternative schemes, the term carbon price used in this document is a generic term for a range of policies. It may be taken to include, for example, carbon taxes, as well as carbon emission permits associated with a tradable emission permit scheme.

In the term 'carbon price', carbon is shorthand for carbon dioxide, one of several greenhouse gases that contribute to climate change. The focus on carbon dioxide follows from it being the most abundant of greenhouse gases (other than water vapour) and the accepted convention in the literature of expressing non-carbon dioxide greenhouse gases as carbon dioxide 'equivalents' (CO_2e).

of employment and wages; others are expected to suffer, especially those communities reliant on aluminium and iron and steel industries.

Energy efficiency also plays a role, with improvements in energy conversion in the supply of energy and energy end-use. For example, the International Energy Agency (IEA, 2006) finds that accelerating energy efficiency improvements alone can reduce the world's energy demand in 2050 by an amount equivalent to almost half of today's global energy consumption. To achieve this, however, governments may need to implement measures that both encourage investment in energy-efficient technologies and encourage energy users to identify ways in which energy savings can be made.

Impact on gross domestic product

The economic cost of mitigating climate change can be measured by the impact on gross domestic product (GDP).

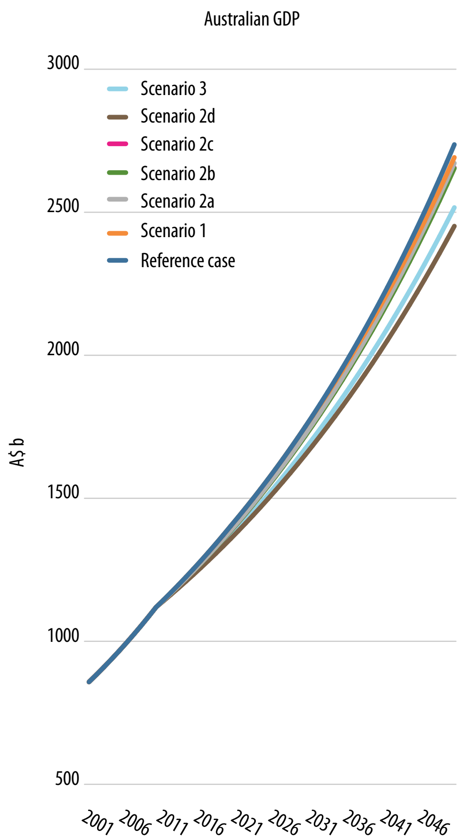
When viewed as a time path for the period 2001 to 2050 (Figure 1), it is projected that both the Australian and world economies will continue to experience strong economic growth under all modelled scenarios, including scenario 2d (where Australia makes unilateral emission cuts) and scenario 3 (where Australia forms part of a coalition of developed countries in making emission cuts).

The delay experienced across the scenarios in achieving the GDP level projected in the reference case for 2050 is less than 18 months, with two exceptions. The exceptions are scenarios 2d and 3, where Australia experiences the largest relative impact to GDP due to its voluntary scenario decision to impose a higher carbon price than the rest of the world in order to achieve a deep cut in greenhouse gas emissions (50 per cent below 1990 levels by 2050) and its inclusion in the coalition of developed countries. In these cases, the delay in achieving the GDP level projected in the reference case is around five years.

Impact on consumer energy prices

The economic cost of greenhouse gas abatement can also be measured by the impact of a carbon price on consumer energy prices.

Even with a carbon price in place, Australians are projected to be spending



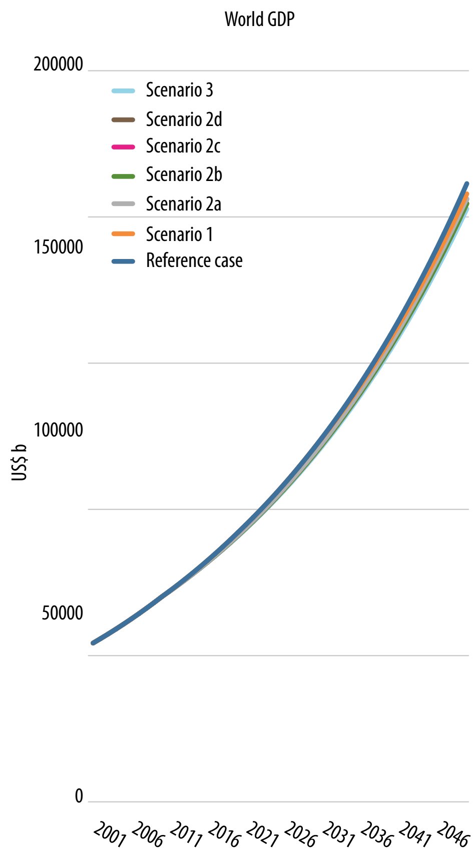


Figure 1: Time path of projected economic growth by scenario

a lower proportion of their income on electricity in 2050 than in 2006 (Figure 2).

While retail electricity prices will increase by 2050 by between 7 and 20 per cent, those increases will be below the change in real income per capita in Australia which is expected to rise by over 100 per cent by 2050 as GDP increases. By 2050 the share of average full-time wages spent on electricity is expected to decline from around 1.1 per cent in 2006 to between 0.5 and 0.7 per cent [1]. This is inclusive of carbon prices imposed in the scenarios.

When considering changes in income and energy costs, the opportunity exists to recycle any potential carbon tax or permit revenues through the tax system, to either reduce personal income tax or reduce the impacts on the expense side of the household budget. It is also important to consider how various income groups would be impacted by the whole package of policy changes. It was assumed in the scenarios that there would be some offsetting tax changes to reduce the impact of the carbon tax on vulnerable groups. However, it was not possible to model the various options in detail.

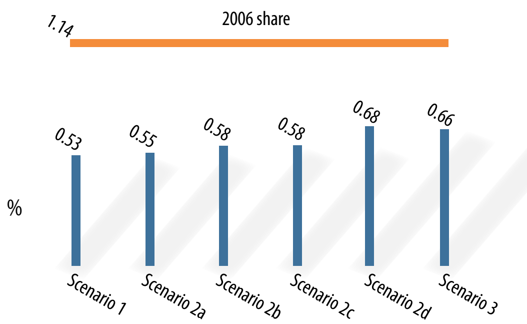


Figure 2: Household electricity consumption share of real average full-time wages in 2050 under the mitigation scenarios compared to 2006 levels

1 Assuming wages track income per capita. An estimate of average residential electricity prices across Australia in 2005-06 was 10.1c/kWh. There is significant variation, however, depending on the Australian state of residence. Fees are also typically a mix of fixed and usage-based rates.

Impact on industry

The economic cost of greenhouse gas abatement can also be measured by the impact on industry sectors.

The Australian economy is dominated by its services sector (68 per cent of GDP in 2005-06). However the sectors most likely to be affected by the introduction of a carbon price are aluminium and iron and steel because they are highly energy intensive, and agriculture because it emits large volumes of greenhouse gases. In 2006 aluminium and iron and steel comprised about 4.5 per cent of the value of exports, while the agricultural sector accounts for about 3 per cent of GDP and 16 per cent of the value of exports.

Australia is among the world's lowest-cost producers of minerals and metals and, combined with abundant mineral resources and low sovereign risk, low-cost energy is at the heart of this competitive position.

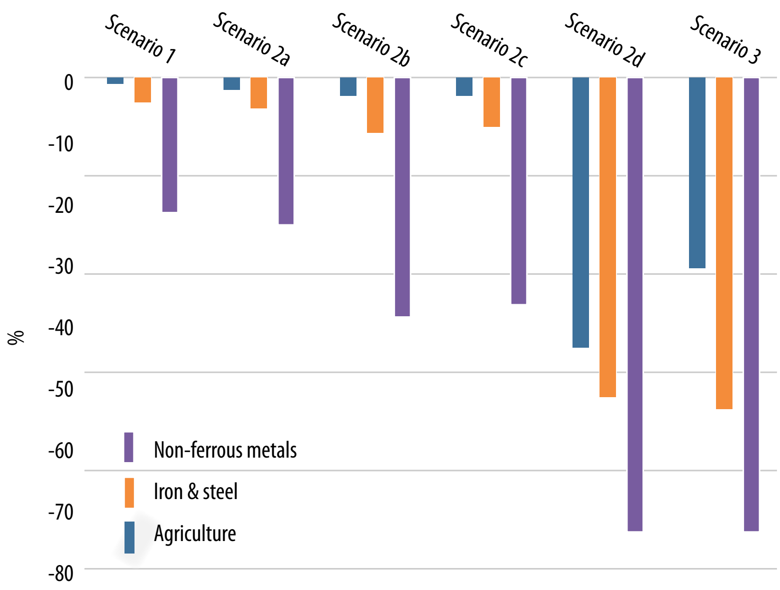


Figure 3: Changes in industry output in 2050 across scenarios, relative to the reference case (selected industries only)

The economic modelling (Figure 3) suggests that industry output for agriculture and iron and steel will be reduced by 2050 by between 1–3 and 4–9 per cent respectively compared to the reference scenario, where Australia acts in concert with the international community (under economic modelling scenarios 1 and 2a–c), but that output is reduced by between 32–34 and 53–54 per cent respectively compared to the reference scenario where Australia makes unilateral deep cuts (scenario 2d), or acts as part of a smaller international coalition (scenario 3). The reduction in non-ferrous metals output by 2050 is more significant under all scenarios – between 22 and 39 per cent compared to the reference scenario in scenarios 1 and 2a-c, and about 75 per cent in the case of the case of scenarios 2d and 3.

These reductions in output accumulate gradually from the time the carbon prices are introduced and the modelling also assumes that there is no protection provided to these energy intensive industries.

These reductions in output accumulate gradually from the time the carbon prices are introduced and the modelling also assumes that there is no protection provided to these energy intensive industries.

By contrast, the impact of a carbon price on the services sector is projected to have only a minor impact, on the basis that energy is a relatively small input to their industry.

While the economic modelling does not comment on how such impacts would be managed, it could be reasonably expected that such impacts would present challenges to regional employment and the balance of trade.

The impacts are projected to be the greatest in scenarios 2d and 3, where Australia makes a deeper cut in greenhouse gas emissions than other countries. Under such scenarios, it is plausible to expect carbon leakage to countries with lesser or no carbon constraints.

Carbon leakage is a process whereby emission intensive production (and the associated employment and wealth creation opportunities) moves from regions or countries under a carbon constraint to regions or countries without such a constraint, or a lesser constraint. As a result, emissions abatement in one region is offset by increased emissions elsewhere.

The economic modelling does not consider border adjustments to limit carbon leakage, or tradeable emission permits that would also reduce costs. For example, the Australian State and territory governments have recently released a discussion paper (National Emissions Trading Taskforce, 2006) on a proposed emission-trading scheme that indicates that energy intensive users may be allocated permits after a process of identifying those most affected by carbon pricing. In the absence of a multilateral agreement, exempting selected industries that are carbon intensive and trade exposed would reduce the potential for carbon leakage. However, it would spread the same economic burden over a reduced portion of the economy.

The cost of not addressing climate change

The reference scenario represents a world that takes no action to reduce greenhouse gas emissions with the exception of some existing and announced policies. Applying the reference case emissions to a simple climate model, the climate is expected to warm by between 2.6 and 5.7°C by 2100, with a mid point of 4.0°C. Modelling also exposes the prospect of significant further warming beyond 2100.

Globally, the sectors that are considered to be most vulnerable to changes in the climate include natural ecosystems; cropping, livestock; water resources; public health; settlements and infrastructure; and natural environmental systems.

Australia's degree of vulnerability in these sectors, as well as to extreme weather events, suggests that the risks to some aspects of natural systems and water resources are high, whereas most systems with a strong socio-economic component are more likely to be able to reduce the risks due to their adaptive capacity. However, risks to food and fibre production depend greatly on the change in rainfall, so for many regions the risks could range from low to high.

Key biophysical vulnerabilities

Figure 4 highlights the risk-weighted [2] damages for four key biophysical vulnerabilities: the Greenland ice-sheet, coral reef systems, the ocean's thermohaline circulation and species extinction . (Refer to Section 6 for a detailed description of these biophysical vulnerabilities.) The analysis shows that, under the reference case, in the best case, the probability of loss of coral reefs to bleaching is close to 100 per cent, there is little or no possibility of avoiding irreversible melting of the Greenland ice-sheet, the species at risk of extinction rate is between 60 to 80 per cent and the functioning of the North Atlantic thermohaline circulation would be reduced by more than one third.Figure 4. Risk-weighted damages for four key biophysical measures under the reference case and for two CO_2 concentration stabilisation levels achieved through GHG mitigation.

2 Weighted risks are a measure of probability times consequence, and are created by multiplying the likelihood of global warming in 2100 by the consequences of that warming.

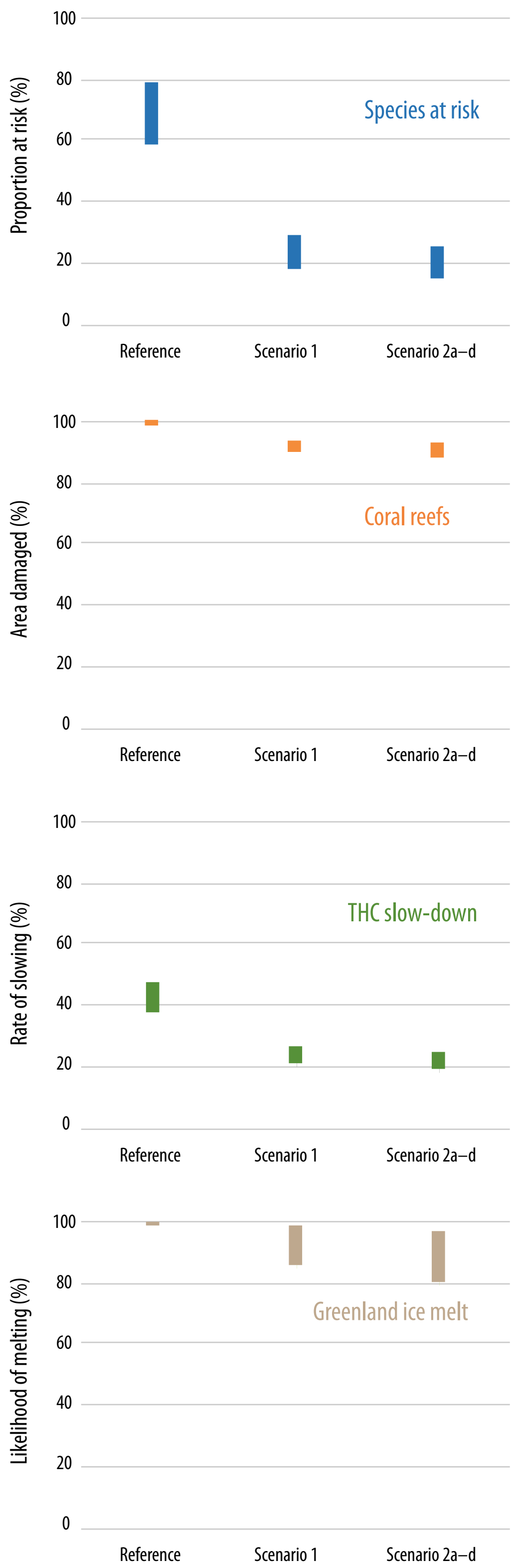


Figure 4: Risk weighted damages for four biophysical vulnerabilities: the Greenland icesheet, coral reef systems, the ocean's thermohaline circulation and species extinction

The three bars in each quadrant of the diagram above refer to the risk-weighted range of impacts under the reference case and two mitigation scenarios groups: 1 and 2a-d. The type of impact varies depending on the vulnerability being examined. For example, for coral reefs, it is the area damaged. A detailed description of the biophysical vulnerabilities can be read in Section 6.

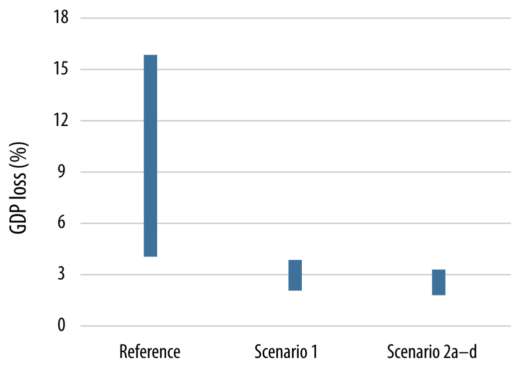


Figure 5: Range of economic damages in 2100 estimated via sensitivity analysis of alternative damage curve shapes

Damages to the economy

The cost of not addressing climate change can also be traced through to damages to the economy or GDP. The shape and magnitude of economic damages with respect to increasing warming is unknown, but is widely assumed to become strongly non-linear under rapid climate change. (Section 6, Figure 2)

Conducting a sensitivity analysis of alternative damage curve shapes has provided an estimate of the range of economic damages in 2100 (Figure 5). Under the reference case, World GDP is shown to be reduced by at least 4 per cent by 2100 with the range including damages up to 16 per cent. This is broadly consistent with the research released by Stern et al (2006).

A possible reason why the true economic impact may be higher than estimated by many studies is that most climate damages models do not adequately take into account the damages from climate variability and extreme events, and climatic 'tipping points'. Non-market items, such as ecosystem function, whose impact on the economy is not yet sufficiently understood, are also often not included.

On the other hand, the potential for the economy to adapt to higher temperatures may be a basis for supporting estimates in the lower end of the range. It may be plausible to be optimistic about economic damages being manageable under lower rates of warming, while remaining pessimistic about higher rates of warming.

A thorough survey of adaptation measures has not been conducted as, given the models available and the state of the science, it would not have been possible to incorporate adaptation measures comprehensively into the analysis.

One example of an adaptation measure that could directly affect the energy sector would be incorporating dry cooling into new power stations to address scarcity of water. Another adaptation measure could be the increased use of air conditioning, due to the more regular occurrence of extreme temperatures. Both measures would increase the amount of fuel required for electricity production, due to decreased generation efficiency in the first case, and increased electricity usage in the second. In some cases, the impact of climate change may be positive. For example, this will be the case in regions or activities where the benefits of warmer winters outweigh warmer summers.

The benefits of addressing climate change

The benefits of addressing climate change through mitigation would be the avoided damages – both biophysical and economic.

The benefits of avoiding biophysical damages

In general, the increase in the temperature from the mitigation scenarios 1 and 2a-2d is restrained to between 1.5 and 3°C. Specific biophysical impacts of the expected benefits of addressing climate change under these scenarios are summarised from Figure 6 and are as follows:

- a reduction in species at risk by 40 to 55 percentage points
- a reduction in the portion of coral reef systems damaged by bleaching of 5 to 10 percentage points
- a reduction in the loss of functioning of the North Atlantic thermohaline cycle of between 15 and 20 percentage points
- a reduction in loss of the Greenland ice-sheet by 2 to 15 percentage points.

The expected benefits to coral reefs and the Greenland ice-sheet is not as great as the other systems due to their greater sensitivity to temperature change. However, the greenhouse gas abatement achieved brings those systems much closer to their critical thresholds so that any additional abatement over and above the EFF's scenarios would yield rapidly increasing marginal benefits to those systems. A detailed description of the biophysical indicators can be read in Section 6.

However, not all damages (biophysical or economic) can be avoided. Firstly, greenhouse gases remain in the atmosphere for many years, due to the inertia of the Earth's climate system, and the cumulative effect of emissions in the past that will take many decades to work through the climate system.

Secondly, even in the most optimistic of global greenhouse gas abatement scenarios, the point at which global emissions actually start to fall, rather than continuing to rise, is also thought to be some decades away due to the long lives of greenhouse gas emitting infrastructure.

Economic benefits

Using the damage functions introduced above as a guide, the expected economic benefits to GDP from greenhouse gas abatement can also be estimated.

In this case, the benefit is defined as the avoided reduction in global GDP. As previously outlined, the cost of climate change to global GDP in the reference case is expected to be at least four per cent and potentially up to 16 per cent by 2100 (Figure 5). Under the mitigation scenarios 1 and 2a-2d, the reduction in global GDP is reduced to between two and four per cent (depending on the damage curve selected). The result is that, compared to the reference case damages, the expected benefit of greenhouse gas abatement would be a saving of at least two per cent of global GDP in 2100, but potentially higher.

To put this economic benefit in perspective, the economic modelling shows that the cost to the world economy of reducing greenhouse gas emissions would be between 1.7 and 4.3 per cent of GDP in 2050.

It can be argued that costs incurred up to 2050 are directly comparable to the benefits that would be derived in 2100. As demonstrated in the climate modelling, emissions up to 2050 are the key driver of 2100 climate outcomes. Post 2050 emissions reductions are unlikely to make much difference to impacts in 2100 because of the inertia in the Earth's climate system. Hence it could be speculated that the economic costs of greenhouse gas abatement to 2050 appear to be fully justified by the economic benefits to be gained at the world level in 2100. Given, however, the uncertainty in the true shape of the economic damages curves it would appear too early to draw this conclusion. For this reason, CSIRO undertook an analysis that estimated the minimum benefits in 2100 required to balance the costs of mitigation to 2050.

The analysis shows that, the conclusion that the costs of mitigation may be offset by the benefit of avoided climate damages only relies on the more conservative damage curves in the low to mid range of estimates in the literature.

On this basis, if a single-bottom line approach to costs and benefits is taken by concentrating solely on monetary outcomes, then the costs to 2050 may well be balanced by benefits in 2100. If benefits are expanded to include the environment then there is a range of biophysical benefits, as shown by the four examples above. Therefore, on a global basis, the multiple benefits of avoided damages in 2100 are likely to outweigh the costs to 2050. Further work would be required to assess specific benefits for Australia.

THE ROLE OF AUSTRALIA IN ADDRESSING CLIMATE CHANGE

There are a number of reasons why Australia, as a country, has a strong vested interest in taking part in global action to address climate change.

Australia exports $38 billion worth of energy-related commodities each year. At the same time, much of Australia's environment is particularly sensitive to climate change – coral reefs, alpine ecosystems and water resources, all of which are vibrant entities in the public psyche. Economic and social impacts of climate change, such as extreme weather events and loss of tourism industries, are also a consideration. Another concern is that uncertainty about future responses to climate change is affecting investment in energy assets (see discussion ahead).

Many in the community hold the view that Australia, as one of the largest emitters of greenhouse gas (GHG) per capita amongst developed countries and one of the wealthiest nations in the world, has both the responsibility and capability to reduce emissions. At the same time, it is also recognised that Australia is in a unique global position of having a large land mass populated by few people, and that it processes mineral commodities for the world market.

Whatever the motivation there is no doubt Australia has a strong interest in addressing the issue. The question is what role Australia should play. Since Australia only emits 1.5 per cent of total global GHG emissions (excluding land use change, WRI 2006), it could continue to work with other countries to reduce the cost of deployment of low emission technologies and to negotiate an inclusive international agreement that ensures other countries also address their GHG emissions.

At present, there is an international policy framework that has the sign-on of all countries, that is the United Nations Framework Convention on Climate Change and the associated Kyoto Protocol which makes binding targets on developed countries to 2012. Australia has not ratified the Kyoto Protocol but has undertaken to meet the agreed target. The present international discussions regarding future climate change agreements are primarily influenced by differences of opinion over the framework for arriving at an effective and appropriate level of participation from all countries.

The United Nations Framework Convention on Climate Change (UNFCCC), which came into effect in 1994, places the heaviest burden for dealing with climate change on developed nations, including Australia.

This approach recognises firstly, that those that have responsibility for creating the problem should have primary responsibility for addressing it. Developed countries have contributed three quarters of World cumulative greenhouse gas emissions since 1850.

Secondly the approach recognises that, because developed countries have a higher capacity to address the problem due to their relative wealth position, they have a greater responsibility to act. This feature of the UNFCCC, while supported at the time, has not retained comprehensive global support. Developed countries have questioned whether this framework is a viable basis for a long-term agreement on addressing climate change. A key consideration is that the framework does not provide any indication of how long developed countries should bear the larger part of the economic cost.

Developing countries are expected to account for more than half the world's total annual GHG emissions this century. Hence, it will become more difficult and costly for developed countries to effectively address GHG emissions on their own. This outcome is demonstrated in scenario 3, which projects a larger cost to Australian GDP growth compared to scenario 2a for the same global greenhouse gas abatement outcome (Figure 1). Scenario 2a is based on all countries participating in a global greenhouse gas reduction scheme, whereas scenario 3 involves developed countries only, with China and India joining the scheme in 2020.

It is difficult to predict what might move the world beyond the current impasse. Technology transfer could potentially play a role in bringing the position of developed and developing countries closer together if some agreement for the contribution to costs of technology development and the rate and other arrangements for transfer were able to be developed. The Asia Pacific Partnership on Clean Development and Climate established in January 2006 is one approach to beginning such efforts. The key focus of the partnership, which consists of Australia, China, India, Japan, the Republic of Korea and the United States, is the development, deployment and transfer of existing and emerging cleaner technologies (although no firm timetable for each of these activities has been set).

THE NATURE AND TIMING OF GOVERNMENT INTERVENTION

Addressing climate change will require an enormous transformation of infrastructure and society's use and relationship with, not just energy but a broad range of products and services. A range of government programs and legislation is already targeting greenhouse gas reduction and adaptation. However, a much greater level of government intervention in Australia and globally must take place to achieve the scale of transformation required to address climate change in a meaningful way.

A carbon price has been used extensively in the economic modelling commissioned for this Report because it is the simplest way to model greenhouse gas reduction policies in economic models.

A carbon price is one mechanism to align global economies to accept the increased cost of reducing emissions. A carbon price leads to emission reductions in two ways: firstly, by having an immediate impact on the profitability of high and low emission industries – negative in the case of high emission industries and positive in the case of low emission industries – which encourages activities that reduce high emission activities and encourage low emission activities. Secondly, a carbon price indicates to firms that future investment decisions of firms should give preference to low emission technologies and activities.

Other policies for reducing GHG emissions include for example, regulation to create standards for household and industrial buildings, appliances, machinery and processes, communication and awareness, low emission technology funding grants, direct subsidisation or differential tax treatment of fuels or technologies and policies which require the mandatory use of a minimum amount of a particular technology or fuel.

Many of these policies already exist in Australia. The challenge is to determine what combination of policies and what level of ramping up is required and when.

This Report does not discuss the optimal combination of policies required, since this is a matter for policy makers. However, it is agreed that a combination of policies will be required, rather than a single policy instrument approach. The degree of ramping up is determined by the national GHG emission abatement goal. The goal is a function of the role of Australia as a country in addressing climate change, which is covered in the discussion on the previous page.

The modelling has included two scenario groups: early action where carbon prices are introduced in 2010, and late action where a carbon price is introduced in 2030.

Although the modelling uses carbon prices as the primary policy instrument, in practice, reducing emissions will be based on a range of policies and measures with the key variables being the nature of the policies and measures, the timing of implementation, and the rate of change. These could include policies and measures that would encourage the adoption of low cost emission abatement opportunities in the short term (such as energy efficiency), allow the orderly deployment of existing technologies and industries (such as renewables), and deliver strategic government and industry frameworks driving the development, commercialisation and deployment at scale of new and emergent low emission technologies.

Without advocating a particular approach, the key advantages of adopting an emission reduction goal that begins early such as in 2010 include:

- It keeps open the opportunity to further reduce the environmental impact of climate change in the future by making greater emission cuts (this opportunity will be lost if early action is not taken)
- It reduces energy sector investment uncertainty if it means policy is announced sooner
- It could accelerate technological change of the "learning by doing" type if it means faster deployment
- It is generally affordable for Australia, although it has some adverse impacts on specific industry sectors.

On the other hand the key advantages of adopting an emission reduction goal that begins later, such as in 2030 include:

- Arguably it gives time for the existing (or future) international negotiations to reach an agreement about global and national emission reduction targets;
- It could avoid locking in any particular low emission technologies if a new lower cost technology emerges
- It does not mean no action since, for example, other policies such as directing funds at research and development of low emission technologies could take place in the interim
- It reduces the impacts on some specific industry sectors.

CLIMATE CHANGE UNCERTAINTY AFFECTS INVESTMENT

The debate over the extent to which human activity has contributed to climate change has largely been put aside and business, instead, is focussed on climate risk as a business reality for which they must plan (see sidebar) (CDP4 Report 2006).

Climate change is a significant business risk, and one that could potentially disrupt how the world does business. Climate change is also a significant business opportunity for some sectors, particularly those associated with low emissions technology.

While business is accustomed to working with risk, climate change poses some unique challenges, including:

- the long-term horizon of potential impacts
- uncertainty over what, exactly, the effects will be
- having worldwide impact, but one that may vary depending on geography and industry
- potential macroeconomic impacts that could significantly alter entire regions and industries, and shift the ways in which companies do business and the locations from which they operate.

The Carbon Disclosure Project

In February 2006, the non-profit Carbon Disclosure Project sent its fourth request for information to major businesses around the world asking how those companies incorporate climate change risk into their planning. The letter was signed by 211 institutional investors, representing assets of more than $31 trillion.

The 2005 survey – signed by 155 institutional investors representing $21 trillion in assets – was answered by 71 per cent of the UK Financial Times Global 500 (FT500) companies, up from 59 per cent in 2004 and 47 per cent in 2003. A key result from the 2005 survey was more than 90 per cent of the 354 responding companies saying climate change posed a commercial risk and/or opportunity for their companies.

The Australian energy sector will require several tens of billions of dollars of new investment to both replace ageing plant and develop new plant to meet growing demand for energy. Addressing climate change is expected to further increase the level of investment required.. Uncertain or conflicting regulatory regimes heighten business risks, potentially reducing and delaying investment decisions.

To reduce uncertainty, business needs an efficient and politically realistic policy framework that matches the investment horizons required to achieve long-term environmental performance goals at low economic cost. A clear and long term policy framework, including the implementation timeline, will allow technology developers to plan the delivery of lower emission technologies on time and allow developers to make long term investments decisions with confidence.

As discussed there are a variety of policies that can be applied to address climate change. Business can reasonably expect regulatory approaches to be part of the response. Due to its implications for investment risk, the potential for a carbon price to be introduced in the future is of particular interest to business.

The EFF does not advocate any particular approach to designing a domestic or international carbon price, if one were to be introduced. However, it is acknowledged that some approaches are better suited for managing specific risks. For example, carbon taxes levied by government could potentially offer greater certainty for government tax revenues and investors. Tradeable permits would not provide certainty as prices vary in response to the prevailing market for permits; such permits, however, provide greater certainty that a desired emission abatement level is achieved [3].

In each scenario modelled by the EFF, the required emission abatement to attain a CO_2 concentration stabilisation target of 575 ppm at 2100 was achieved by the introduction of a carbon price. The spread of carbon prices projected for the period 2010 to 2050 is shown in Figure 6.

At some of the carbon prices projected there is a risk that unless some emitters were allocated long-term emission permits, some assets would become 'stranded'. This situation occurs when an asset is permanently shut down as it

3 The McKibbin-Wilcoxen Blueprint endeavours to manage the trade-offs between addressing different types of risks (McKibbin, 2005) by adjusting a carbon tax at fixed intervals to incorporate new information about the costs of abatement and the climate impacts associated with different emission levels

is worth less on the market than it is on a balance sheet due to the fact that it has become obsolete in advance of complete depreciation. A driver of obsolescence may be changes in policy that lead to expected ongoing operating losses.

When reflecting on the future of energy in Australia, this problem of managing carbon price risk is most pronounced in the public and private electricity generation sector.

Investments in electricity infrastructure require several years' lead-time, with assets having lifetimes of 20 to 50 years. The Energy Supply Association of Australia estimates that A$30 billion of investment is required in stationary electricity generation by 2020.

Reliable electricity supply underpins the Australian economy. If the risks faced by the electricity sector are compounded by uncertainty in future climate change policy, there is the possibility of inefficient or under-investment in new infrastructure, and reduced incentives to invest in maintenance or expansion of existing electricity generation assets.

The outcome of this could be either much higher prices for electricity or shortfalls in supply.

These outcomes would have economic impacts (eg. lost production), cause personal inconvenience (eg. power outages), reduce social equity (eg. reduced affordability or access to electricity dependent services) and could affect political decisions. An estimate of the possible level of disruption is an important metric that is difficult to quantify.

Risk also affects investment in research and development, which will be necessary to support efforts to reduce emissions effectively and efficiently. The

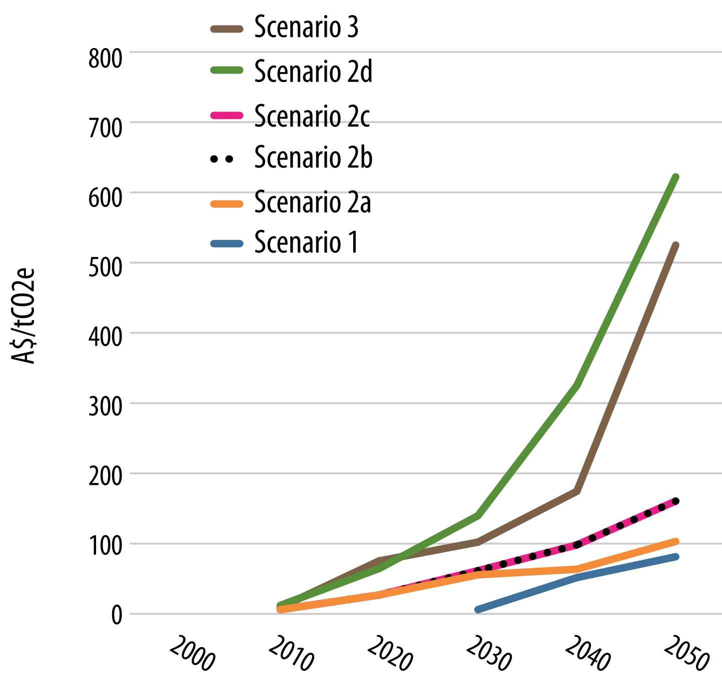


Figure 6: Projected carbon price levels by scenario

timing and size of future investment in low emissions technology research and development may be enhanced by the introduction of further effective policies or programs specifically designed to facilitate such research and development. Regardless of the type of policy response introduced, investors and financiers need a practical and politically realistic framework that supports the management of risk.

THE LOW-EMISSION TECHNOLOGY MIX

In discussing the future of Australia's energy, the EFF concluded that there is no single solution to addressing the challenges presented in the scenarios. A combination of improvements in energy end-use efficiency with the adoption of many available low-emission technologies will be required.

All technologies have varying degrees of advantages and disadvantages from economic, social or environmental perspectives. Each has a slightly different challenge. Carbon capture and storage (CCS) from coal and gas-fired electricity generation is yet to be demonstrated in Australia and a regulatory and liability regime for CCS does not yet exist. Many renewable energy technologies have been proven for some time but require the introduction of a carbon price to be competitive. Many renewables would benefit from research and economies of scale to reduce their costs and to develop strategies for managing intermittency. Nuclear power is the largest low emission technology in terms of present global market share but requires further assessment to determine its social acceptability and cost competitiveness.

Of critical concern is the need to foster and support research and development in low-emission technologies and to do so with a sense of urgency, irrespective of whether a carbon price is introduced.

The role of culture and values in adopting low-emission technologies

Australians consume energy for a variety of reasons – entertainment, heating, cooling, industrial processes, information management, mobility and even fashion. Aside from a few industrial processes, the energy costs of these purchasing decisions is often minor compared to the other features of the whole package of goods or services being consumed. This feature of the way households and low-energy intensive businesses relate to energy suggests a relatively easy path to adopting a higher cost low-emission technology mix, at least from a financial point of view.

There are, however, other facets to the question of technology adoption. Energy-use efficiency technologies and distributed generation may require changes to lifestyle. Other technologies, such as wind, change the landscape. Alternative transport fuels, modes and engines could affect the way the general populace views mobility. There is the potential to severely underestimate the social values and behaviour change possible over the next 50 years. For example, water use efficiency in metropolitan areas of Australia has improved considerably over the past few years as its importance has been strongly promoted by state and local governments.

This Report has looked forward 44 years to 2050. Looking back over the same period, values have shifted considerably (refer to Box for a view 44 years back in time).

The qualitative scenarios developed by the EFF explicitly recognise the potential for society to make alternative choices.

In *Clean Green Down Under*, for example, society supports a new political party that incorporates sustainability, or triple bottom line thinking, into all aspects of government and private decision-making, including responding to climate change. The scenarios also recognise the potential for society to turn away from, or at least delay the risks of, participating in global emission reduction schemes – refer *Day after Tomorrow* and *Centralised Failure*.

The social modelling research also offers insight into the potential for social change. While the research was not designed to draw broad conclusions about the plausibility of Australians adopting any of the scenarios, the study did demonstrate that a broad range of views exist in regard to potential technology development paths in Australia, and that, for many individuals, their views and opinions were susceptible to

Back-casting: looking back in order to assess the potential for change in the future

In order for the EFF to look forward in time to 2050, in an innovative attempt to identify a range of plausible scenarios available to Australian society for future energy options, the EFF reflected briefly on life in Australia at an equidistant time in the past…1962. This retrospective glimpse was intended to provide some understanding of the scale and scope of changes that can occur over a 44-year period and to give impetus to imaginative and perhaps more far-reaching but plausible alternative futures.

In 1962:

- Australians paid for all their goods in pounds, shillings and pence…decimal currency was still four years away.
- The EK Holden had fins and had been joined on the 6-cylinder market by the new Ford Falcon, Chrysler Valiant and the first of the Japanese cars, the Datsun, only two years before.
- Black and white television had only come to Australia six years earlier and was still a relatively rare luxury in many homes.
- Air conditioning in homes was pretty well unheard of, telephones had dials and home necessities such as milk, bread, meat, and fruit and vegetables were still home-delivered.
- The Commonwealth Electoral Act allowed Aboriginal people the right to enrol and vote at federal elections, but they were not included in the census until 1967.
- Smoking was permitted in hospitals and offices, and on airplanes and public transport.
- The Beatles were yet to hit the pop charts; Johnny O'Keefe ruled the Australian airwaves with Bobby Vee, Bobby Vinton and Bobby Rydell popular in the US.
- The first Australian troops arrived in Vietnam, initially as military advisors to the South Vietnamese forces.
- The major office machinery items were typewriters, some being electric, copies of documents were made via carbon copies or 'Roneoed' on Gestetner printers smelling of methylated spirits; battery powered calculators, photocopiers, word processors, printers and mobile phones were still many years off.
- Interestingly, fuel consumption for a well-tuned Holden was about 24 miles per gallon, or some 11 litres per 100km…pretty well what a current large car achieves…before you switch on the air conditioner …however the power it produced for that fuel consumption was less than half that of current family cars.

change following the provision of new information and exposure to group discussion.

Overview of low-emission technology options

The economic modelling presents a significant amount of detail on the possible future mix of technology in the electricity and road transport sectors.

All modelling, particularly those with a long timeframe, is speculative given the inherent uncertainties of the energy technology innovation process, the long timeframes involved, and the fact that economic models lack the richness of real life.

The process undertaken by the EFF revealed gaps in its knowledge, for which further investigation is recommended into the potential impact on the future of energy.

- Attracting and retaining skilled labour to build and operate new technologies may decline. Skills relating to both new and existing technologies will require ongoing training, development and investment to ensure safe and effective operation. While attracting and retaining skills is always a key business challenge, there is some reason to expect that the problem may worsen in the future, since the energy sector, under some scenarios, would be undergoing much faster change than it has experienced in the past. At the same time, the proportion of working-age people in the total population is projected to decline.
- The electricity generation, distribution and retail companies may re-integrate into energy service companies. The need for optimisation of energy at the end-user level in a low carbon world could lead to energy providers employing a totally integrated low-emission energy solution involving, for example, energy efficiency, cogeneration, export to, and import from the distribution system. Retailers seeking to reduce exposure to the risk of daily price volatility may also be a motivating factor. These could eventually necessitate a review of the Australian National Electricity Market.
- The electricity sector and transport markets may integrate. Today's undiversified companies may evolve into integrated energy companies with very diverse technology portfolios and potentially supplying both the electricity and transport fuel markets.
- There is no risk-free approach to focussing Australian technology research and development, and industrial development. With limited resources (in relation to the size of the Australian economy relative to the research task), how much research and development, and industrial deployment should Australia target incremental compared to targeting step-change technologies?
- Energy storage will effect energy options. The ability to store electricity would improve the system's ability to meet peak demands and allow a much greater uptake of intermittent renewables.

Following is a discussion on several broad technology categories currently available to Australia when considering its future energy requirements.

Carbon capture and storage

Carbon capture and storage (CCS) is crucial to the future of coal if a carbon price is introduced in Australia. It is not only crucial from the coal industry's perspective, but is also potentially one of the lowest cost abatement options for Australia.

Carbon capture and storage technology has been utilised at relatively small scale in the oil and gas industry for enhanced oil or gas recovery for approximately 30 years, However, it is still at a relatively early stage of development with respect to the much larger scale and economics required to reduce CO_2 emissions from power generation. No full-scale plant is yet to be built anywhere. The world's first demonstration plant is currently planned for operation from 2011 in Queensland. Several other applications have been announced in the United States and Europe.

Current estimates indicate that Australia's 'storage capacity' is sufficient to meet CO_2 sequestration needs for hundreds of years however there are still significant issues to be resolved. They include reducing the cost of CCS, matching CO_2 emission source and sequestration location, potential conflicts with ground water supplies and the petroleum and mineral industries, and the rate of projected reduction in capture cost.

Other challenges requiring resolution include:

- methodologies for assessing and managing the risk of leakage, and defining acceptable leakage rates
- the current lack of legislative clarity around rights to use, and liability for, identified potential CO_2 reservoirs
- monitoring and verification techniques and standards.

Any significant implementation of CCS, therefore, will require public support.

Nuclear power

Nuclear power is an existing low-emission electricity generation technology, currently providing around 17 per cent of global electricity generation. Significant community concerns remain around its safe deployment, its possible connection to the proliferation of nuclear weapons, and disposal of waste. Future nuclear power systems are under development that may go some way to reducing the costs of nuclear power and the concerns surrounding safety and waste.

In the economic modelling, ABARE assumed that the future costs of nuclear power would be those proposed by Gittus (2006), which draw largely on information from Westinghouse. These costs are considered to be at the lower end of the range of costs forecast in the international literature reviewed in the draft report of the *Department of Prime Minister and Cabinet Uranium Mining, Processing and Nuclear Energy Review* (Figure 7).

For the scenarios where nuclear was included, the modelling projected that the role of nuclear power in Australia would remain relatively minor, in volume terms, with an estimated two medium-

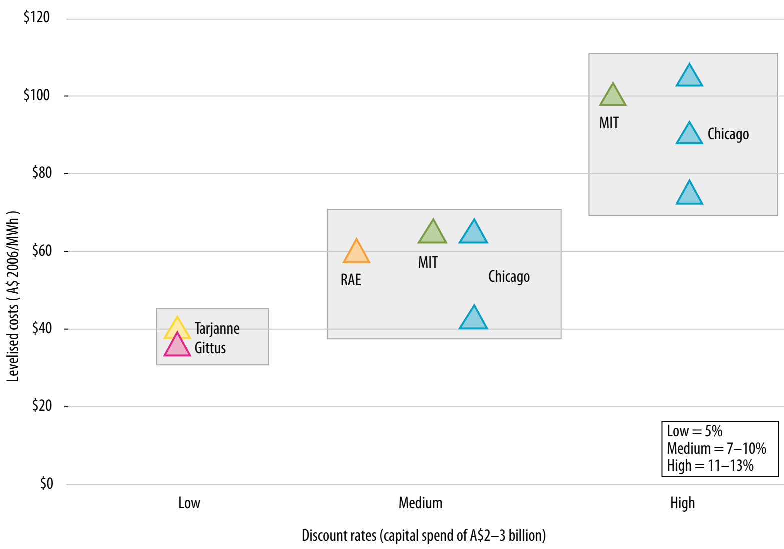


Figure 7: Indiciative ranges of nuclear power cost (source: Commonwealth of Australia, 2006)

sized (1 gigawatt) plants (Figure 7E) in scenarios 2c (1000 megawatt) and 2d (750 megawatt), where nuclear power was assumed to be available.

This result is driven by a constraint applied in the economic modelling that limited the rate at which this technology was taken up. While the potential for non-cost issues to place a cap on the amount of nuclear power taken up by 2050 is plausible, it is considered that the limit chosen by the EFF's economic modeller, ABARE, was conservative, and at odds with the qualitative scenario, Atomic Odyssey, which was intended to represent a maximum plausible uptake of nuclear power.

The constraint on the introduction of nuclear power to Australia was predicated on:

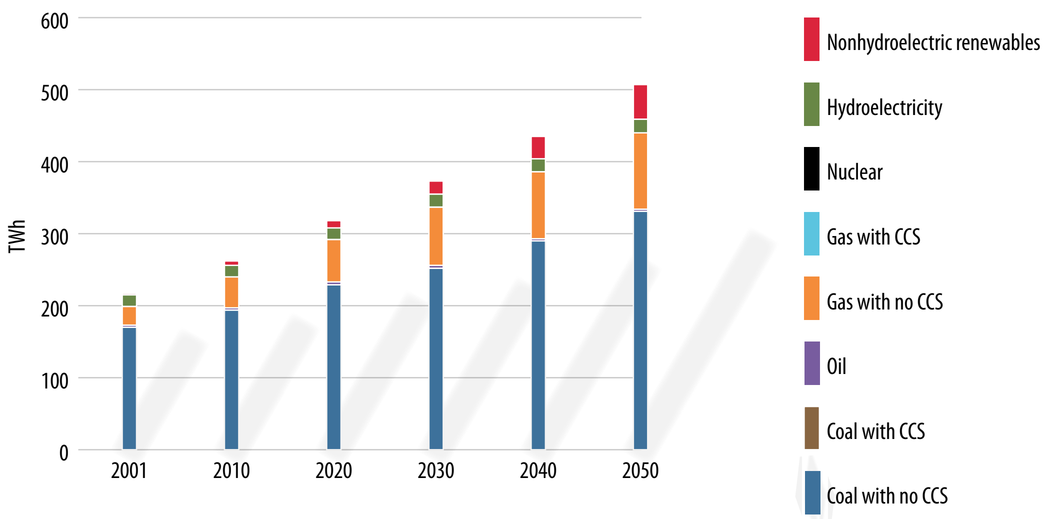
- Political delays reflecting the dichotomy of opinion amongst Australian society on the overall merits of nuclear power; in particular, concerns about the safety of radioactive waste storage and implications for nuclear weapons proliferation.
- The lack of skills and supporting infrastructure available in Australia to manage a large-scale introduction of nuclear plants, leading to extra cost outlays that affect the relative economics of the technology.
- The absence of a regulatory framework for the development approval, construction, operation and decommissioning of major scale nuclear power stations. Implementing such a regime requires a long lead-time and political will.
- Delays in identifying acceptable sites for nuclear plants driven by community concerns over safety and amenity.

Had ABARE assumed nuclear power costs in the upper half of the estimated cost range from international literature, some or all of the contribution of nuclear power would have been displaced by other technologies.

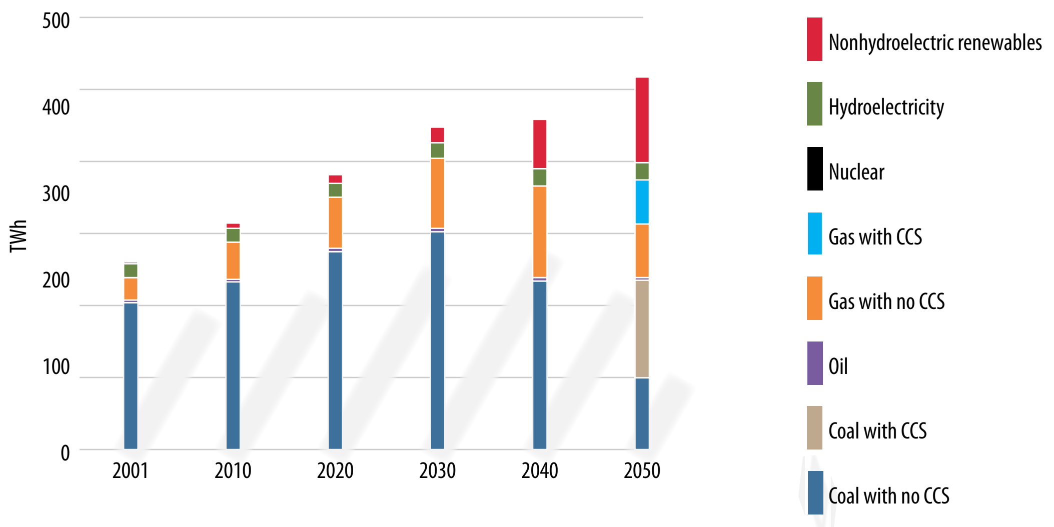
A higher uptake of nuclear power is deemed to be plausible, in the qualitative scenario, *Atomic Odyssey*, given that the following constraints to higher uptake are overcome:

- Economic costs are in the lower half of the estimated costs range
- Early confirmation that CO_2 capture and storage technology is not going to work

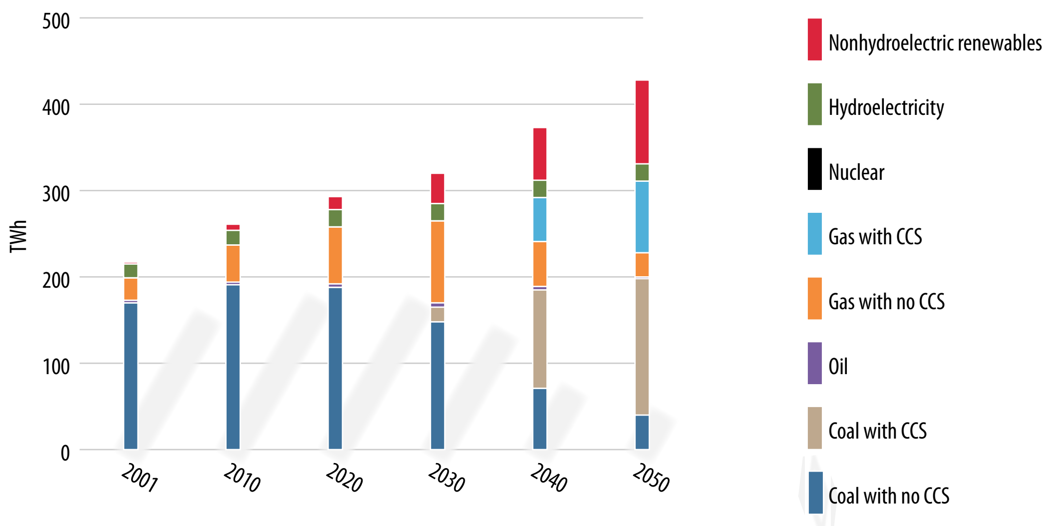
.Figures 8: Technology shares in Australian electricity generation by scenario to 2050



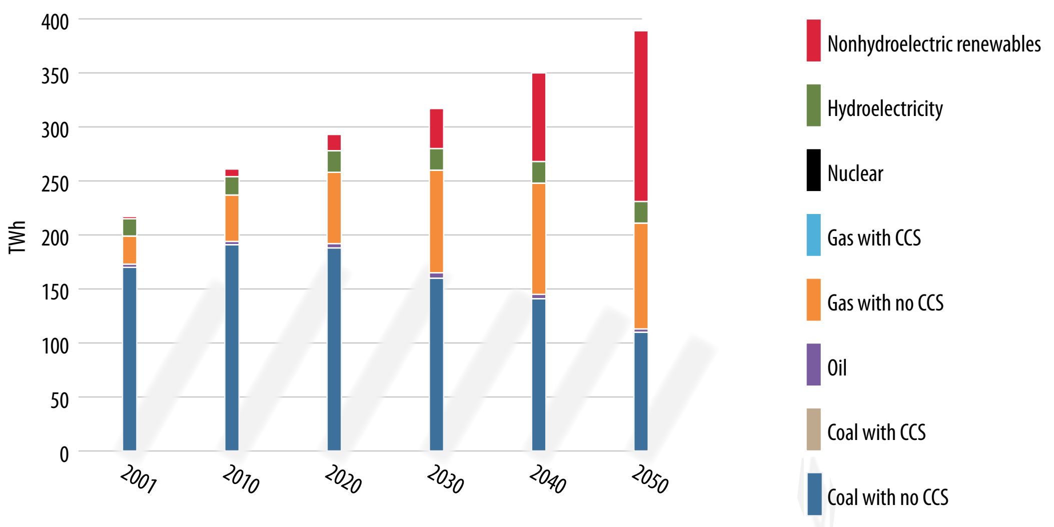
8A:Reference case - Technological development and government policies progress along known paths; no implementation of significant greenhouse gas emission reduction policies



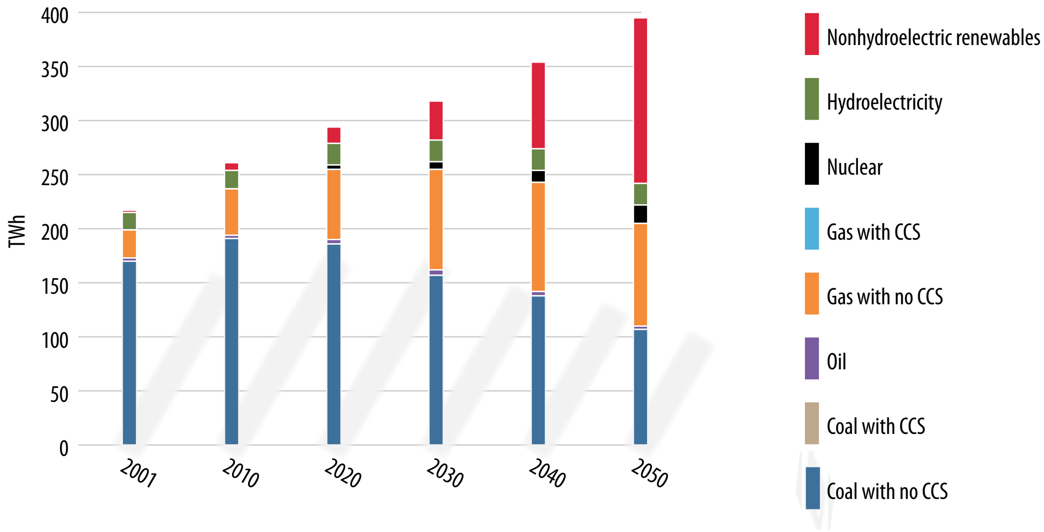
8B: Scenario 1 - Late action including all countries with a full range of abatement technologies except no nuclear in Australia



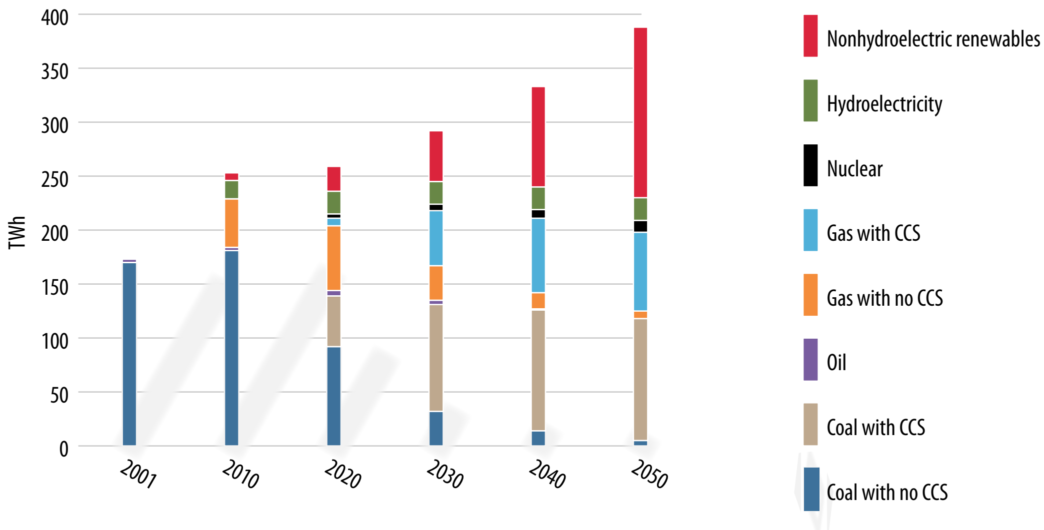
8C: Scenario 2a - Early action including all countries with a full range of abatement technologies except no nuclear in Australia



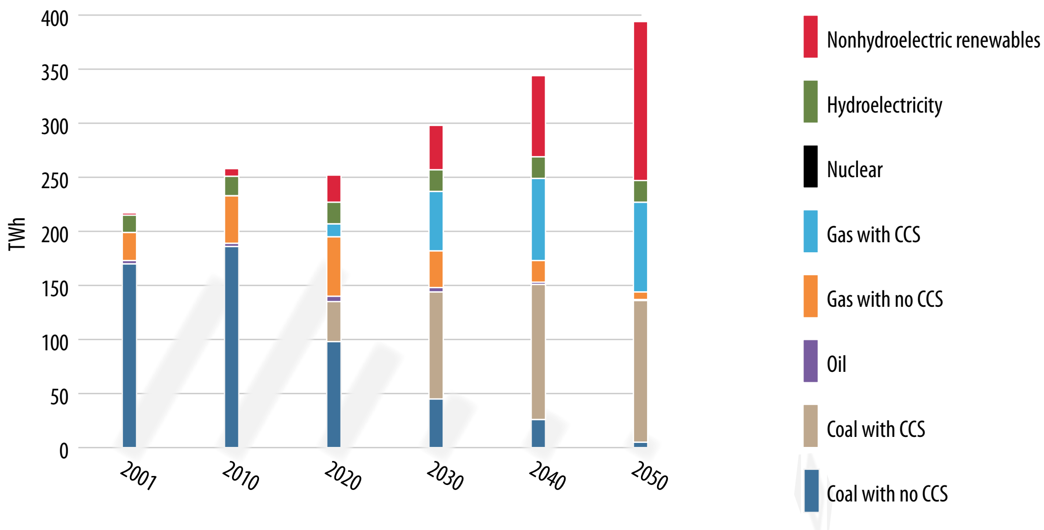
8D: Scenario 2b - Early action including all countries without CCS globally and no nuclear in Australia



8E: Scenario 2c - Early action including all countries without CCS globally but Australia can access nuclear



8F: Scenario 2d - Early action including all countries with a deep cut in Australia's emissions and all technologies available



8G: Scenario 3 - Early action including only an international coalition of developed countries, China and India with all technologies available except no nuclear in Australia

- Significant improvements in nuclear waste disposal capability
- Technical breakthroughs in the ability of nuclear power to co-produce hydrogen and desalinated water, and a high demand for these by-products
- A reinvigorated United Nations supporting both a global treaty on nuclear materials proliferation and a new terrorism task force.

Non-hydro renewables

Renewable energy is the term used to describe a wide range of naturally occurring replenishable energy sources.

The economic modelling generally concludes that renewables will play a much more substantial role in energy supply than they currently do with the introduction of a carbon price and as their relative costs fall. By 2050, the share of non-hydro renewables in total electricity generation ranges between 10 and 41 per cent across the scenarios. This Report supports the plausibility of this result, but notes that there are many uncertainties yet to be resolved in understanding the role of specific renewable energy technologies (as with technologies such as CCS and nuclear).

The economic modelling indicates that wind and biomass would dominate non-hydro renewable electricity generation (Figure 9).

When considering biomass and wind, an upper limit to the take-up rate of each was set, based on assumed land and wind resource availability.

In relation to biomass the issue of food-crop competition was not specifically addressed although the biomass uptake shown is accepted as being achievable without substantially reducing food production. Costs associated with accessing the electricity grid and transporting feedstock (most forms of biomass have relatively low energy density, requiring larger volumes to be transported, stored and handled compared with the volumes of oil or coal that contain the same amount of energy) were taken into account.

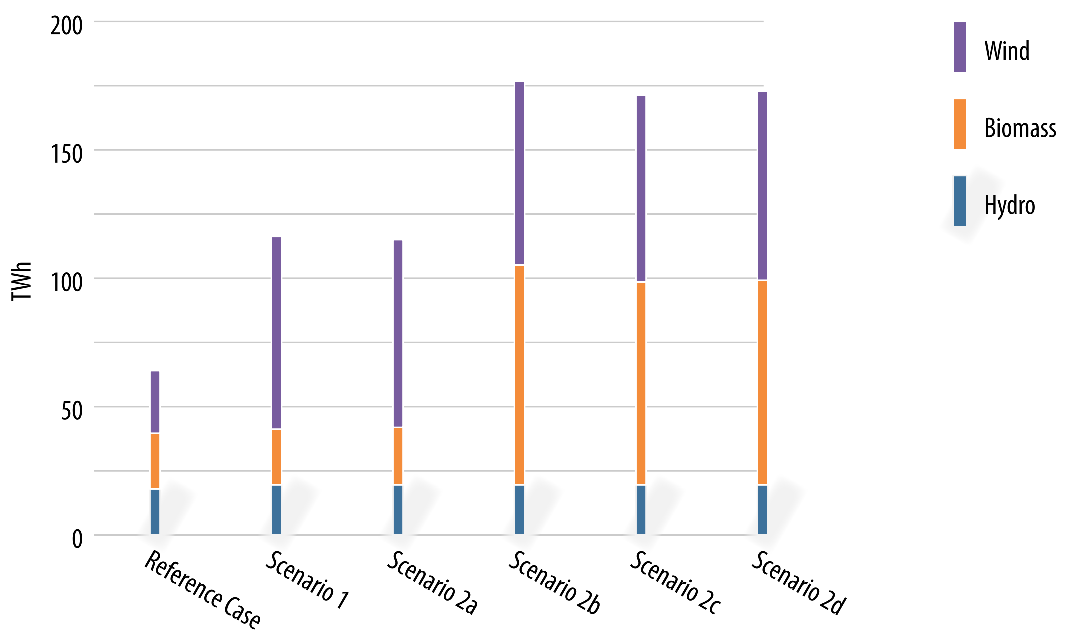


Figure 9: Amounts of renewable energy technology categories taken up by scenario in 2050

Recognising the potential difficulty in managing intermittency associated with wind and solar energy, the contribution of each of these technologies was also constrained to not exceed 20 per cent of total system generation.

There is some uncertainty about whether this constraint is at the right level. Wind is already at a high penetration in overseas countries and South Australia, suggesting the constraint may be too low. The highly probable future development of cost-effective electricity or energy storage would also play a large role in addressing intermittency issues and increasing their relative contribution.

The uptake of wind technology may also be constrained by community concerns about visual impact, noise, and bird mortality. Long-term harvesting of biomass on a regular basis from the same site results in a depletion of soil nutrient levels. Careful management is required to provide a sustainable system and avoid the need to apply expensive and energy-intensive fertilizers.

It is likely that a richer set of non-hydro renewables – including solar thermal, solar photovoltaic, geothermal and wave technologies - would be taken up in addressing Australia's future energy needs. Similarly, other renewable energy technologies are expected to emerge in the period to 2050.

Hydro electricity

Remaining large hydropower sites are limited in Australia, but some smaller sites will be exploited. Hydropower will continue to play an important role as a provider of electricity at peak times due to its ability to quickly ramp up and down following changes in electricity demand. In that respect, it has synergies with wind.

However, as the scale of electricity generation increases in Australia, as a consequence of present legislative environmental restrictions, the lack of significant new hydropower sites means that there will be increasing pressure on other technologies, such as natural gas-based electricity generation, to provide an increasing share of this peaking function in the Eastern States.

Distributed generation

Distributed energy represents a structural break from the current electricity generation system that is characterised by large centralised power generation located on the basis of being near a water or fuel source. Distributed energy is, by contrast, purposefully located near the end-user to reduce electricity transmission and distribution line losses and, ideally, to make use of waste heat from the electricity generation process.

It was projected by the economic modelling that distributed energy would play a substantial and economically viable role in several scenarios (Figure 10). In most cases the particular distributed energy technology taken up was natural gas-fired turbines with a cogeneration by-product of waste heat used to increase the overall efficiency of the process. Under a high carbon price (towards 2050) the role of gas-fired distributed generation is reduced on the basis of emissions being higher than centralised renewables, and coal or gas with CO_2 capture and storage.

While distributed generation may be viable, there remain several uncertainties yet to be fully resolved:

- The emergence of integrated energy companies and the types of distributed generation technologies and service contracts they may seek to promote (eg. emphasis on reducing

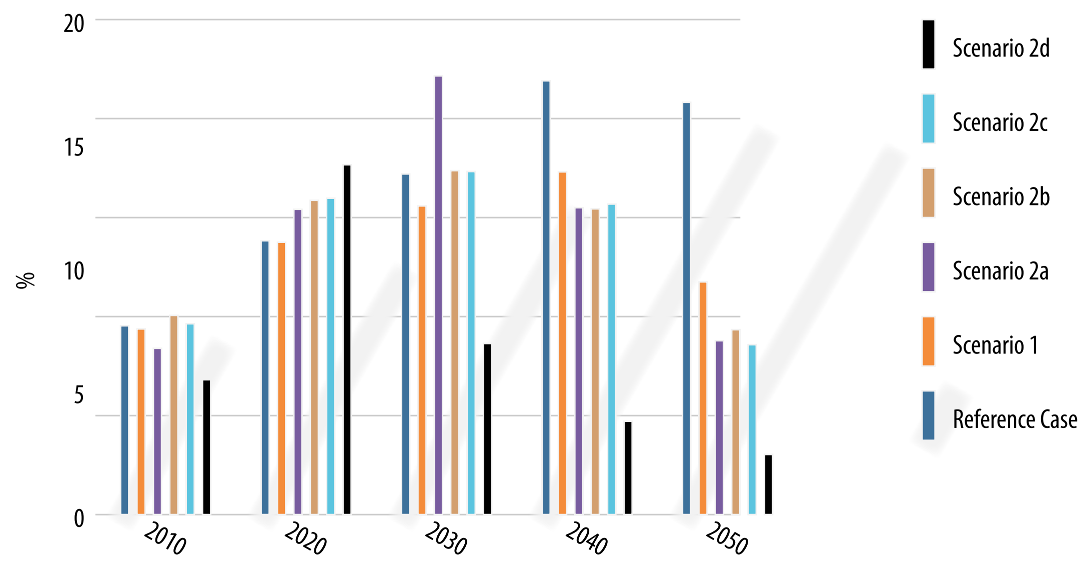


Figure 10: Share of distributed generation in total electricity generation by scenario

peak demand on the grid would favour certain technologies)

- Local environmental restrictions (eg. emission and noise)
- Emergence of new technologies suited to small scales (eg. micro wind turbines, cost effective fuel cells and exotic solar harvesting (such as solar devices capable of being inexpensively incorporated into buildings)
- The impact of exposure to retail price volatility via smart meters (which signal changes in the electricity price during the day to households and business) and associated supply contracts which offer incentives to respond to daily price changes.

Demand management

While the future of energy can often seem to be a debate focussed on energy supply technologies, the EFF is equally aware of the role of demand management and energy efficiency as a strategic response to climate change and for improving energy security.

The economic modelling generally supports the view that reductions in demand following the introduction of a carbon price can be expected to play a significant role in greenhouse gas abatement. Projections indicate that electricity demand reduces by up to 22 per cent, relative to the reference case (Figure 11).

The changes in demand in the economic modelling are largely due to changes in the structure of the economy, due in turn to shifts in economic activity away from high energy-intensive industries to low energy-intensive industries. The economic modelling does not specifically take into account additional demand management measures relative to the reference case and, as such, there is further potential for changes in demand over and above that calculated by the economic modelling. They could include:

- improvements to the energy efficiency of housing stock
- changes in industrial processes
- changes in vehicle car size preferences
- changes in preferences for more energy-efficient appliances over other appliance features.

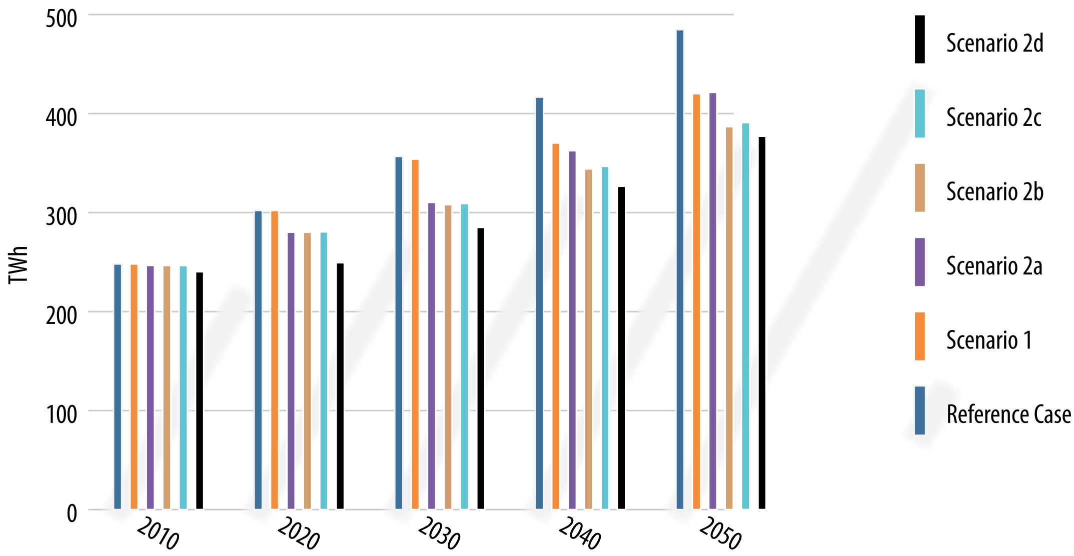


Figure 11: Electricity demand by scenario

Alternative fuels and vehicles

In understanding the challenge of predicting what fuel and engine technologies will play a role in the future of transport in Australia, two widely-held points of view need consideration:

- Australians buy a vehicle-fuel-engine combination primarily for mobility, not because they are passionate about a particular fuel
- the access that vehicle manufacturers have to new technological developments means that the transport sector has the capacity to rapidly adjust to new technology; what has been lacking has been the consumer demand to economically deploy these technologies.

Accepting these views, it is plausible that a variety of alternative fuels could achieve significant market share in the future, providing they are cost-effective (as a substitute for oil if prices rise substantially or in the context of a carbon price). Natural gas and coal could be expected to play a role given Australia has large reserves of both. In order to reduce their emissions, however, upstream capture

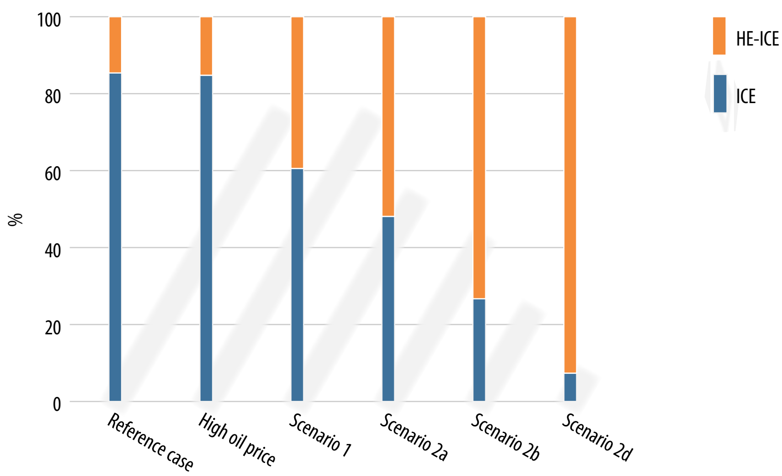


Figure 12: Projected share of internal combustion engine (ICE) and hybrid electric-internal combustion engine (HE-ICE) vehicles

and storage of CO_2 would be required, including conversion to carbon free fuels such as hydrogen. As coal and gas are traded internationally the price of domestic transport fuels derived from these primary energy sources would be subject to international price pressures.

Biofuels are another available transport fuel. Their availability will not necessarily be limited by arable land (although that is a consideration at the extreme) but rather by issues concerning availability of water, competing use of land (such as food production), potential biotechnology breakthroughs, regional development considerations and ecosystem impacts. Together, these represent a complex set of interactions, making it difficult to predict the future scale of the role of biofuels.

Electricity is the third major alternative fuel category to potentially play a role in the future of energy through the production of hydrogen or through the use of advanced storage technologies in vehicles that remove the need for liquid or gaseous fuels to be stored on board. The challenge in assessing the likelihood of electricity becoming a major transport fuel source is when and how to ensure electricity storage or fuel cell technologies will evolve to the required performance level.

In terms of engine technologies, the internal combustion engine is expected to remain dominant in the short term due to its huge economies of scale. Hybrid electric internal combustion vehicles could be expected, however, to play an increasing role, as explored in several of the qualitative scenarios and as already witnessed in its role as a niche player in the present vehicle market. The economic modelling projected significant uptake of hybrid electric vehicles by 2050 in the reference case and increasingly so with higher carbon prices (Figure 12).

The uncertainty around hybrids centres on what price point is necessary for it to achieve the same economies of scale as stand-alone internal combustion engines, (some of which achieve the same efficiencies as the hybrid) and to what extent is it a long-lasting vehicle-engine platform. In other words, how soon will the 100 per cent electric or fuel cell vehicle follow? The economic modelling did not evaluate fuel cell and electric vehicles. Past technology cycles provide some guidance but are ultimately speculative.

SECURING AFFORDABLE TRANSPORT FUELS

The challenge of securing affordable transport fuels arises because Australian households and businesses are strongly geared to liquid fuel-based transport and our current preferred fuels are subject to international price movements that have historically displayed significant volatility (Section 2, Figure 7).

Econometric studies support the notion that transport fuel consumption is relatively non-price sensitive. That is, it takes disproportionately large price movement for fuel consumption to change. The design of Australian cities and infrastructure accommodates our desire for personal mobility via passenger vehicles. Public transport has relatively low uptake. Its best uptake (which is still low) is in congested cities where it can be more convenient due to dedicated rail corridors and bus lanes.

Despite Australia's affinity for the passenger vehicle, the EFF considered that the economic risk associated with cost of transport fuel to be important in the short to medium term but not likely to be a long-term threat to economic growth. Nor is it in the same magnitude as the challenge of addressing climate change.

Australia is fundamentally energy rich, due to its extensive resource base of fossil fuels, renewables and uranium. Gas reserves are particularly important as a potential substitute for petroleum in transport applications. Likewise our deposits of coal offer potential for conversion to transport fuels such as diesel and hydrogen. While known oil reserves are declining, Australia remains relatively unexplored.

Furthermore, in the long-term, vehicle technology (either domestic or imported) can be expected to respond with significant improvements in efficiency. Given all of these long-term options, securing affordable transport fuels is about dealing with a medium-term risk.

Prior to 2004, Australians believed that A$1.00 per litre of petrol was expensive. At the time of this Report, that price is relatively appealing. To determine the economic impacts of substantially higher oil prices the EFF examined a scenario where, driven by geopolitical instability, the world experiences an oil price peak of US$100/bbl by 2014, after which the price declines to the historical trend.

To understand what price impact this scenario has at the household level the average Australian weekly fuel bill is compared in Figure 12 when prices are US$40/bbl, US$60/bbl or US$100/bbl. Note that weekly fuel costs increase proportionately less than the increase in oil prices due to excise and other factors, such as transport and refining costs, constituting a significant portion of fuel costs. To put this excise rate in the context of carbon price impacts (Figure 13) the excise rate (which is fixed at 38 cents per litre) is roughly equivalent to a carbon price of around A$170/t$CO_2$.

In terms of the broader economy, the impact of the oil price increasing to US$100/bbl is projected in the economic modelling to result in a 3.1 per cent reduction in real GDP in 2010, relative to the reference case. Output from the non-ferrous metals, air transport and iron and steel industries experience the

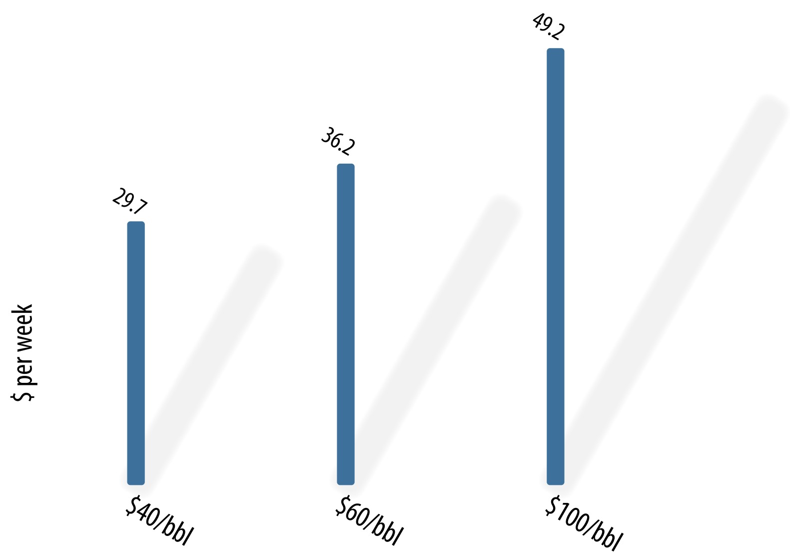


Figure 13: Impact of alternative oil price forecasts on weekly cost of petrol assuming average distance travelled of 15,000 kilometres per year (costs will vary according to exchange rate and other factors at the time)

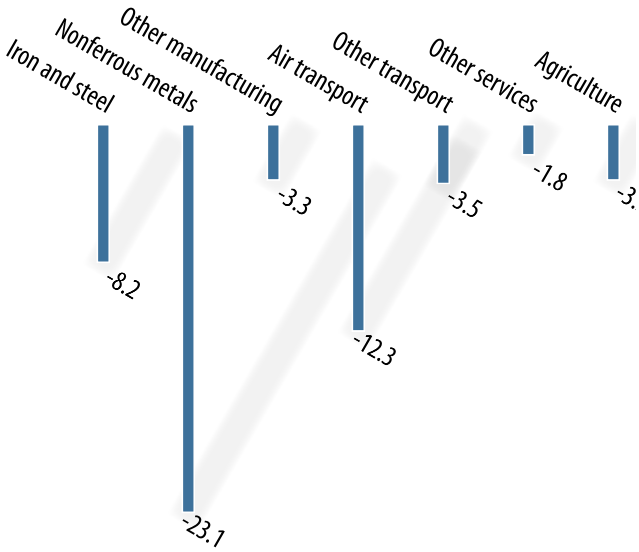


Figure 14: Changes in industry output for selected industries in 2010 under the high oil price scenario relative to the reference case

largest decline, as these industries have a relatively high exposure to oil prices in their cost structures (Figure 14).

Potential future increases in the oil price may be offset by improvements in the fuel efficiency of the average internal combustion car or new vehicle technologies, such as hybrid electric engines.

Increases in income may also cushion the effect of further increases in the price of oil. However, the offsetting effects of increases in income would not be as apparent in the climate change response scenarios 1, 2a-2d because the oil price increase occurs suddenly in the next decade (as postulated by the scenario), unlike a carbon price that increases in stages over a 45-year period. In this case, the projected real income per capita increase is only a factor of 10 per cent compared to the present day, which is insufficient to offset the estimated 44 per cent increase in single passenger vehicle weekly fuel costs.

There are a number of demand side measures that could reduce the economic risks of exposure to the international price of oil. Urban structures, for example, that support a greater uptake of public transport could reduce the economic impact of high oil prices. Similarly, mandated energy efficiency targets for vehicles already exist in a number of different parts of the world – including, for example California, a society seemingly as wedded as Australia is to the private vehicle as the main form of transport. Many of the qualitative scenarios developed by the EFF explored substantial changes in city design and the culture of mobility.

The role of Intelligent Transport Systems (ITS) in being able to inform consumers, assist planners and traffic managers, improve public transport performance, enhance fuel efficiency and also the efficiency of personal and freight transport also has potential. There are many successful cases of ITS applied to CO_2 reductions but more will need to be done to drive the social acceptance of ITS as a contributor.

There are also many potential alternative fuel and engine technologies that could be explored, some of which also have benefits for addressing climate change. The economic modelling projected an increasing role of a selected set of alternative fuels (Figure 15). Discovering more oil in Australia would not reduce exposure to high oil prices per se since any new oil would be sold at international prices. However, it would be expected to reduce the impact of high oil prices on our net value of trade, thus reducing impacts on the overall economy.

Current government policies that address resilience to oil price changes include preferential treatment of excise for alternative fuels (including biofuels) and subsidies for LPG engine conversions or new vehicles. Securing affordable transport fuels may require such ongoing government intervention. Consideration would need to be given to whether the current excise regime could provide further incentives to all users.

While existing measures are recognised as important, there is a small risk that the volatility of oil prices may retard the additional investment in preparatory action required to make Australia more resilient to future price variations.

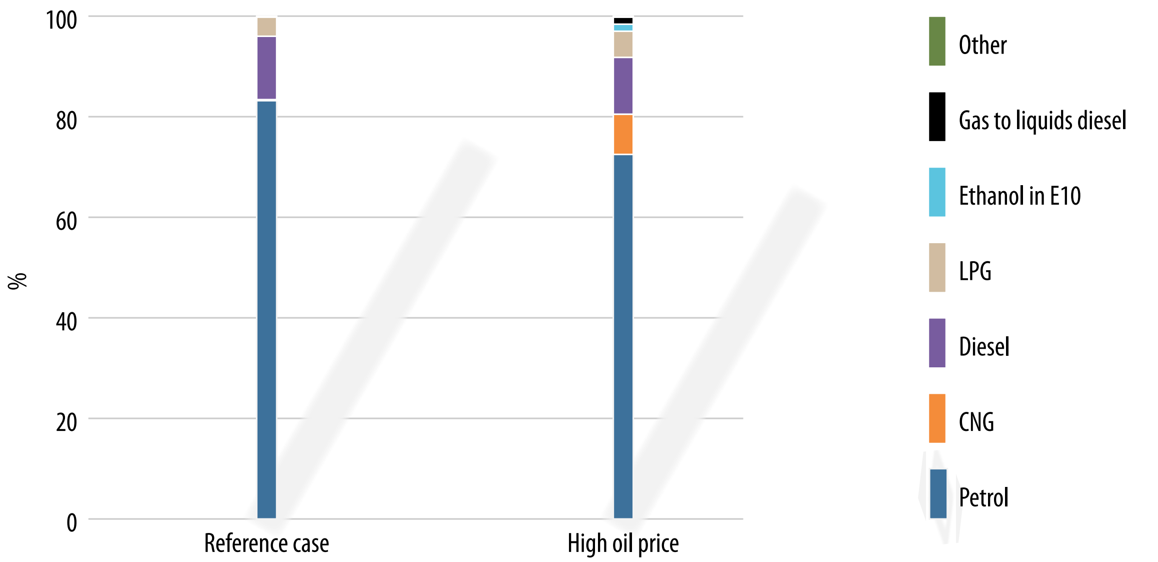


Figure 15: Uptake of alternative fuels in 2010 under high oil price scenario

ABBREVIATIONS AND ACRONYMS

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AGO	Australian Greenhouse Office
ANUCLIM	Australian National University climate software model
bbl	barrel
Bcm	billion cubic metres
°C	degrees celsius
CCS	carbon capture and storage
CIS	Commonwealth of Independent States
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CNG	compressed natural gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EDR	Economic Demonstrated Resources
EFF	Energy Futures Forum
EJ	etajoules
ESM	Energy Sector Model
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
GL	gigalitres
GMT	global mean temperature
GSP	Gross State Product
Gt	gigatonne (billion tonnes)
GTEM	global trade and environment model (ABARE)
GW	gigawatt (one billion watts)
GWh	gigawatt hours
HE-ICE	hybrid electric internal combustion engine
ICE	internal combustion engine
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
ITS	Intelligent Transport Systems
Kt	kilotonnes
kW	kilowatt
kWh	kilowatt hour
LNG	liquefied natural gas
LPG	liquefied petroleum gas
Mt	megatonne
MW	megawatt
NEA	Nuclear Energy Agency
NEM	National Electricity Market
NEMMCO	National Electricity Market Management Company (Australia)
NGCC	natural gas combined cycle
NGO	Non government organisation
OECD	Organization for Economic Cooperation and Development
PF	pulverised fuel
PJ	petajoules
PJ/y	petajoules per year
ppm	parts per million
SRES	Special Report on Emission Scenarios (IPCC 2006)
t CO_2e	tonnes of carbon dioxide equivalent
THC	Thermohaline Circulation
TIR	Total Identifiable Resources
TWh	terawatt hour
TWh/y	terawatt hours per year
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council on Sustainable Development
WRI	World Resources Institute

GLOSSARY

abatement	Reduction of greenhouse gas emissions.
anthropogenic	Attributable to human activity.
atmospheric concentration of greenhouse gases	A per unit volume of the amount of greenhouse gases present in the Earth's atmosphere.
base load	Minimum amount of power that is demanded constantly throughout a day; includes lighting, industrial processes, heating, appliance stand-by power and 24-hour commercial services. (See also peak load and mid load.)
carbon capture and storage (CCS)	The capture of carbon dioxide from power generation plants or other sources with subsequent permanent storage in geological sites, in this report, CCS does not include ocean storage.
carbon dioxide (CO_2)	The principal anthropogenic greenhouse gas.
carbon leakage	A process whereby emission intensive production moves from countries (or regions) under a constraint to countries (or regions) without such a constraint – as a result, emission abatement in one region is offset by increased emissions elsewhere.
coking coal	Coal used for making coke that is then used to make steel.
ferrous metals	Metals containing iron, including carbon steel and stainless steel.
fossil fuel	Fuel extracted from a hydrocarbon deposit that was derived from living matter in the remote geological past – petroleum, coal and natural gas.
integrated coal gasification combined cycle (IGCC)	An alternative to coal combustion is coal gasification. When coal is brought into contact with steam and oxygen, thermochemical reactions produce a fuel gas, largely carbon monoxide and hydrogen, which when combusted can be used to power gas turbines.
gigatonne	One billion tonnes.
greenhouse gas	A gas that contributes to the warming of the Earth's atmosphere by reflecting radiation from the Earth's surface; for example, carbon dioxide.
hydrogen	Colourless, odourless, flammable gas,
mid load	Amount of power demanded above base load, but outside of the regular peak period, when demand is moving up or down.
mitigating climate change	Activities that reduce greenhouse gas emissions and, thereby, reduce CO2 concentration in the atmosphere.
mode	Plants with an utilisation rate of around 40 per cent.
natural gas combined cycle (NGCC)	An electricity generation plant that burns natural gas in a turbine, with the waste gases recovered and sued to generate additional electricity in a steam cycle.
non-ferrous metals	Metals that do not contain iron, including aluminium, copper, silver and lead.
peak load	Electricity consumed at times when many uses demand electricity at the same time; peaks are regular seasonal, weekly or daily increases in demands.
pulverised fuel	Pulverised fuel (PF) combustion is the most widely used method for burning coal for power generation. In PF combustion, coal is milled to a powder and blown into the boiler with air. As a powder, the coal has a large surface area and is easily combusted in burners. This provides the heat that is used to produce superheated steam to drive turbines and hence generate electricity. At present, nearly all of the world's coal-fired electricity is produced using PF combustion systems.
renewable electricity	Electricity derived from natural processes – for example, solar, wind, hydropower, geothermal and biomass.
sequestration	The storage of carbon dioxide in terrestrial, geological or ocean sites.
sub-critical pulverised fuel	Pulverised fuel plants operating under conventional pressure conditions.
super-critical pulverised fuel	Pulverised fuel plants that operate at a higher pressure.
thermal coal	Coal used in generating electricity.

REFERENCES

Australian Bureau of Agricultural and Resource Economics 2003, 'Australian Energy: National and State Projections to 2019-2', *ABARE eReport 03.10*, ABARE, Canberra.

— 2005a, *Australian Commodity Statistics 2005*, ABARE, Canberra.

— 2005b, 'Australian Energy: National and State Projections to 2029-30', *ABARE eReport 05.9*, ABARE, Canberra.

— 2006a, *Australian energy statistics*, ABARE, Canberra, http://www.abareconomics.com/interactive/energy/index.html

— 2006b, *Australian Commodities*, vol. 13, no.3, ABARE, Canberra.

Australian Bureau of Statistics 2006, *Australian Social Trends 2006*, ABS No. 4102, ABS, Canberra, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4102.02006?OpenDocument

Australian Greenhouse Office 2006, National Greenhouse Gas Inventory 2004, AGO, Canberra http://www.greenhouse.gov.au/inventory/2004/pubs/inventory2004.pdf

Ahammad H, Matysek A, Fisher BS, Curttoti R, Gurney A, Jakeman G, Heyhoe E and Gunasekera D 2006, *Economic Impact of Climate Change Policy: The role of Technology and Economic Instruments*, ABARE Research Report 06.7, Canberra.

Australian Nuclear Science and Technology Organisation 2006, *Introducing Nuclear Power to Australia: An Economic Comparison*, ANSTO, Canberra. http://www.ansto.gov.au/ansto/nuclear_options_paper.pdf.

Arnell NW 1999, 'Climate change and global water resources', *Global Environmental Change*, 9, S31-S46.

Ashworth P, Littleboy A, Thambimuthu K, Pisarski A and Beath A *Understanding and incorporating stakeholder perspectives to low emissions technologies in Australia*. Paper presented to the Greenhouse Gas Technologies 2006 conference in Trondheim, Norway, July 2006.

Australian Business Roundtable on Climate Change 2006, *The Business Case for Early Action*

Austroads 2004, *Impact of Climate Change on Road Infrastructure*. Austroads Report AP-R243, 121 pp. http://www.btre.gov.au/docs/joint_reports/climate_change.pdf

Berkelmans R, De'ath G, Kininmonth S and Skirving WJ 2004, 'A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns, and predictions', *Coral Reefs*, 23, 74–83

Beaumont LJ and Hughes L 2002, 'Potential changes in the distributions of latitudinally restricted Australian butterfly species in response to climate change', *Global Change Biology*, 8, 954–971.

Brereton R, Bennett S and Mansergh I 1995, 'Enhanced greenhouse climate change and its potential effect on selected fauna of southeastern Australia: a trend analysis', *Biological Conservation*, 72, 339–354.

Brown SR 1980, *Political Subjectivity: Applications of Q methodology in political science*. New Haven: Yale University Press.

Cary GJ 2002, 'Importance of changing climate for fire regimes in Australia', in Bradstock RA, Williams JE and Gill AM (Eds), *Flammable Australia: The Fire Regimes and Biodiversity of A Continent*, Cambridge University Press, Cambridge UK, 26–46.

Commonwealth of Australia 2006, *Uranium Mining, Processing and Nuclear Energy – Opportunities for Australia*?, Report to the Prime Minister by the Uranium Mining, Processing and Nuclear Energy Review Task Force.

Cooke M 2000, 'Five Arguments for Deliberative Democracy', *Political Studies*, vol. 48, no. pp. 947-969

Crimp S, Balston J, Ash A, Anderson-Berry L, Done T, Griner R, Hilbert D, Howden M, Jones R, Stokes C, Stoeckl N, Sutherst N, and Whetton P 2004, *Climate Change in the Cairns and Great Barrier Reef Region: Scope and Focus for an Integrated Assessment*, Australian Greenhouse Office, 100pp.

Crimp SJ, Flood NR, Carter JO, Conroy JP, and McKeon GM 2002, *Evaluation of the Potential Impacts of Climate Change on Native Pasture Production – Implications for Livestock Carrying Capacity*, Australian Greenhouse Office, Canberra, 54 pp.

CSIRO and Melbourne Water 2005, *Implications of Climate Change for Melbourne's Water Resources*, Melbourne Water, Melbourne, 26 pp.

Dryzek JS 2000, *Deliberative Democracy and Beyond: Liberals, Critics, Contestations*, Oxford: Oxford University Press.

Dryzek J S 1990, *Discursive Democracy: Politics, Policy and Political Science*, Cambridge: Cambridge University Press.

Energy Efficiency and Greenhouse Working Group 2003, Towards a National Framework for Energy Efficiency – Issues and Challenges Discussion Paper, http://www.nfee.gov.au/about_nfee.jsp?xcid=64

Energy Strategies 2004, *A Clean Energy Future for Australia*, Clean Energy Future Group, http://www.wwf.org.au/publications/clean_energy_future_report/.

Electricity Supply Association of Australia 2004, Electricity Prices in Australia 2002/2003, ESSA, Melbourne.

— 2006, *Electricity Gas Australia 2006*, ESAA, Melbourne.

Geoscience Australia 2006a, *Oil and Gas Resources of Australia 2004*, Geoscience Australia, Canberra.

— 2006b, *Australia's Identified Mineral Resources 2006*, Geoscience Australia, Canberra.

CSIRO and ABARE 2006, *Modelling Energy Futures Forum Scenarios Using ESM*, CSIRO, Canberra.

Greenpower 2006, *Facts and Stats: Audits and Reports*, http://greenpower.gov.au/pages/Facts-Uptake.php

Grubler A, Nakicenovic N and Victor DG 1999, 'Dynamics of energy technologies and global change', *Energy Policy*, vol. 27, pp247-280

Hales, S., de Wet, N., Maindonald, J. and Woodward, A. 2002, *Potential Effect Of Population And Climate Changes On Global Distribution Of Dengue Fever: An Empirical Model*, The Lancet, 360, pp 830–834

Hare W 2003, *Assessment of Knowledge on Impacts of Climate Change – Contribution* *to the Specification of Art. 2 of the UNFCCC*, WGBU, Berlin, http://www.wbgu.de/wbgu_sn2003_ex01.pdf

Hassall and Associates 1998, *Climate Change Scenarios and Managing the Scarce Water Resources of the Macquarie River Basin*, Australian Greenhouse Office, Canberra, 114 pp.

Hennessy K, McInnes K, Abbs D, Jones, R, Bathols J, Suppiah R, Ricketts J, Rafter T, Collins D and Jones D 2004, *Climate Change in New South Wales, Part 2: Projected Changes in Climate Extremes*, consultancy report for the New South Wales Greenhouse Office by the Climate Impact Group of CSIRO Atmospheric Research and the National Climate Centre of the Australian Government Bureau of Meteorology, 79 pp.

Hennessy, K, Page C, McInnes K, Walsh K, Pittock B, Bathols J and Suppiah R 2004, *Climate Change in the Northern Territory*, consultancy report undertaken for the Northern Territory Department of Infrastructure, Planning and Environment by the Climate Impact Group, CSIRO Atmospheric Research, Melbourne.

Hilbert DW, Bradford M, Parker T and Westcott DA 2004, Golden bowerbird (*Prionodura newtonia*) habitat in past, present and future climates: predicted extinction of a vertebrate in tropical highlands due to global warming. *Biological Conservation*, 116, 367

Hilbert DW, Ostendorf B and Hopkins M 2001, Sensitivity of tropical forests to climate change in the humid tropics of North Queensland, *Austral Ecology*, 26, 590–603.

Howden SM and Crimp S 2001, Effect of climate and climate change on electricity demand in Australia. In: *Integrating Models for Natural Resources Management Across Disciplines, Issues and Scales*, Proceedings of the International Congress on Modelling and Simulation, December 2001, Canberra. Ghassemi F, Whetton P, Little R and Littleboy, M, (Eds.), Modelling and Simulation Society of Australia and New Zealand, Canberra, 655–660.

Howden SM and Jones RN 2001, *Costs and benefits of CO_2 increase and climate change on the Australian wheat industry*, Australian Greenhouse Office, Canberra, Australia.

Hughes L, Cawsey EM and Westoby M 1996, Geographic and climatic range sizes of Australian eucalyptus and a test of Rapoport's rule, *Global Ecology and Biogeography Letters*, 5, 128–142.

International Energy Agency 2006, *Coal Information 2005*, IEA, Paris

— 2006, *Energy Technology Perspectives-Scenarios and Strategies to 2050*, IEA, Paris.

IEA Greenhouse Gas R&D Program 2000, the potential of wind energy to reduce CO2 emissions, Report number PH3/24, IEA Greenhouse Gas R&D Program.

International Energy Agency /Nuclear Energy Agency 2005, *Projected Costs of Generating Electricity - 2005 Update*, International Energy Agency, Paris.

IPCC 2001a, *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Houghton, JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, and Johnson CA (eds.), Cambridge University Press, Cambridge, UK and New York, USA, 881 pp.

— 2001b, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, McCarthy JJ, Canziani OF, Leary NA, Dokken DJ and White KS (Eds.), Cambridge University Press, Cambridge, UK, and New York, USA, 1032 pp.

— 2001c, *Climate Change 2001: Synthesis Report*. Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Watson RT and the Core Writing Team (Eds), Cambridge University Press, Cambridge, UK and New York, USA.

IPCC WGI, 2004, *Workshop on Climate Sensitivity*, IPCC Working Group I Technical Support Unit, Boulder Colorado, 177 pp.

Jones RN 2004b, 'Incorporating agency into climate change risk assessments', *Climatic Change*, 67, 13–36.

Jones RN and Hennessy KJ 2000, *Climate Change Impacts in the Hunter Valley – A Risk Assessment of Heat Stress Affecting Dairy Cattle*, CSIRO Atmospheric Research report for the New South Wales Government, 26 pp.

Jones RN and Page CM 2001, Assessing the risk of climate change on the water resources of the Macquarie River Catchment, in Ghaseemi F, Whetton P, Little R, and Littleboy M (Eds.), *Integrating Models for Natural Resources Management across Disciplines, Issues and Scales (Part 2),* Modsim 2001 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Canberra, 673–678.

Jones RN and Preston BL 2006, *Climate change impacts, risk and the benefits of mitigation*, A report for the Energy Futures Forum, CSIRO Marine and Atmospheric Research, Melbourne, Victoria.

Kirschbaum MUF 1999, 'The effect of climate change on forest growth in Australia. In', *Impacts of Global Change on Australian Temperate Forests*, Howden, SM and Gorman, JT (Eds), Working Paper Series 99/08, CSIRO Wildlife and Ecology, Canberra, 62–68.

Lovel R, Katz E, Solomon FL 2004, 'Participation processes for the minerals industry' CSIRO *Minerals Report DMR-2375*, Melbourne, Australia.

Lowy Institute 2006, *Key findings of a multination public opinion survey in the Asia-Pacific from an Australian perspective*, The Lowy Institute and the Chicago Council on Global Afffairs, http://www.lowyinstitute.org/Publication.asp?pid=484

Matysek A, Ford M, Jakeman G, Gurney A and Fisher BS 2006, *Technology: Its Role in Economic Development and Climate Change*. ABARE Research Report 06.6, Prepared for Australian Government Department of Industry, Tourism and Resources. ABARE, Canberra, 109 pp.

McInnes KL, Suppiah R, Whetton P.H, Hennessey KJ, and Jones RN 2002, *Climate Change in South Australia*, consultancy report undertaken for the South Australian Government by the Climate Impact Group, CSIRO Atmospheric Research, Aspendale, VIC.

McInnes KL, Walsh KJE, Hubbert GD, and Beer T 2003, 'Impact of sea-level rise and storm surges on a coastal community', *Natural Hazards*, 30, 187–207.

McInnes KL, Macadam I, Hubbert GD, Abbs DJ and Bathols J 2005, *Climate Change in Eastern Victoria, Stage 2 Report: The Effect of Climate Change on Storm Surges*, a consultancy report undertaken for the Gippsland Coastal Board by the Climate Impacts Group, CSIRO Atmospheric Research.

McKibbin W 2005, *Sensible Climate Policy*, Issues Brief, February, The Lowy Institute for International Policy, Sydney

McMichael AJ, Woodruff R, Whetton P, Hennessy K, Nicholls N, Hales S, Woodward A, and Kjellstrom, T 2003, *Human Health and Climate Change in Oceania: A Risk Assessment*. Commonwealth Department of Health and Ageing, Canberra, 128 pp.

Mendelberg T 2002, 'The Deliberative Citizen: Theory and Evidence' in Carpini MD, Huddy L and Shapiro RY (eds), *Research in Micropolitics, Volume 6: Political Decision Making, Deliberation and Participation*. Elzever Press, 151-193.

Mendehlsohn R and Williams L 2004, 'Comparing forecasts of the global impacts of climate change', *Mitigation and Adaptation Strategies for Global Change*, 9, 315–333.

Massachusetts Institute of Technology 2003, *The Future of Nuclear Power: An interdisciplinary MIT study*, MIT, Cambridge, Massachusetts. http://web.mit.edu/nuclearpower/

Monash University Accident Research Centre 1993, *Vehicle Mass, Size and Safety*, Report prepared for Federal Office of Road Safety, Canberra.

National Emissions Trading Taskforce 2006, *Discussion paper: Possible design for a national greenhouse gas emission trading scheme*, NETS, Canberra http://www.emissionstrading.net.au/key_documents/discussion_paper

O'Hara TD 2002, 'Endemism, rarity and vulnerability of marine species along a temperate coastline', *Invertebrate Systems*, 16, 671–684.

Page, B, CEO Energy Supply Association of Association, Interview on ABC PM program 27, October 2005

Pouliquen-Young O and Newman P 2000, *The Implications of Climate Change for Land-based Nature Conservation Strategies*, Final Report 96/1306. Australian Greenhouse Office, Environment Australia, Canberra and Institute for Sustainability and Technology Policy, Murdoch University, Perth.

Somerville M, Wyborn D, Chopra PN, Rahman SS, Estrella D and van der Meulen T 1994, *Hot Dry Rocks Feasibility Study*. ERDC Australia, Report 94/243.

Stern N, Peters S, Bakhshi V, Bowen A, Cameron C, Catovsky S, Crane D, Cruickshank S, Dietz S, Edmondson N, Garbett S, Hamid L, Hoffman G, Ingram D, Jones B, Patmore N, Radcliffe H, Sathiyarajah R, Stock M, Taylor C, Vernon T, Wanjie H, and Zenghelis D 2006, *Stern Review on the Economics of Climate Change*, Cambridge University Press.

Suppiah R, Whetton PH and Hennessy KJ 2001, *Projected Changes in Temperature and Heating Degree-days for Melbourne, 2003-2007: A Report for GasNet*, CSIRO Atmospheric Research, Aspendale, VIC, 19 pp.

Suppiah R, Whetton PH and Watterson G 2004, *Climate Change in Victoria*, a consultancy report undertaken for the

Victorian Department of Sustainability and Environment by the Climate Impacts Group, CSIRO Atmospheric Research.

Sutherst RW 2000, *Pests and Pest Management: Impact of climate change*, Report No 00/16 Rural Industries Research and Development Corporation, Canberra, 34 pp.

Sutherst RW, Collyer BS and Yonow T 2000, The vulnerability of Australian horticulture to the Queensland fruit fly, *Bactrocera* (Dacus) *tryoni*, under climate change, *Australian Journal of Agricultural Research*, 51, 467–480.

Swiss Re Insurance, 'Natural catastrophes and man-made disasters in 2004', *Sigma No 1/2005*, Swiss Re.

Thomas MH 2002, *Energy and energy intensive industry*, Proceedings, Living with Climate Change Conference, Canberra, 19 December 2002, National Academies Forum, Canberra.

University of Chicago 2004, *The Economic Future of Nuclear Power*, http://www.anl.gov/Special_Reports/NuclEconSumAug04.pdf.

US Department of Defense 2003, *A Strategy: Moving America Away From Oil: Technology Fuel Efficiency*, Office of Net Assessment, Office of the Secretary of Defense

White NA, Sutherst RW, Hall N and Wish-Wilson P 2003, 'The vulnerability of the Australian beef industry to impacts of the cattle tick (*Boophilus microplus*) under climate change', *Climatic Change*, 61, 157–190.

Williams AA, Karoly DJ, and Tapper N 2001, 'The sensitivity of Australian fire danger to climate change', *Climatic Change*, 49, 171–191.

Williams SE, Bolitho EE, Fox S 2003, 'Climate change in Australian tropical rainforests: an impending environmental catastrophe', *Proceedings Of The Royal Society Of London Series B-Biological Sciences*, 270, 1887–1892.

Williams SE and Hilbert DW 2004, Climate change threats to the biological diversity of tropical rainforests in Australia', in Laurance WF and Peres C (eds) *Emerging Threats to Tropical Forests*, in press.

Woodruff D, Hales S, Butler C and McMichael A 2005, *Climate Change Health Impacts in Australia: Effects of Dramatic CO2 Emissions Reductions*, Australian Conservation Foundation and the Australian Medical Association, Australia.

World Resources Institute 2006, *Navigating the Numbers: Greenhouse Gas Data and International Climate Policy*, WRI, Washington

World Trade Organization 2004, *World Trade Report: Exploring the linkage between the domestic policy environment and international trade*, number 37 http://www.wto.org/english/res_e/booksp_e/anrep_e/world_trade_report04_e.pdf