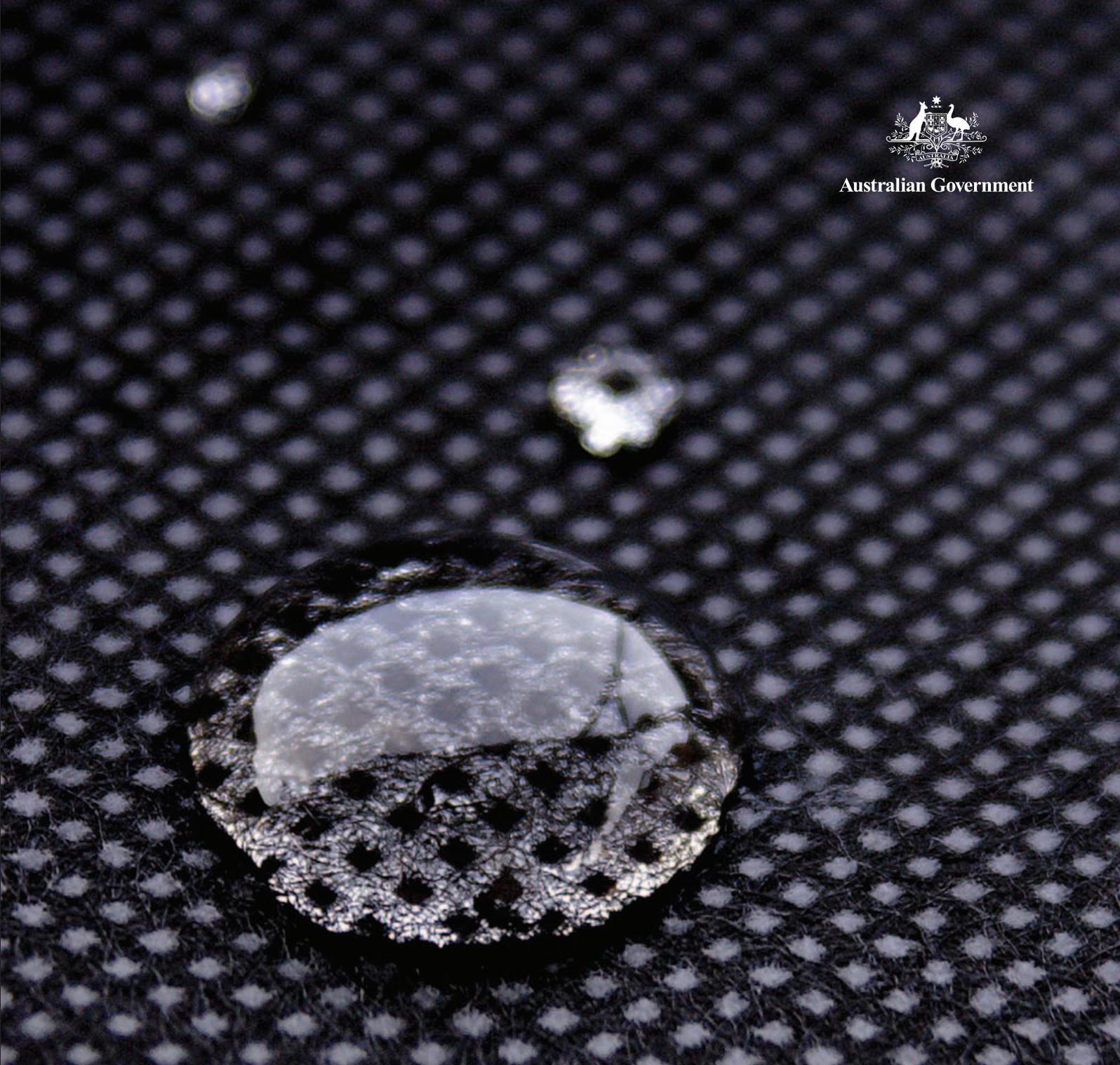




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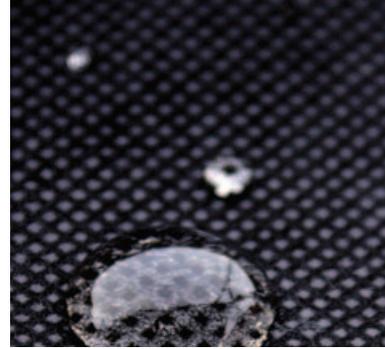
Challenges at Energy-Water-Carbon Intersections

PMSEIC

Challenges at Energy-Water-Carbon Intersections

Report of the PMSEIC Expert Working Group

October 2010



Citation: PMSEIC (2010). *Challenges at Energy-Water-Carbon Intersections*. Prime Minister's Science, Engineering and Innovation Council, Canberra, Australia

Acknowledgements

The Expert Working Group would like to express appreciation to the Office of the Chief Scientist for both initiating and supporting this work. Special thanks go to the Chief Scientist for Australia, Professor Penny D Sackett, for her leadership, and also to the support staff of the Office for their dedication, skill and patience. We particularly wish to thank Will Howard, Amelia Russin and Sarah White, who have given outstanding service in the final, hectic stages of preparing this report.

We thank Dr Julie Arblaster of the Bureau of Meteorology for producing the analysis of climate model projections shown in *Figures 2.4* and *2.5*; Dr Peter Briggs of CSIRO Marine and Atmospheric Research for assistance with graphics and database management; Dr Paul Graham of CSIRO Energy Technology for the energy projections in *Figures 4.1*, *4.3* and *4.4*; and Dr Brian Walker of CSIRO Ecosystem Sciences for information on resilience thinking.

We would also like to thank representatives from the Department of Innovation, Industry, Science and Research; the Department of Agriculture, Fisheries and Forestry; the Department of Climate Change and Energy Efficiency; the Department of Resources, Energy and Tourism; the Department of Sustainability, Environment, Water, Population and Communities; and the National Water Commission for providing information on current government programs.

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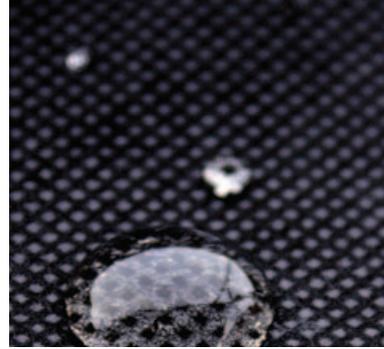
A report for the Prime Minister's Science, Engineering and Innovation Council (PMSEIC)

This report has been prepared by the independent PMSEIC Expert Working Group on Challenges at Energy-Water-Carbon Intersections. The views expressed in this report are those of the Expert Working Group and not necessarily those of the Australian Government.

Cover design by Dan Stenhouse.

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Foreword from the Chair

This is a vast topic: the energy-water-carbon intersection is the cradle of life and sustains all ecosystems and all human societies. It is also perhaps the most important arena for the continued prosperity and quality of life of the entire world, including Australia, as we enter what can be called the 'century of the finite planet'. In this era the world is fully connected in many ways: by trade, by information technology, and most fundamentally by sharing a common planetary home with finite natural resources. The twenty-first century will be shaped by the finite nature of our planet and its resources, just as industrialisation shaped the nineteenth and technology the twentieth centuries.

For the whole Expert Working Group charged with preparing this report, it has been a privilege to work on what we believe is the central challenge of our age.

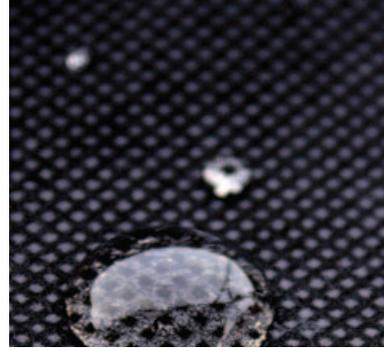
In addressing this task we have been led to base our work on two underpinning concepts. The first is the need for an integrative approach to energy, water and carbon, which together play essential and intersecting roles in the total system formed by the natural environment and human society. The second is the concept of system resilience, embodying the abilities to recover from shocks, to adapt through learning and to undergo transformation when necessary. All of these abilities will be critical as Australia faces the challenges of coming decades, many of which will require transformative changes.

It is inevitable that a study of this nature cannot explore all important issues in the necessary depth. We have had to take a broad approach to important technical questions on the costs and benefits of specific strategies, and the interactions between strategies. Many other high-level questions are worthy of further intensive exploration, including risk analyses of climate change, approaches to the problem of sharing emissions reductions, the effects of potential global oil shortages, and the reliability and longevity of land-based carbon sequestration. Our recommendations include development of the integrative approaches that are needed to answer these and related crucial questions.

We wish to record our appreciation to our colleagues, who have taken up the burdens of day-to-day working life as we have been engaged on this project, and above all to our partners and families, who have supported us throughout and accepted our absences and distractions with grace.



Michael Raupach (Chair)
on behalf of the PMSEIC Expert Working Group on Challenges at Energy-Water-Carbon Intersections



Executive Summary and Recommendations

Intersections between energy, water and carbon

Energy, water and carbon form the cradle of life itself, and sustain us at every level from the cells of our bodies to ecosystems and economies. Together, energy, water and carbon provide the foundation for the evolutionary emergence of new forms from old ones, not only in living organisms but also in human societies and cultures.

New global phenomena are emerging at these intersections. Economic growth has been powered through two centuries by cheap energy based on fossil fuels. This growth has been accompanied by emissions of carbon dioxide (CO₂) and other greenhouse gases (GHGs), which are now leading to human-induced climate change. An increasing human population is requiring more water and other natural resources, to the point where demand in many regions is approaching or exceeding the supply from nature. The world is now fully connected not only by trade and information technology, but also by sharing a common planetary home with finite natural resources—realities that will dominate the twenty-first century, as industrialisation dominated the nineteenth and technology the twentieth centuries.

This report analyses the implications of energy-water-carbon intersections for Australia. Our focus is upon the intersections between energy for human use, water for human use and carbon as a contributor to human-induced climate change through emissions of CO₂ and other GHGs.

Energy-water-carbon intersections encompass all the exchanges of energy, water and carbon between societal sectors and natural environments. These exchanges connect stationary energy systems, water systems, land systems and food production, transport systems, built environments, industrial systems, and the ecosystems upon which all these aspects of the human enterprise are based.

Intersections between energy, water and carbon arise in multiple ways, involving both supply and demand. On the supply side, energy systems use water; water systems use energy; current energy generation is GHG-intensive; and land uses for food, fibre and energy production all require water. On the demand side, energy consumption and GHG emissions have in the past increased together inexorably as wealth has increased.

Resilience

The challenge for Australia is unique. We are a developed nation with high growth rates for population, energy use and GHG emissions, approaching those of the developing world. Along with the rest of the world, we face the challenge of largely decarbonising our economy within a few decades if risks from climate change are to be kept acceptably low (*decarbonisation* is the reduction and eventual elimination of net GHG emissions). We inhabit a dry continent with high water demands for urban, industrial and agricultural uses. We also need water to maintain and repair ecosystems.

The implications of all of these realities need to be addressed to ensure future prosperity for Australia. The connections between energy, water and carbon mean that these challenges are not separate issues: attempts to fix a problem in one area without regard for effects elsewhere can have unintended consequences that may make matters worse overall.

Great challenges also represent great opportunities. Australia can find paths to a future combining a low-carbon economy and the ability to thrive with limited water availability.

A key characteristic of such a future is resilience. This embodies three attributes:

- *The ability to recover*: Resilience is achieved by ensuring the ability to recover from shocks and jolts, rather than trying to prevent them. Building resilience requires a focus on the retention of diversity and redundancy, as opposed to the maximisation of short-term efficiency.
- *The ability to adapt to change by learning*: Resilience depends on adaptive learning, through diversification and selection of successful strategies. This means that failures in resilient systems are essential: they need to occur safely, early and often.
- *The ability to transform*: At a 'fork in the road', a resilient system can transform and reconfigure itself. This may mean the adoption of new ways of thinking and doing, rather than being constrained by technological or philosophical inertia.

At energy-water-carbon intersections, resilience takes advantage of potential synergies and addresses tensions. Resilient pathways will simultaneously reduce GHG emissions, lower overall water demand, maintain overall environmental quality and allow living standards to continue to improve. In contrast, pathways that are inconsistent with resilience have the potential to satisfy only some of these essential goals, while worsening the outcome for others. Such pathways may lead to undesirable states from which recovery is difficult.

Sectoral and holistic approaches

Across energy, water, land, urban and industrial sectors there are many options to increase Australia's future energy and water security while lowering emissions, thereby increasing overall resilience. Some of these options can be implemented quickly by exploiting existing technologies. Others involve long-term transformations such as significant technological developments on the supply side, institutional and regulatory changes, or behavioural changes to alter patterns of demand.

While the challenges and opportunities *within* sectors are great, the linkages *between* sectors present further, important challenges. Because of these linkages, a whole-of-system approach to energy-water-carbon challenges is critical. This involves both market and non-market strategies.

Market-based strategies incorporate prices on carbon and water that reflect and transmit the full, linked costs and benefits of energy, water and carbon. However, some impediments to change cannot be overcome by markets alone, such as social barriers, institutional distortions, technological inertia and lock-in, and insufficient investment in innovation. Non-market strategies for overcoming these impediments include:

- regulation of water consumption and GHG emissions, such as mandated efficiency standards or measures to limit peak usage rates
- facilitation of behavioural change through education and incentives
- support for effective innovation, through knowledge generation and application to diversify the range of available options.

Key Recommendations

The five recommendations of the Expert Working Group address major components of an overall path to energy-water-carbon resilience for Australia: (1) consistent principles for the use of finite resources of water and carbon emissions; (2) improving the distribution and use of energy and water with smart networks; enhancing the energy-water-carbon sustainability of (3) landscapes and (4) the built environments in cities and towns; and (5) enhancing Australia's knowledge and learning capabilities to meet new demands for integrative knowledge.

All of the recommendations span sectors and industries. Our focus is on developing the knowledge, systems and approaches needed to address challenges that demand long-term transformations, rather than advocating particular solutions in particular places.

The recommendations cover a range of time scales, from short-term and focused to long-term and transformational. While the recommendations are designed as a complete set, implementation begins with short-term steps. This does not lessen the importance of long-term recommendations, but it does mean that not everything has to be done at once.

Recommendation 1: Consistent principles for the use of finite resources

Energy, water and emerging carbon markets already exist, each with the potential to foster desired technological and behavioural adaptations. However, energy-water-carbon linkages require that these markets, and their non-market environments, all function under consistent guiding principles for the use of finite resources.

The Expert Working Group recommends that consistent principles for finite resource use be developed and implemented for energy, water and carbon. These principles will ensure that (1) markets transmit full, linked, long-term costs to society; (2) accounting is comprehensive and consistent with natural constraints and processes; and (3) markets work together with non-market strategies, including implementation of robust governance arrangements, promotion of behavioural change and effective regulation of use.

Outcomes: The goal is to ensure that finite resources are used effectively, efficiently and in ways that are consistent with long-term sustainability and resilience.

Consistent pricing principles will ensure that the costs of using finite common resources are properly recognised and met rather than hidden and deferred to cause problems in the future. To do this, it is necessary that markets, regulations, institutional arrangements and decisions about infrastructure reveal the full costs and benefits implied by energy-water-carbon linkages. These costs and benefits can then be shared efficiently throughout cycles of production, distribution, consumption and re-use.

Important linkages that can be recognised by market mechanisms include the use of energy (with associated emissions) to supply water, for example through desalination or energy-intensive recycling; the use of water to mitigate GHG emissions, for example through carbon forestry that decreases catchment runoff; and the links between energy (with associated emissions) and water consumption in urban environments.

Comprehensive, rigorous and transparent accounting for energy, water resources, GHG emissions and carbon stocks will enable administrative systems to identify and avoid perverse effects.

Non-market strategies also need to be consistent with principles governing energy, water and carbon markets. These strategies include the regulatory environment, administrative arrangements, communication and education programs, building codes, planning controls and efficiency standards.

Steps to implementation: Implementation of this recommendation begins with (1) an assessment of the essential principles for finite resource use that need to underpin energy, water and carbon management policies. This will lead to (2) development of and agreement on a set of consistent guiding principles for pricing, accounting and non-market strategies; (3) evaluation of the consequences of these principles for governance and regulation; and (4) a timetable for transition from the existing set of arrangements to one that can be relied upon to send clear pricing, accounting and other information to users.

An example of a possible outcome of this process would be a National Energy and Water Efficiency Target scheme, combining state and federal rebates, incentives and regulations affecting purchase decisions under a single point of entry for the public. This would make price and incentive signals consistently visible to the public. The design of such a scheme would flow from the consistent principles called for in this recommendation.

An essential foundation for these principles is a price on carbon, as for water and energy.

A second foundation is a set of national monitoring and accounting systems for energy, water and carbon that are comprehensive, consistent, inclusive of both natural and human components, and appropriately linked. This is addressed in *Recommendation 5*.

Recommendation 2: Smart networks for energy and water systems

This recommendation proposes the development of parallel smart networks for electricity, gas and water in the urban domain, and the uptake of smart network technology in irrigation. Applied to electric power, a smart grid uses information technology (IT) to improve the efficiency of power generation, transmission, distribution and use. Smart networks can apply the same principles to gas and water systems. Trials of smart network technology for electricity are already under way.

The Expert Working Group recommends (1) the design, testing and assessment of smart networks for electricity, gas and water, through a research and implementation program leading to commercial demonstration; and (2) the application of smart network technology to improve distribution efficiency and water productivity in irrigation.

Outcomes: In urban environments, the program will lead to *more efficient distribution*, particularly in the effective integration of intermittent and distributed renewable energy sources into existing networks; *facilitation of behavioural change* through the provision of information on usage rates and costs of water, energy and GHG emissions; *more effective markets*, which need to evolve together with smart networks, so that real-time information conveys the most appropriate incentives to customers; and *cost reductions through the sharing of IT infrastructure* between electricity, gas and water networks, particularly for metering.

In the irrigation domain, a benefit from smart networks is improvement of the energy efficiency of water supply in irrigation, which is an important energy-water-carbon linkage. A major further benefit is the improvement of economic water productivity through optimisation of the amount and timing of water given to plants.

Steps to implementation: Implementation of these proposals would begin with pre-deployment studies, leading to full trials. In both the urban and irrigation domains, implementation of this recommendation can be based on partnership with and extension of existing programs.

This recommendation can deliver significant benefits in a relatively short time frame. It also has longer-term aspects, particularly through the use of smart networks to encourage behavioural change and to integrate renewable energy sources into an evolving energy distribution system.

Recommendation 3: Resilient landscapes

In rural Australia, intersection points between energy, water and carbon are strongly linked with landscape productivity and ecosystem health. To meet the resulting challenges, the central need is the development of landscape resilience.

The Expert Working Group recommends a national Resilient Landscapes Initiative, to support the evolution of land systems as resilient producers, water catchments, carbon storages, ecosystems and societies. The initiative will assist communities and industries to resolve tensions and take advantage of emerging opportunities presented by these multiple roles. The initiative will operate through a diverse set of regional projects.

Outcomes: The challenges facing rural Australia over coming decades include production of significantly more food with less water, contribution to major nationwide reductions in GHG emissions, and restoration of stressed land and river ecosystems. This initiative seeks to develop an integrative approach to these challenges. Components for integration include (1) food and fibre production; (2) bioenergy production; (3) soil carbon sequestration; (4) carbon sequestration through forestry; (5) management of water availability and runoff, especially in the presence of water demand from forests and crops; (6) ecosystem health; (7) exploration of alternative production technologies, such as algal biofuels; and (8) rural social development leading to healthy socio-ecological systems. Energy-water-carbon intersections appear directly in the first five of these components and indirectly, but significantly, in the final three.

Steps to implementation: This is a long-term, transformational initiative involving staged implementation over many years, probably decades. Its core is a set of regional focal projects, large enough in number to represent the diversity of Australian landscapes, ecosystems, rural industries and social systems and to provide opportunities for learning and diffusion of successful strategies between projects. These projects will be aimed not only at transformations within their focal regions, but also at subsequent diffusion of ideas and approaches to other regions.

Steps to implement this vision may include:

1. *An initial development and scoping study* involving key stakeholders from governments, industry, community and the innovation system, centrally supported by a Commonwealth Government authority. This would be modestly funded and would run for a period of around two years. It would lead to a detailed plan including selection of focal regions and determination of specific regional goals and approaches, which will vary from region to region.

2. *Initial trials of goals and methods* in a limited number of regions, to integrate landscape components listed above. This would ensure—through adaptation and learning in the project itself—that goals and methods are appropriate, robust and capable of evolving to meet changing needs.
3. *Extension to a wider set of focal regions*, spanning the diversity of Australian landscapes, rural industries and social systems. Ongoing evaluation, learning and adaptation would be part of this process.
4. *Fostering of learning and diffusion of successful strategies*, both between focal regions and throughout Australian landscapes and stakeholder communities.

This initiative will require a whole-of-government perspective that builds on existing developments in rural and regional Australia, farm sector linkages and basic research.

Recommendation 4: Resilient cities and towns

Australians inhabit built environments from great cities to the Red Centre. Meeting the combined energy, water and carbon challenges in our cities and towns will require technological innovation for energy and water supply; development of systems that are resilient to shocks; overall reduction in demand for constrained natural resources, particularly water and GHG emissions; and astute investment in infrastructure. These developments need to occur together.

The Expert Working Group recommends the development of a national Resilient Cities and Towns Initiative, to foster resilient, low-emission energy systems, water systems and built environments by focusing jointly on technological developments in supply and on adaptation in demand as Australia's urban populations grow. The initiative will operate through a set of demonstration projects, united in a national approach.

Outcomes: This initiative aims to foster the design of resilient energy, water, transport and related urban systems that meet human needs with minimum emissions and environmental impact, while also enhancing urban quality of life. These systems will reshape energy and water supply; recycle energy, water and carbon resources presently discarded as waste; and incorporate efficiency, conservation and demand management measures. The initiative will engage with the economic, social and physical processes driving demand; capitalise on industrial and employment opportunities made available by sustainable technologies; and manage trade-offs in the decarbonisation of the energy economy.

Steps to implementation: As for *Recommendation 3*, this is a long-term, transformational initiative involving staged implementation over many years. The demonstration projects at the core of the initiative would encompass the diversity of Australian urban environments from major cities to small towns.

Steps to implementation would be similar to the four elements outlined in *Recommendation 3*, starting with a scoping and evaluation process involving key stakeholders from governments, industry, community and the innovation system, centrally administered by a Commonwealth Government authority. The scoping processes for *Recommendation 3* and *Recommendation 4* would involve significantly different stakeholders and options, but could be centrally supported by the same government structure.

A program like this would build upon such initiatives as the Renewable Energy Futures Fund, the Prime Minister's Task Group on Energy Efficiency, the Smart Grid/Smart City Program, the Solar Flagship Program and national initiatives operating in individual sectors.

Recommendation 5: Enhanced knowledge and learning system

All of the foregoing recommendations place high demands on new knowledge and innovation, particularly for integrative understanding of whole-system behaviours. There is a growing gap between the largely compartmentalised knowledge provided by our current innovation system and the kind of cross-disciplinary, cross-sectoral understanding that is needed to enable innovation across energy, water, carbon and related domains. We cannot manage what we do not understand, and we cannot manage what we do not measure.

The Expert Working Group recommends enhancing the development of integrative perspectives across the Australian knowledge system, by (1) establishing a core research effort in integrative systems analysis, to understand and map the connections between energy, water, carbon, climate, agriculture, ecosystems, the economy and society; (2) including incentives for integrative analysis in existing academic, government and sectoral innovation investment structures; and (3) enhancing support for stable, ongoing delivery of essential information.

Outcomes: Through both short-term and long-term actions, this recommendation will improve Australia's ability to develop resilience through adaptation and learning, and will address the rapidly emerging need for integrative perspectives that overcome the ongoing compartmentalisation of research funding and organisations into silos representing traditional disciplines and sectors.

In keeping with the principle 'we cannot manage what we do not understand', this recommendation will lead to a better understanding of the whole-system characteristics that emerge from energy-water-carbon intersections, including resilience, adaptability, transitions and thresholds. Understanding these characteristics will lead to the identification of potentially successful and unsuccessful pathways, particularly the dead-end pathways that lead to long-term problems for society if action is not taken early and from which escape is difficult. Examples of integrative issues for this effort include the implications of climate change and population growth for the economy, urban amenity, agricultural productivity, ecosystem health and societal wellbeing.

In keeping with the principle 'we cannot manage what we do not measure', the recommendation will lead to stable, ongoing, continuous, operational delivery of essential biophysical, ecological, geographic, economic and social information through greatly enhanced support and integration. These kinds of information are crucial for both research and operational goals in integrative frameworks.

Steps to implementation: The first part of the recommendation can be initialised quickly, but is long-term in its ultimate time frame and transformational in intent. It proposes a major enhancement of Australia's capability through the establishment of a national program for integrated systems analysis, based on existing successful international models. A significant part of the mandate of the program will be the education and training of researchers and practitioners in integrated systems thinking.

The second part of the recommendation proposes the rapid incorporation of integrative perspectives into the evolution of the current innovation system. A specific action to do this would be to include a priority for integrative analysis in the National Research Priorities, which would encourage shifts in funding criteria by the Australian Research Council and in other government research funding initiatives. A further action in support of the second part of the recommendation would be to implement a research-coalition model for linking the diverse existing providers of energy, carbon and water research with the users of that research. Such a model can encourage both fundamental and applied research with appropriate overall priority setting and selection.

The third part of the recommendation proposes enhanced support for and integration of essential biophysical, ecological, geographic, economic and social information. These kinds of information are presently supplied by numerous systems with varying levels of continuity and linkage to other systems. The important need is not to bring all of these into a single 'super-system', but rather to ensure stability of funding, effective delivery of information and effective connectivity between different kinds of information from different systems.



1. Introduction

Key points

- Australia faces major challenges at energy-water-carbon intersections to mitigate climate change while continuing to supply energy and to cope with limited water availability while maintaining an increasing population.
- These challenges will demand transformational responses.
- Underpinning themes throughout this report are the need for an integrative perspective and the concept of system resilience.
- All five recommendations of the report span sectors and focus on the knowledge, systems and approaches that will be required for transformation, rather than on particular sectoral solutions.

Background

Energy, water and carbon are, together, the foundations of life. They are also at the heart of the economic, social and environmental health of all human societies. The intersections between energy, water and carbon are deep: almost any change in one of these domains has consequences for the other two.

Australia faces major challenges at energy-water-carbon intersections. With the rest of the world, we need to mitigate and adapt to climate change caused by increasing greenhouse gas (GHG) emissions, if risks from climate change are to be kept acceptably low. We must cope with limited water availability, while maintaining an increasing population and producing more food. These challenges will demand transformational responses. Mitigation of climate change will require a nearly complete decarbonisation of both the Australian and global economies in a time frame of a few decades, particularly in the energy generation, transport and land sectors. Water systems will need to distribute, use and re-use Australia's limited water more efficiently. Australia's landscapes collectively need to function as producers, watersheds, carbon stores, healthy ecosystems and vibrant societies, while ensuring that each of these functions coexists with the others. Cities and towns, which provide homes for most of the Australian population, need to evolve to reduce GHG emissions, to use less water per person and to house a population that is still growing, while maintaining and enhancing quality of life.

This report considers the implications of challenges at energy-water-carbon intersections. Because the connections between energy, water and carbon are multiple and fundamental, we adopt an integrative perspective throughout. The emphasis is on the total system formed by the natural environment and human society, in which energy, water and carbon play essential and intersecting roles. To address the changes that will be needed in this whole system because of challenges at energy-water-carbon intersections, we build upon the concept of resilience. A resilient system can recover from shocks and disturbances, adapt through learning and undergo transformation when necessary.

Using the need for an integrative perspective and the concept of system resilience as underpinning themes, we offer five recommendations, each addressing a broad part of the picture:

1. The governance and sharing of water and GHG emissions, with both market and non-market mechanisms.
2. The efficient distribution and use of energy and water with smart networks in urban and agricultural settings.
3. Enhancing the resilience and sustainability of Australian landscapes in meeting energy-water-carbon challenges.

4. Enhancing the resilience and sustainability of the built environments in Australia's cities and towns.
5. Enhancing Australia's knowledge and learning capabilities to meet not only sectoral challenges but also new demands for integrative knowledge about the whole system formed by energy, water, carbon, ecosystems, the economy and human society.

Each of these recommendations spans sectors. Our focus is on developing the knowledge, systems and approaches needed to address challenges that demand long-term transformations, rather than advocating particular sectoral solutions in particular places.

Section 2 of this report describes the intersections between energy, water and carbon, including the realities that shape the system, the implications of climate change, recent trends in Australia's GHG emissions and water use, and constraints on GHG emissions and water availability. *Section 3* examines the integrative perspectives that are essential to meet intersecting energy-water-carbon challenges, including the Earth System view; resilience as a critical concept for working with connected, evolving systems; and the critical role of knowledge and learning. *Section 4* analyses five sectors that play central roles in energy-water-carbon intersections: stationary energy, transport energy, water systems, land systems and urban systems. *Section 5* describes our five recommendations in detail, noting that all recommendations are trans-sectoral. Finally, *Section 6* offers conclusions, including an indication of topics that require further development and analysis. Several *Appendices* are provided and contain supporting material, including a glossary of terms and abbreviations.

Terms of Reference

With a planning horizon of 20 years:

1. Identify key linkages between energy, water and carbon that are potentially crucial to Australia's low-carbon economic future.
2. Conduct a preliminary analysis of these linkages to identify significant drivers (e.g. linkages between desalination plants/energy use/carbon dioxide emissions).
3. Using this information, identify significant implications for energy, water and carbon policy, with particular regard to the mitigation of and adaptation to climate change.
4. Formulate options for government consideration, which may include but need not be limited to:
 - improvement of existing or establishment of new data collection, analysis and interpretation capabilities
 - identification and resourcing of new areas of research, where gaps in knowledge currently limit evidence-based policy choices
 - establishment of mechanisms to further refine robust and sophisticated models at energy-water-carbon intersections, including socioeconomic parameters
 - potential changes to regulatory or institutional arrangements, in order to assist transformational change to a low carbon economy through addressing energy, water and carbon linkages.
5. Document the relative contributions of fundamental and applied published research to the findings and identify any key areas for future research.
6. Identify other significant linkages not addressed in (1) and potential drivers not identified in (2), and prioritise them for potential future action.

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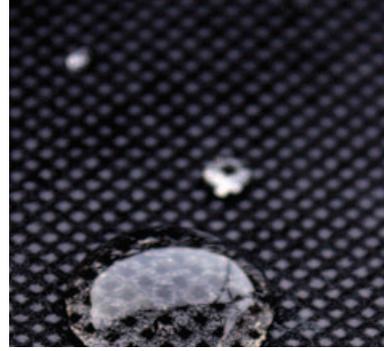
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2. Energy-Water-Carbon Intersections

This section describes the intersections between energy, water and carbon, including the realities that shape the system, the implications of climate change, recent trends in Australia's GHG emissions and water use, and constraints on GHG emissions and water availability.

2.1 The challenge

Key points

- Energy, water and carbon are deeply connected in every aspect of life and society, through both supply and consumption.
- To keep climate change below dangerous levels, global and national limits on greenhouse gas emissions are needed.
- Australia faces strong constraints on water availability, particularly in southern regions. The available water per person in southern Australia will decrease in future because of both population increases and the effects of climate change.
- Because energy, water and carbon are so tightly linked, attempts to address a problem in one area without regard for its implications elsewhere can have unintended consequences that will often make matters worse overall.

Energy, water and carbon are each central to the economic, social and environmental health of all humankind (*Figure 2.1*). Energy and water are essential for practically all activities. We, and the biosphere we inhabit, are carbon-based life forms. In the industrial era, carbon has acquired another significance as the primary fuel for energy systems based on fossil fuels (coal, oil and gas). In recent decades, the resulting build-up of carbon dioxide (CO₂) and other GHGs in the atmosphere has begun to warm the earth's climate—a trend that will continue to be driven as GHG emissions continue to increase. This climate change, in turn, is interacting with population growth to increase stresses on Australia's water supplies, along with food production and the environment.

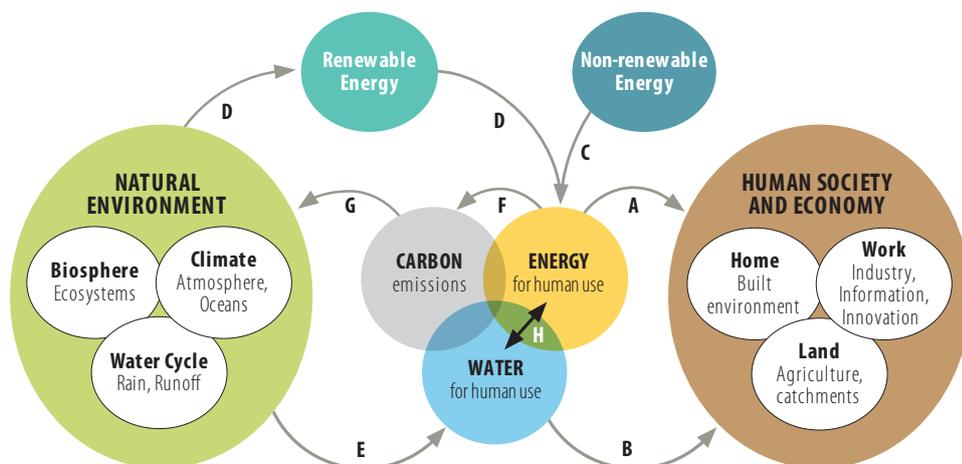


Figure 2.1: Energy, carbon and water are central to the interaction between the natural environment (left) and human society and economy (right). Energy and water are both vital for all human activities (A, B). Energy for human use is derived primarily from fossil fuels and other non-renewable sources including nuclear energy (C) and from renewable sources (D). Water for human use is dependent on the natural water cycle (E). Fossil-fuel-derived energy consumption leads to the build-up of carbon dioxide and other greenhouse gases in the atmosphere (F), which is changing the earth's climate (G) and influencing water availability, ecosystem function and agricultural productivity (E, B). There are also interactions between water supply and energy supply because energy systems use water and water systems use energy (H). Many more connections could be shown in this figure.

Three basic realities underlie the intersections between energy, water and carbon in Australia. First, energy, water and carbon are deeply connected in every aspect of life and society, through both supply and consumption. Intersections through supply arise because our energy systems use water, our water systems use energy, and current energy generation is GHG intensive. Most land uses for food and fibre production, or for carbon sequestration, also require energy and water. Intersections through consumption arise because energy use and GHG emissions have historically increased with wealth—a connection no major economy has yet broken (Raupach et al, 2007).

The next reality is that of human-induced climate change. To keep climate change below dangerous levels, global and national limits on GHG emissions are needed. This is a particular challenge for Australia, with its present strong reliance on GHG-intensive energy sources.

Third, Australia faces strong constraints on water availability, particularly in southern regions, because of natural geography. Rainfall over most of Australia is low and variable. In addition, the available water per person in southern Australia is likely to fall over the next 20 years, both because of population increases and because total water availability in this region is likely to decline further as a result of climate change.

At the highest level, these three realities shape the nature of energy-water-carbon intersections in Australia. There will be increasing future demands for energy and water because of population and economic growth, which are linked to goals for the wellbeing of the nation and its inhabitants. On the other hand, there are future constraints on both GHG emissions and water availability. Constraints on emissions are imposed by the emission trajectory chosen by Australia, in response both to global agreements and to assessments of the risk posed by the impacts of climate change on Australia. Constraints on water availability are already significant and are likely to become more severe (in southern Australia, the home of most of the population) depending on the extent of global climate change.

These fundamental connections between energy, water and carbon will strongly influence the development of Australia over coming decades. As a nation, we seek a mix of energy sources that will meet demand while keeping below the emissions constraint, and we seek to bridge the gap between water supply and demand in the face of population growth and likely decreases in rainfall.

Because energy, water and carbon are so tightly linked, attempts to address a problem in one area without regard for its implications elsewhere can have unintended consequences that will often make matters worse overall. For instance, we could bridge part of the water gap with desalination, but at the cost of increasing energy demand. We can relax the emissions constraint by sequestering carbon in the land, possibly at the cost of decreasing water availability. These interactions are so pervasive that a central theme of this report is the search for integrated solutions.

Finding a path through these often conflicting requirements is the challenge posed by the intersections between energy, water and carbon.

2.2 Climate change and its implications for Australia

Key points

- The climate of the earth, including Australia, has changed. Surface temperatures have increased over the last century and many other associated changes have been observed. The available evidence implies that greenhouse gas emissions from human activities are the main cause. It is also expected that if greenhouse gas emissions continue at business-as-usual rates, temperatures will further increase significantly over the coming century and beyond (AAS, 2010).
- These conclusions are based on decades of research and thousands of studies. Remaining uncertainties work in both directions: future climate change may be less severe or more severe than current best estimates.
- Australia is highly vulnerable to the impacts of climate change, despite its high adaptive capacity.

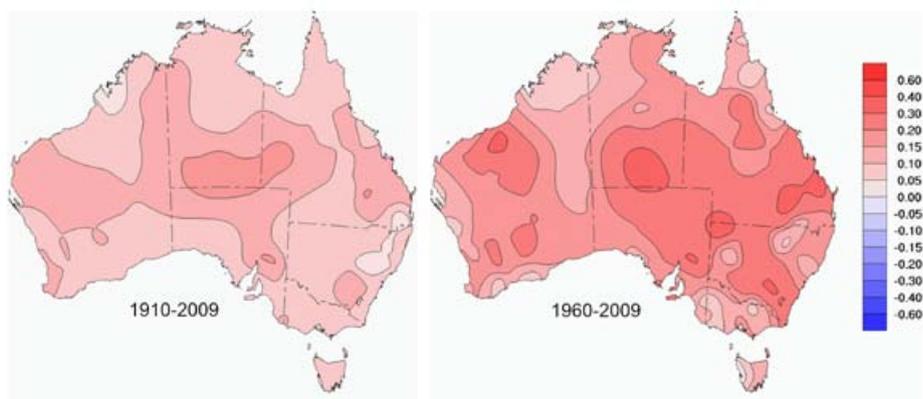
Climate change and its causes: Human-induced climate change is caused primarily by the build-up in the atmosphere of GHGs as a result of human activities. These gases include water vapour, CO₂, methane, nitrous oxide, ozone and some synthetic gases. All of these (except the synthetic gases) occur naturally and make life on Earth possible by insulating our planet's surface against the chill of space—this is the 'natural greenhouse effect'. The concentrations of most of these gases are being directly increased by human activities, causing extra warming—this is the 'enhanced greenhouse effect', the main driver of human-induced climate change. Water vapour, although it makes the largest contribution to warming, is not directly influenced by human activities but rather responds to (and amplifies) the effects of changes in the atmospheric concentrations of other gases (AAS, 2010).

Of the gases contributing to human-induced climate change, CO₂ is the most important (accounting for a large fraction of all the climate forcing due to these gases), followed by methane and other gases (Hofmann et al, 2006; IPCC, 2007a). The global sources of increasing CO₂ in the atmosphere are emissions from fossil fuel combustion and industrial processes, accounting in 2008 for about 88 per cent of total CO₂ emissions, and emissions from land use change, which account for the remaining 12 per cent (Le Quere et al, 2009). Global CO₂ emissions from fossil fuels have increased nearly exponentially for more than a century, with particularly high growth over the decade 2000–09 at over 3 per cent per year (Le Quere et al, 2009). Global CO₂ emissions from land use change have been approximately steady for the two decades since 1990, but there are indications in recent data of a decline in recent years (Le Quere et al, 2009).

Evidence for climate change: There are multiple lines of evidence that the earth has warmed by about 0.8 degrees since pre-industrial times, and that GHG emissions from human activities are a primary cause. If GHG emissions continue to increase at business-as-usual rates, further warming of several degrees is expected to occur, accompanied by many other climate changes including changes to rainfall patterns, sea levels, ocean currents, ice sheets, ecosystems, food production patterns and much more. These conclusions are the outcome of decades of research and thousands of observation-based and model-based studies, synthesised and assessed by the 2007 Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC, 2007a). A recent report by the Australian Academy of Science (AAS, 2010) has documented the evidence base for the broad scientific findings of climate change science over the past century and identifies the remaining uncertainties. Uncertain aspects include detailed projections of regional climate change and the magnitude and timing of climate thresholds and tipping points (sudden changes in state from which it is difficult to recover). It is important to note that uncertainties work in both directions: future climate change may be less severe than current best estimates, or it may be more severe.

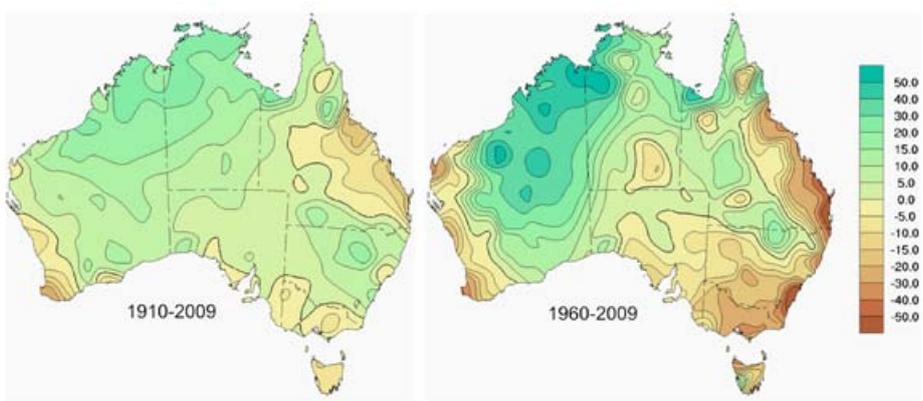
Australian climate trends over past decades: Climate change is already occurring in Australia. The continent has warmed over the last century at a rate which has been greater in the latter part of this period (*Figure 2.2*). The warming from 1960 to 2009 was about 0.7 degrees (CSIRO and Bureau of Meteorology, 2010), which is greater than the mean global warming over the same period.

Trends in rainfall over recent decades indicate drying in the southwest and east (*Figure 2.3*). Possible causes of these trends include both natural climate variability and human-induced climate change, with increasing evidence that human-induced climate change is at least part of the cause (Nicholls, 2004; Larsen and Nicholls, 2009; AAS, 2010; Timbal et al, 2010).



Source: Bureau of Meteorology

Figure 2.2: Historical trends in Australian annual temperature ($^{\circ}\text{C}/\text{decade}$) over the periods 1910–2009 (left) and 1960–2009 (right). Bureau of Meteorology trend maps are available at www.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi.



Source: Bureau of Meteorology

Figure 2.3: Historical trends in Australian annual rainfall (in mm per decade) over the periods 1910–2009 (left) and 1960–2009 (right). Bureau of Meteorology trend maps are available at www.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi.

Runoff and stream flow in southwest Australia have declined strongly from previous average levels since the 1970s. In southeast Australia, runoff and stream flow have declined since the 1990s. Flows in the Murray River have been at historically low levels through the period 2000–08 (CSIRO, 2008).

It is important to be aware of the ‘rainfall-runoff amplifier’, which causes proportional changes in runoff to be about three times greater than changes in rainfall in typical Australian conditions (Zhang et al, 2004; Raupach et al, 2009). For example, a 10 per cent decrease in rainfall would lead to a 30 per cent decrease in available water in river flows. This is a basic hydrological property of landscapes that occurs because the drier the conditions, the greater the fraction of the available soil water used by vegetation (trees and grasses) as transpiration. Informally expressed, the vegetation gets the ‘first drink’ from the available water. This rainfall-runoff amplifier is the largest single contributor to recent historically low flows in the Murray–Darling Basin (Raupach et al, 2009).

Future climate change in Australia: Figures 2.4 and 2.5 show the changes in patterns of temperature and rainfall across Australia in a ‘2 degree world’ and a ‘4 degree world’, respectively. These ‘worlds’ represent scenarios in which increasing GHG concentrations result in global temperature increases of 2 and 4 degrees Celsius greater than the average in 1980–99. These maps were calculated from climate projections obtained with multiple climate models used in the IPCC Fourth Assessment (IPCC, 2007a; IPCC, 2007b), assuming a ‘business-as-usual’ emissions scenario with high GHG emissions through the twenty-first century (the ‘A2’ scenario). The maps show the changes in temperatures and rainfall across Australia (relative to 1980–99) at the time when global average warming reaches 2 degrees (Figure 2.4) or 4 degrees (Figure 2.5) above the 1980–99 global average. Under the assumed emissions scenario, global warmings of 2 and 4 degrees (relative to 1980–99) are reached by around 2050 and 2100, respectively, with the exact time depending on the climate model.

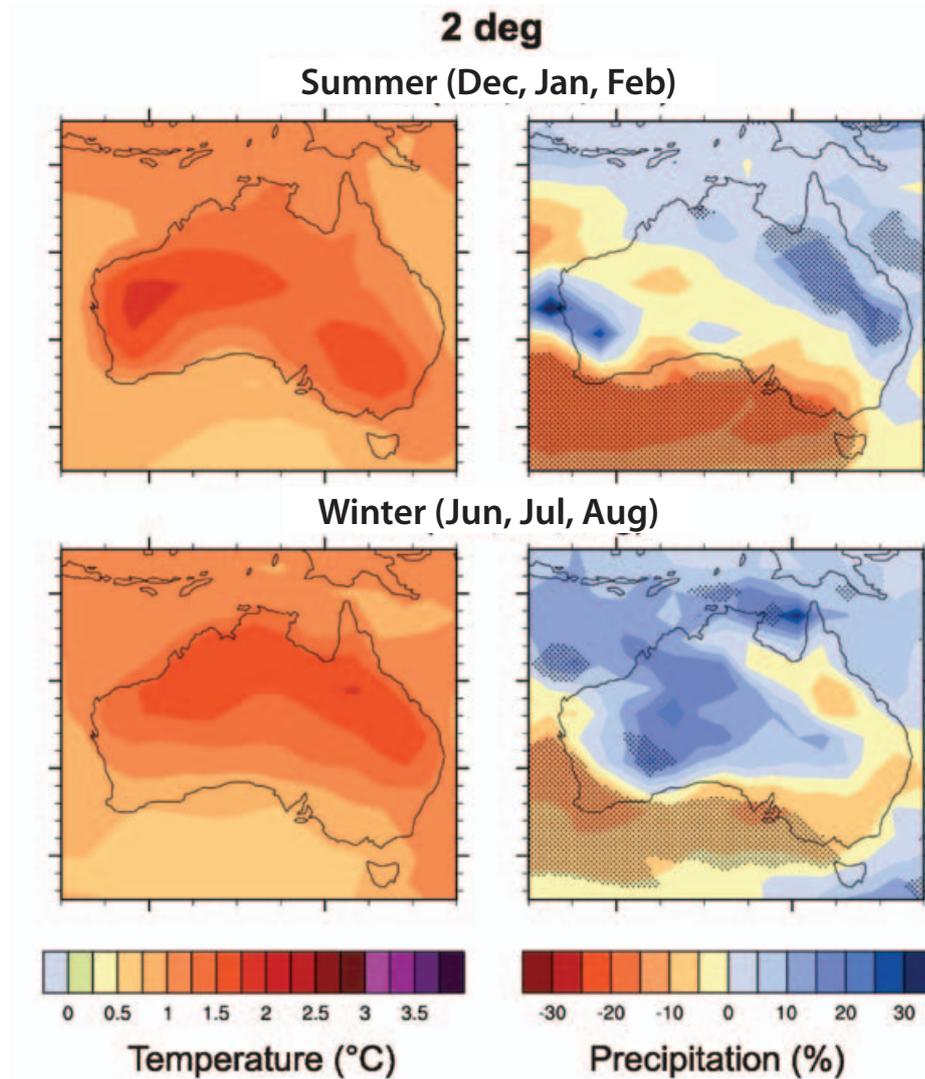


Figure 2.4: Projected changes in surface air temperature (°C) and precipitation (%) for Australia, under a high-emission, 'business-as-usual' scenario for greenhouse gas emissions through the twenty-first century (the 'A2' scenario), at the time when global temperature reaches 2 degrees (2 deg) above the 1980–99 average (a climate which occurs around 2050 in these projections). Upper and lower panels show projected changes in summer (Dec, Jan, Feb) and winter (Jun, Jul, Aug), respectively. The maps show average results from multiple climate models used in the IPCC (2007) Fourth Assessment, averaged for this report as follows: projected changes are calculated as the difference between the 20-year average during the period when 2°C of warming is first attained and the corresponding average value during 1980–99. For the precipitation panels, stippling denotes areas where the models show strong agreement (where the magnitude of the average change exceeds the variability between models as measured by the inter-model standard deviation). For the temperature panels there is no stippling because all regions show strong agreement.

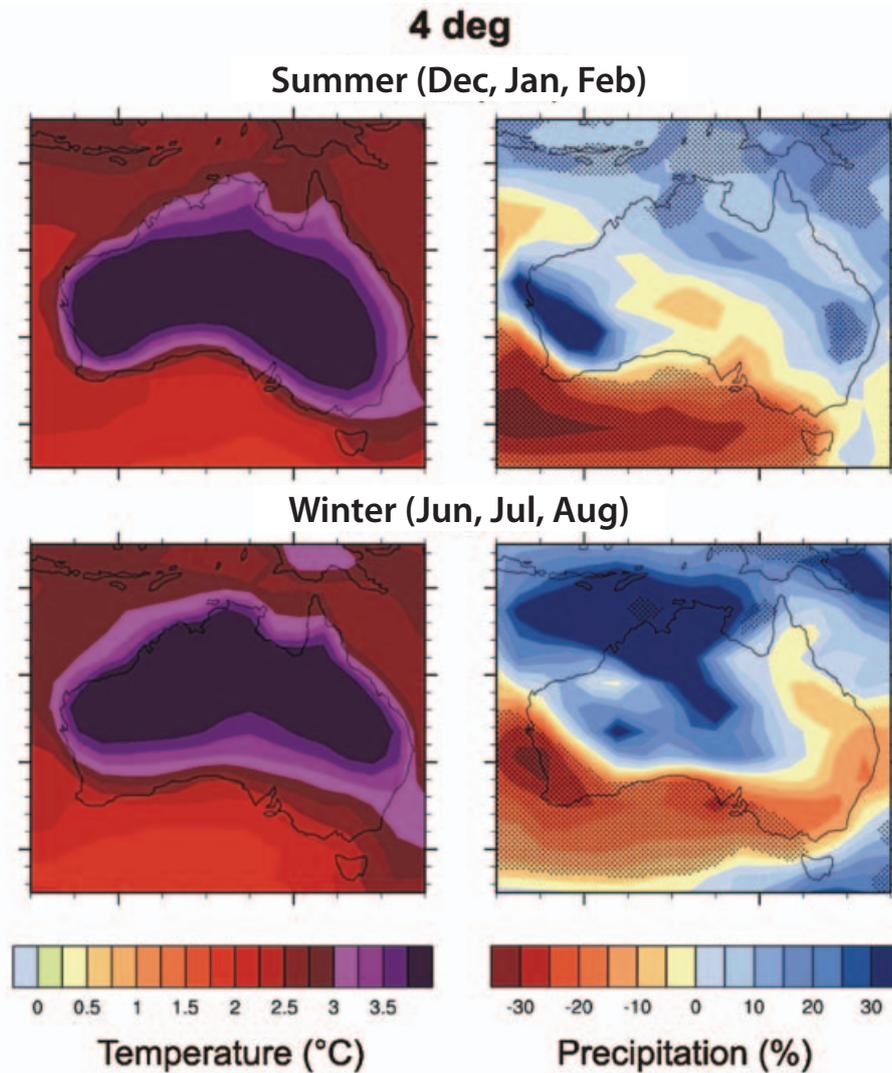


Figure 2.5: Same as Figure 2.4, but for 4 degrees (4 deg) of global warming relative to 1980–99, under a high-emission, ‘business-as-usual’ scenario for greenhouse gas emissions through the twenty-first century (the ‘A2’ scenario), at the time when global temperature reaches 4 degrees above the 1980–99 average (a climate which occurs around 2100 in these projections).

Temperatures are projected to increase over Australia, broadly in line with global increases. The distribution of projected average warming generally agrees well between different climate models. Over southern Australia warming is projected to be greater in summer than winter, which will pose challenges for bushfire management and emergency services. Extreme heat wave events are expected to increase over much of Australia (CSIRO and Bureau of Meteorology, 2007).

Australian rainfall is projected to decline in the south while increasing in the north (CSIRO and Bureau of Meteorology, 2007; CSIRO, 2008). The decline in southern Australia (mainly in Victoria, southern NSW and southwest WA) is projected to occur mainly in winter and to be more severe with every additional degree of global warming. For example, percentage rainfall declines over much of southern Australia are typically two or three times larger in a 4 degree world compared to a 2 degree world. Put another way, a doubling in the global warming caused by GHGs would double or triple Australia’s percentage rainfall reduction over southern regions.

Over most of northern Australia, rainfall is projected to increase. The most widespread increase is expected in summer, when higher rainfall is also expected over much of southern Queensland and northern and eastern NSW.

Model agreement for changes in rainfall is in general weaker than for temperature changes, particularly for projected rainfall changes over Australia's interior. The strongest agreement between models for changes in rainfall is for the projected winter drying over the southern fringe of the continent and the projected summer increase in the far north of Australia.

At a global scale, the impact of a 2 degree warming would be significant (AAS, 2010). A warming of 4 degrees would lead to massive impacts for human societies (Schneider and Lane, 2006), with a number of regions on the planet potentially hostile to human health (Sherwood and Huber, 2010). There is a high probability that human populations in many regions will be affected by shifts in food supply, shifts in water availability (droughts in some regions and floods in others), increased rates of spread of diseases, increased incidence of fire weather, and direct physical climate impacts such as heat stress. There would also be profound impacts on vulnerable ecosystems, both terrestrial and marine (Steffen et al, 2004; Rockstrom et al, 2009). The impacts of climate change will also tend to exacerbate the effects of other stresses associated with the environmental footprints of increasing human populations (Rockstrom et al, 2009; AAS, 2010).

Australia is highly vulnerable to the impacts of climate change, despite its high adaptive capacity. Among the greatest sources of vulnerability are:

- the likely drying trend in southern Australia (see Figures 2.4–2.5 and associated discussion and references)
- consequences of this rainfall decline for agriculture
- major damage to the Great Barrier Reef (Hoegh-Guldberg et al, 2003; 2007)
- damage to many other vulnerable ecosystems
- likely increased incidence of severe bushfires
- increased disease spread—for example, higher temperatures may assist mosquito larval survival in winter and extend the distribution of disease carrying mosquitoes further south (PMSEIC, 2009).

2.3 Patterns of energy use, water use and emissions for Australia

Key points

- The future energy-water-carbon challenge for Australia is shaped by current and recent patterns of energy use, water use and greenhouse gas emissions.
- Australia is exceptional among developed nations in having a developed economy with a high-growth pattern for population, energy use and emissions—this pattern is more characteristic of the developing world.
- Energy consumption and greenhouse gas emissions per person in Australia have increased steadily in recent decades, while water consumption in southern Australia has decreased in response to limited water availability.

Greenhouse gas emissions: Australia's emissions from all sectors, including land use change, have risen from around 550 million tonnes of carbon dioxide equivalents (MtCO₂eq) in 1990 to around 600 MtCO₂eq in 2007 (CO₂eq is the unit used to compare the warming effects of different GHGs, such as CO₂, methane and nitrous oxide, over a 100-year period; DCC, 2009a). There have been three main contributors to emissions over this period: energy, agriculture and land use change (Figure 2.6). The largest source of emissions is the energy sector, with emissions of more than 400 MtCO₂eq in 2007. The dominant contributor to energy emissions is the stationary energy sector, which is in turn dominated by CO₂ emissions from coal combustion (DCC, 2009a). Emissions from the energy sector have increased steadily from 1990 to 2007, rising from around half of Australia's emissions in 1990 to more than two-thirds in 2007. Over the same period emissions from agriculture (mostly methane from ruminant digestion and nitrous oxide from fertiliser use) have been relatively constant, at around 90 MtCO₂eq per year, or 15 per cent of Australia's emissions in 2007. Land use change (including net emissions from deforestation, afforestation and reforestation) has been a declining source of emissions since 1990. This reduction in land use change emissions reflects a substantial decline in annual rates of forest clearing in Australia due to changing regulatory and market conditions (DCCCE, 2010a).

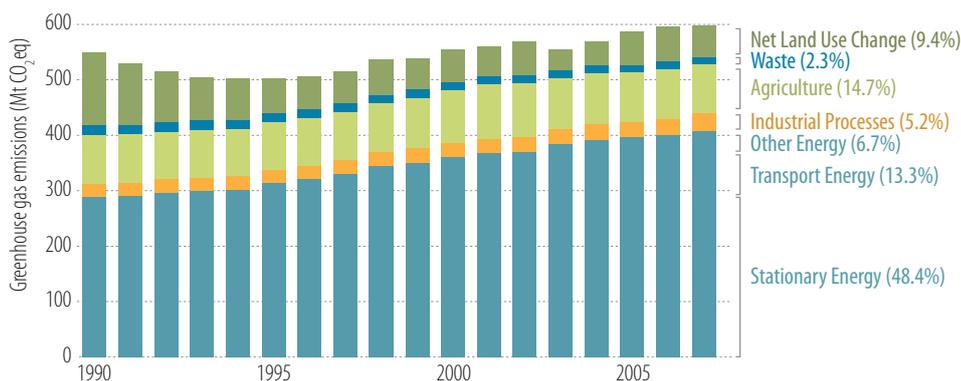


Figure 2.6: Australia's greenhouse gas emissions from all sectors, including net land use change, from 1990 to 2007 (DCC, 2009a; DCCEE, 2010a). Net land use change includes net emissions and removals from deforestation, afforestation and reforestation. Percentages shown on the right indicate the sectoral share of total emissions in 2007 (2007 total = 597 MtCO₂eq). CO₂eq is carbon dioxide equivalents—the unit used to compare the warming effects of different greenhouse gases over a 100 year period; Mt is million tonnes.

At present the only land-based emission sources and sinks accounted for in the *National Greenhouse Gas Inventory* shown in Figure 2.6 are those due to deforestation, afforestation or reforestation of land since 1990 (DCC, 2009a). Changes in carbon stocks on the vast majority of Australia's landscape are not included in these estimates. This land can change yearly from a net carbon sink to an emissions source. This inter-annual variation is driven primarily by climate variability, for instance drought or high rainfall, and natural disturbances such as bushfire or insect attack. These natural factors tend to dominate over influences attributable to humans, such as agricultural land management practices (DCCEE, 2010a).

Energy, population and economy: Australia's recent (2000–07) growth rates in primary energy supply, population and the economy, together with the growth rate in CO₂ emissions from fossil fuels, are all substantially higher than those in most other developed countries. Table 2.1 compares these growth rates for Australia with the average for the 23 'Kyoto Annex II' developed countries, and with the world as a whole. Our recent population growth rate exceeds the world average, and our recent growth rates for gross domestic product (GDP), energy and CO₂ emissions approach those for the world as a whole, which are much higher than for developed countries because of rapid growth in developing nations.

Australia is exceptional among developed nations in being a developed economy with a growth pattern for population, energy use and emissions more characteristic of the developing world.

	World	Australia	Developed Nations
VALUES (2007)			
Population (millions)	6609.3	21.1	893.3
GDP (ppp) (billion \$US2000/y)	61428	667	28311
Primary energy supply (PJ/y)	503664	5194	201101
CO ₂ emissions from fossil fuel combustion (MtCO ₂ /y)	29320	380	11348
INTENSITIES (2007)			
Per capita GDP (k\$/pers/y)	9.29	31.55	31.69
Per capita primary energy (kW/pers)	2.41	7.79	7.13
Per capita CO ₂ emissions (tCO ₂ /pers/y)	4.44	18.00	12.70
Primary energy intensity of GDP (PJ/billion \$)	0.26	0.25	0.23
Carbon intensity of primary energy (gCO ₂ /MJ)	58.21	73.22	56.43
Carbon intensity of electricity and heat generation (tCO ₂ /MWh)	0.507	0.907	0.439
GROWTH RATES (1990–99) (per cent per year)			
Population	1.45	1.14	0.65
GDP (ppp)	3.14	3.95	2.49
Primary energy supply	1.33	2.63	1.52
CO ₂ emissions	1.02	2.69	1.14
GROWTH RATES (2000–07) (per cent per year)			
Population	1.21	1.30	0.66
GDP (ppp)	4.38	3.32	2.20
Primary energy supply	2.88	2.22	0.56
CO ₂ emissions	3.32	2.31	0.46

Table 2.1: Population, gross domestic product measured by purchasing power parity (GDP (ppp)), energy and fossil-fuel carbon dioxide (CO₂) emissions data for the world, Australia and 23 developed nations (the signatories to Kyoto Annex II) for the year 2007. All data from the International Energy Agency (International Energy Agency, 2009a; www.iea.org/co2highlights). Only CO₂ emissions from fossil fuel combustion are shown here; these values differ from the total greenhouse gas emissions from the energy sector shown in Figure 2.6, which include non-CO₂ greenhouse gases. Primary energy supply includes the energy from primary sources (fossil fuels, renewables and uranium) supplied for domestic consumption, including transport and electricity generation, but excluding exported primary energy. The carbon intensity of primary energy is the ratio of total CO₂ emissions from fossil fuels to total primary energy supply; carbon intensity of electricity and heat generation is the ratio of CO₂ emissions from fossil fuels combusted for electricity and heat generation to the output of electricity and heat. Growth rate comparisons between Australia and developed nations are highlighted in red. Growth rates are per cent growth per year. \$US2000 is US dollars in 2000, y is year, PJ is petajoules or 10¹⁵ joules, MtCO₂, tCO₂, gCO₂ are million tonnes, tonnes or grams, respectively, of carbon dioxide, k\$ is thousand US dollars in 2000, pers is person, kW is thousand watts, MJ is million joules, MWh is million watt-hours.

Water use: Australia's per-capita water consumption of 1200 kL per year is among the highest in the world (Figure 2.7), largely because of Australia's substantial irrigation industries, and food and fibre exports relative to a small population.

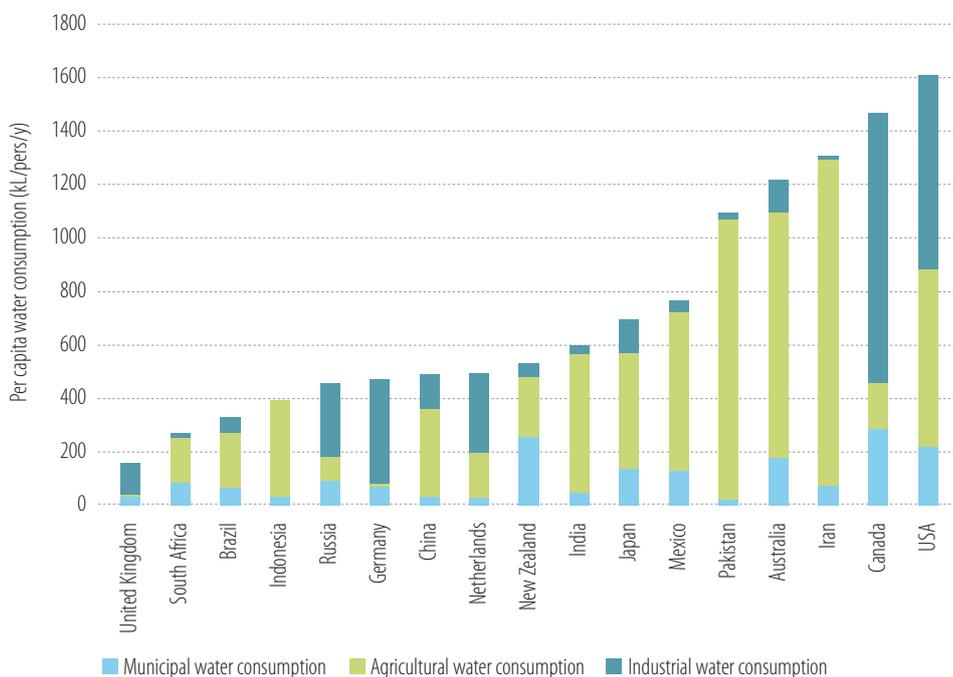


Figure 2.7: Per capita water consumption by sector in selected countries (FAO, 2010). Municipal consumption includes all water delivered through municipal water distribution systems (household, commercial and industrial users supplied by the municipal water system); agricultural consumption is water consumed as irrigation or for livestock purposes and does not include rain-fed agriculture; industrial consumption is water self-supplied by industry, including water consumed by the electricity (not hydroelectric), gas and manufacturing sectors; kL/pers/y is thousand litres per person per year.

Most Australian water consumption is by the agriculture sector (Figures 2.7 and 2.8), which accounts for about 70 per cent of consumption nationally. Municipal consumption (including both household and non-household uses) accounts for about 17 per cent and industrial consumption for the remaining 13 per cent (ABS, 2006). The largest contributor to municipal consumption is household use (Figure 2.9): typically 100 000 litres per person per year, with substantial variation between cities.

Water consumption is sensitive to water availability. There is a tendency for consumption to fall in dry years, illustrated in Figure 2.9 by the decreased municipal consumption in southern Australian cities (Sydney, Melbourne, Canberra, Adelaide and Perth) in a dry year (2004–05) compared with a wetter year (2000–01) (ABS, 2006). There was a similar decline in agricultural water consumption over the same period (Figure 2.8).

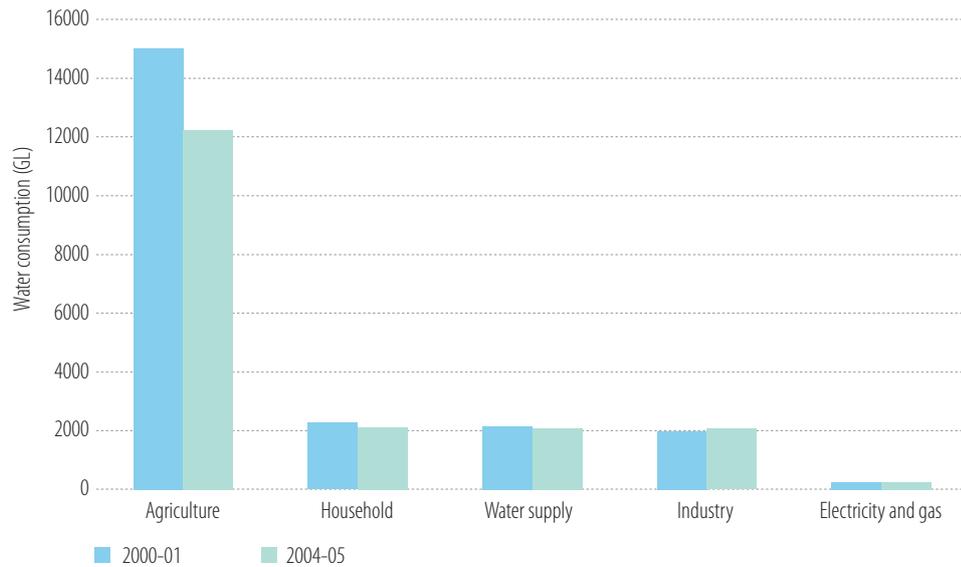


Figure 2.8: Australian water consumption by sector for the years 2000–01 and 2004–05 (ABS, 2006). Consumption is water used but not returned to the environment or supplied to another user for re-use. Agriculture includes water used for stock purposes, irrigation of crops and pastures, services to agriculture, hunting and trapping and the forestry and fishing sector; household includes all water used for domestic purposes, including gardening; water supply includes water consumed or lost during the supply process and water consumed by sewerage and drainage services; industry includes mining, manufacturing and other industries; electricity and gas excludes in-stream use for hydroelectricity generation. GL is billion litres.

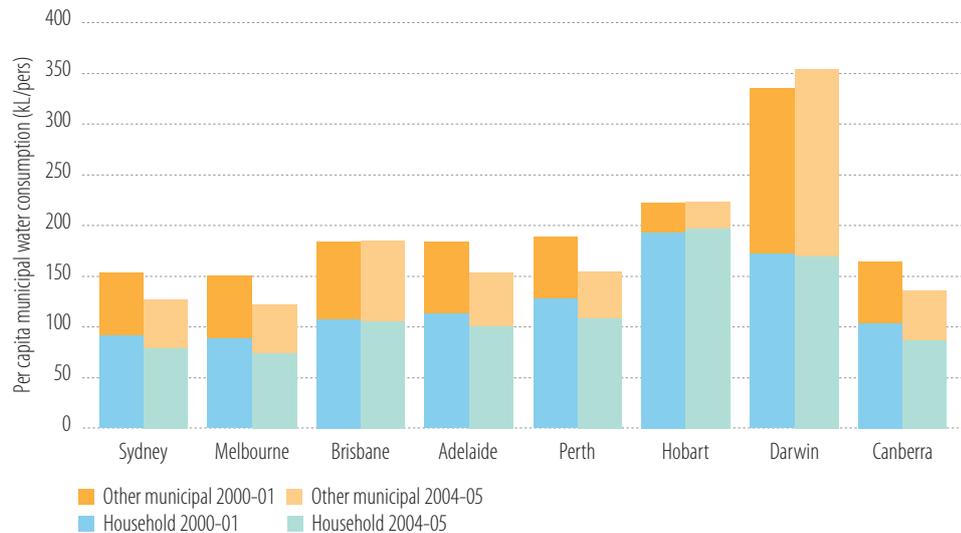


Figure 2.9: Per capita municipal water consumption in Australian cities for the years 2000–01 and 2004–05 (WSAA, 2005). Municipal water is all water delivered through municipal water distribution systems; total municipal consumption comprises household consumption (all domestic uses) and other municipal (commercial, industrial and other water users supplied by the municipal system); kL/pers is thousand litres per person.

A similar response in water consumption has been observed over the last several decades. *Figure 2.10* shows trajectories for Australian population and electricity consumption together with municipal water consumption in Melbourne, for a period of nearly 50 years (1961–2009). Through this period Australia’s population has more than doubled, its electricity consumption has increased 12-fold and electricity consumption per person has grown six-fold. By contrast, total water consumption in Melbourne increased from 1961 to 1980, changed little between 1980 and 2000 and fell thereafter, as water constraints came into effect. Melbourne water consumption per person has fallen significantly since 1980, with most of the recent (post-2002) fall being associated with water restrictions. Thus, per capita water use in Melbourne has fallen over the past 30 years, largely due to the success of demand management programs introduced during a period of drought in the early 1980s. These programs included user-pays water pricing, regulation (such as for dual-flush toilets) and public campaigns to change water-use behaviour.

The message is that growth in water consumption in southern Australia has been much slower than growth in energy consumption. Urban water consumption per person is now decreasing in response to water pricing and efficiency measures, in contrast with electricity consumption and GHG emissions per person (*Table 2.1*), which continue to increase.

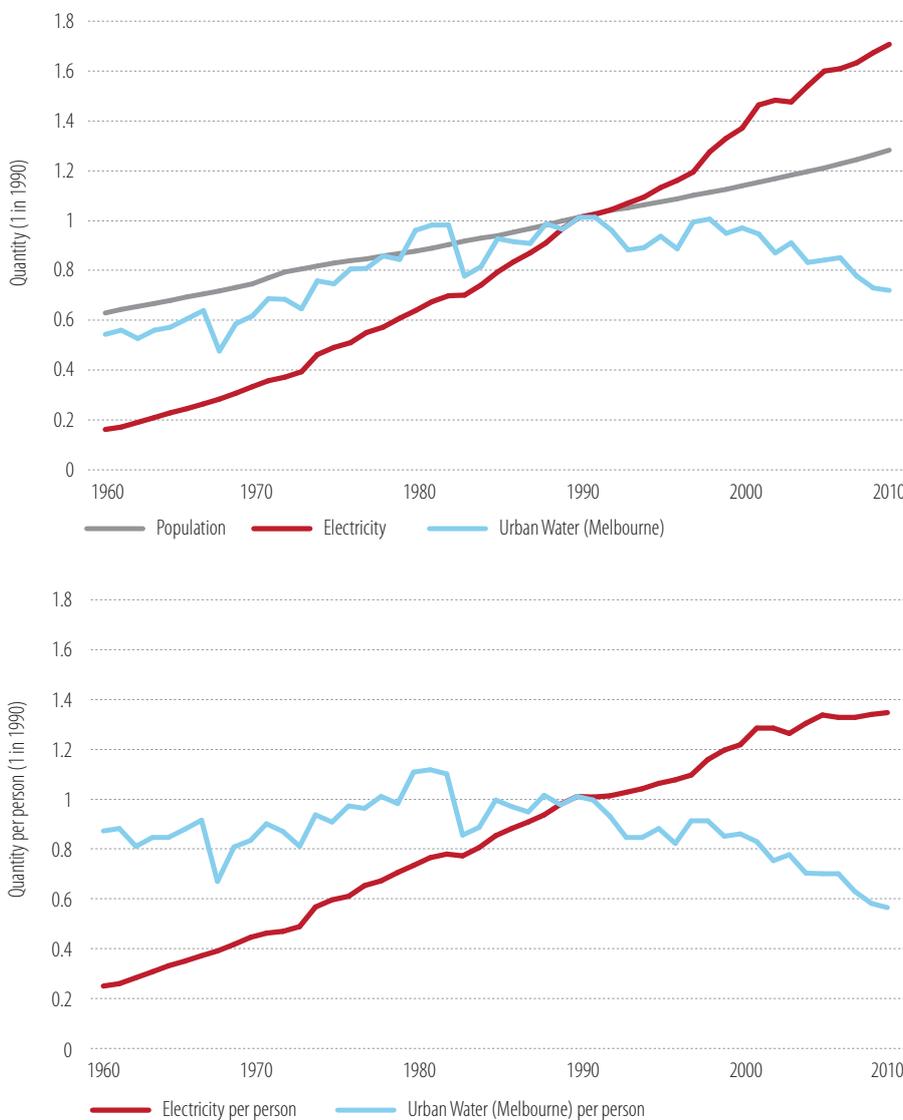


Figure 2.10: (top) urban water consumption in Melbourne, together with Australian population and Australian electricity consumption, all scaled to 1 in 1990, for comparison in relative terms; (bottom) urban water consumption per person in Melbourne and Australian electricity consumption per person, scaled to 1 in 1990. Population data from ABS (2008a), with updates; electricity data from ABARE (2009a); water data from Melbourne Water, as reported by Sachdeva and Wallis (2010).

2.4 Constraints on greenhouse gas emissions and water availability

Key points

- Water is a finite natural resource because its supply from nature is limited. Emissions of CO₂ are also finite, if risks from climate change are to be kept acceptably low.
- Global cooperation is necessary for each nation to minimise the domestic impacts and costs of climate change. Therefore, an appropriate contribution by Australia to the global greenhouse mitigation challenge is important.
- To keep climate change to a global temperature rise of 2 degrees or less, there is an all-time cumulative cap on global and Australian CO₂ emissions. For Australia to make a proportionate global contribution, our emissions, relative to 2000 levels, would need to fall by about 45 per cent by 2030 and over 85 per cent by 2050.

Australia faces constraints on both GHG emissions (if risks from climate change are to be kept low) and on water availability. These constraints are already significant and are expected to tighten as population rises.

It is well known that water is a finite natural resource because its supply from nature is limited. If effective action is to be taken to reduce the risk of dangerous climate change, cumulative emissions of CO₂ (the most important GHG leading to human-induced climate change) must also be considered finite. To limit global temperature rise to any particular value, there is a cumulative cap on global CO₂ emissions over the coming century (Allen et al, 2009; Meinshausen et al, 2009; Raupach and Canadell, 2010). This means that future CO₂ emissions are effectively a finite natural resource (see Box 2.1). Small emissions of CO₂ (and other GHGs such as methane) will be possible after the cap is reached, but these allowable, long-term emissions are much lower than current emissions and so do not affect the challenge of staying below the cumulative CO₂ emissions cap.

Box 2.1 Greenhouse gas emissions as a finite resource

Transformational thinking

Greenhouse gas (GHG) emissions have not traditionally been considered a finite resource. New ways of thinking about GHG emissions must, however, be adopted if we are to successfully mitigate climate change risk and manage carbon, energy and water systems.

Projections of future climate change and GHG emissions suggest there must be a limit on total cumulative emissions over the coming century if risks from climate change are to be kept acceptably low (Allen et al, 2009; Meinshausen et al, 2009). If we agree to place such a limit on global emissions we will be operating within a finite 'budget' or quota of cumulative emissions that can be released into the atmosphere. The capacity of the atmosphere and other natural systems to absorb emissions without harmful climate impacts then becomes a finite resource, as there will be only a certain amount that can be emitted before the capacity is reached.

A quota on emissions has similarities with the sustainable diversion limit (SDL) in the Murray–Darling Basin. The SDL is a quota for annual water extraction, established using scientific advice about the biophysical constraints on water resources in the Murray–Darling Basin (Murray–Darling Basin Authority, 2009). One of the objectives in determining the SDL is to keep the risks of environmental degradation from over-extraction of the water resource acceptably low. Once the SDL is decided, market and other mechanisms can be used to determine how best to share the finite water resource.

If we start thinking about GHG emissions in this new transformational way, we can then treat GHG emissions like a resource that must be allocated, managed and protected in a similar manner to other traditional resources with biophysically-determined constraints, such as water.

If we consider GHG emissions to be a resource, decide on a global quota for emissions and on a fair share of this resource for Australia (bearing in mind that all other nations will be making similar decisions), then we can explore further how Australia might 'spend' its 'allowance' of emissions in the future (Appendix A).

There is an important difference between water availability and CO₂ when each is regarded as a finite natural resource. The cap on water consumption arises from a constraint on the input from nature to human activities, which cannot be exceeded. The cap on CO₂ emissions is a constraint on the output of CO₂ from human activities to nature and is a matter of human choice—essentially between a pathway with continued high emissions and high risks of severe climate impacts, and a low-emission pathway in which risks from climate impacts are much lower.

At the level of individual nations, including Australia, there is a further critical choice about emissions constraints: how should the world share the remaining capped emissions, accounting for differences in development levels and trajectories among nations? In the present situation, where efforts to reach a global agreement are proceeding only slowly, nations need to make that choice for themselves. However, they do so with knowledge of the choices made by other nations and, consequently, the relative contributions of all nations to meeting the global challenge. This forces a degree of global cooperation between nations wanting to minimise the domestic impacts and costs of climate change. Australia is very much a part of this process; therefore, an appropriate contribution by Australia to the global greenhouse mitigation challenge is important.

To assess the magnitude of the connected constraints facing Australia for emissions and water, *Figure 2.11* shows recent and predicted future trends in Australia's population, CO₂ emissions, and rainfall and runoff in southeast Australia, at 10-year intervals from 2000 to 2050, in a scenario consistent with a '2 degree world' (see *Section 2.2 for a discussion of the impacts in Australia of a 2 degree rise in global temperatures*). All quantities are scaled to 1 in 2010 (grey bars) to aid comparison.

The future trajectory for CO₂ emissions shown in *Figure 2.11* is a possible course consistent with Australia acting with other developed nations to achieve emissions reductions aimed at limiting global temperature rise to 2 degrees (see *Appendix A and caption of Figure 2.11 for details*). To meet this challenge, Australia's total GHG emissions (relative to 2000 levels) would need to fall by about 45 per cent by 2030 and over 85 per cent by 2050. Emissions per person, relative to the present (2010), would need to fall by about 65 per cent by 2030 and over 90 per cent by 2050. The steeper per capita reductions arise both because population is increasing and because emissions have already risen from 2000 to 2010.

Southern Australia is a region where water stress is expected to increase rapidly (Vorosmarty et al, 2000), consistent with the Australian climate projections in *Section 2.2*. The trajectory in *Figure 2.11* for rainfall in southeast Australia (Victoria and southern NSW) represents a median fractional decrease of about 3 per cent by 2030 and 6 per cent by 2050. There is very large uncertainty in rainfall predictions, so these numbers are illustrative only, but they are broadly consistent with the projected climate changes shown in *Figure 2.4* and *Figure 2.5*, and with other estimates from climate projections (CSIRO, 2008; Chiew et al, 2009).

The fractional changes in runoff are much greater than in rainfall, because of the 'rainfall-runoff amplifier' in Australian landscapes (a 10 per cent decrease in rainfall leads to a 30 per cent decrease in available water in river flows (runoff); see *Section 2.2*).

The lower part of *Figure 2.11* shows the trends in CO₂ emissions per person, rainfall per person and runoff per person. Per capita emissions, rainfall and runoff decline more rapidly than the corresponding totals because the population is increasing. In particular, water availability per person (from runoff) is likely to fall over the coming decades by around 28 per cent to 2030 and 45 per cent to 2050. These steep declines are the result of population increases and also declining total water availability in southern Australia as a result of climate change.

In summary, *Figure 2.11* shows that constraints on CO₂ emissions and water availability place downward future trends on these resources, against a background of a growing population.

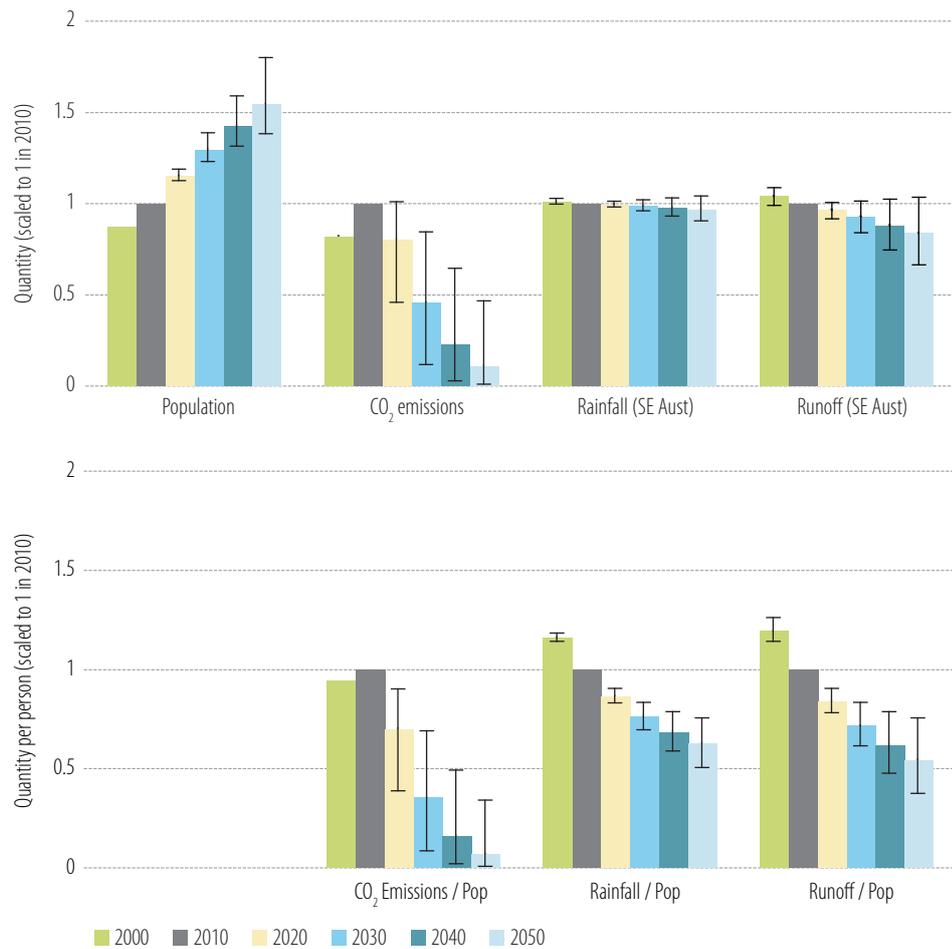
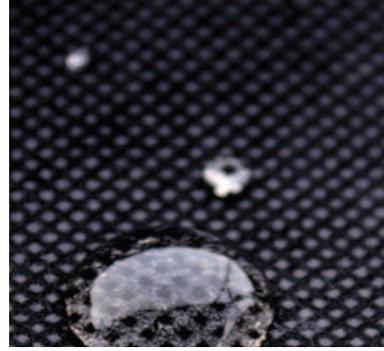


Figure 2.11: The upper panel shows Australia's projected future population and CO₂ emissions, and projected future rainfall and runoff in southeast Australia (Victoria and southern NSW) in a scenario consistent with Australia acting with other developed nations to limit global temperature rise to 2 degrees. Coloured bars represent 10-year intervals from 2000 to 2050. All quantities are scaled to 1 in 2010 (grey bars).

- Bars for population represent the middle ABS population scenario (scenario B: 34.0 million in 2050), with ranges showing high and low scenarios (A and C) (ABS, 2008b).
- The trajectory shown by the bars for CO₂ emissions is consistent with Australia having a share of 0.6 per cent of a cumulative quota of all global CO₂ emissions from 2010 onward. The range lines on the emissions bars represent Australian shares of 1.3 per cent (upper) and 0.3 per cent (lower), which are the shares that Australia would receive if the cumulative CO₂ quota were to be allocated to nations according to distribution of current CO₂ emissions (giving 1.3 per cent to Australia) and distribution of population (giving 0.3 per cent to Australia), respectively.
- Bars for rainfall represent a decrease in southeast Australian rainfall of –8 per cent per degree of global warming. The upper and lower ends of the range lines, respectively, represent models in which rainfall increases by 4 per cent per degree of global warming or decreases by 20 per cent per degree of warming. These rainfall predictions correspond approximately with published rainfall scenarios for southeast Australia (CSIRO, 2008; Chiew et al, 2009).
- Percentage changes in runoff amplify percentage rainfall changes three-fold (Zhang et al, 2004; Raupach et al, 2009).

The lower panel shows the resulting per capita changes in Australian CO₂ emissions and southeast Australian rainfall and runoff, assuming population increases according to the middle ABS population scenario (ABS, 2008b).



3. An Integrated System Perspective

This section examines the integrative concepts that are required to meet intersecting energy-water-carbon challenges, including the Earth System view; resilience as a critical concept for working with connected, evolving systems; and the critical role of knowledge and learning.

3.1 Connections in the Earth System

Key points

- An integrative perspective is essential because the Earth System—the total system formed by the natural world and its human inhabitants—is deeply connected.
- Energy, water and carbon underpin many of these connections and therefore interact with ecosystems, the economy and society.

The natural environment and human society are deeply connected through energy, water, carbon and other natural cycles such as nutrients. The total system formed by the natural world and its human inhabitants is known as the Earth System (*Figure 2.1*). In the past, human societies depended upon the natural environment but did not significantly influence it. In industrial and post-industrial times, humans are having a global effect upon the natural environment through climate change and in other ways, to the extent that this era has come to be known as the ‘anthropocene’—the era when humans are influencing the climatic and ecological processes that maintain their home planet (Crutzen, 2002; Steffen et al, 2004; Rockstrom et al, 2009; Raupach and Canadell, 2010).

Section 2.1 noted three ensuing basic realities for Australia: the connectedness of the system, the impact of climate change and the central role of water availability for Australian ecosystems, production systems and human societies.

Looking further into the human side of energy-water-carbon intersections, additional factors emerge:

- Human-induced climate change is predicted to result in impacts on Australia through increased temperatures, shifts in water availability including likely drying in southern Australia, shifts in agricultural productivity, increased fire risk, impacts on ecosystems and more (*Section 2.2*). Australia’s actions to reduce GHG emissions cannot, on their own, abate global climate change. However, these actions are important politically because they form part of an effective global response to a common challenge.
- Oil remains the single biggest contributor to global human primary energy supply (International Energy Agency, 2009b). It is very likely that global demand for oil will exceed supply within the next 20 years, with consequent increases in oil prices and increases in the economic competitiveness of renewable energy. Further, Australia’s domestic oil supplies are predicted to contribute a progressively smaller fraction of our needs in coming decades. As well as having a major effect on our international balance of trade, this has the potential to drive shifts in energy mix (such as an increased use of coal-to-liquid technologies), which will tend to increase GHG emissions and water use (*Sections 4.1 and 4.2*).
- Australia is the world’s largest coal exporter (International Energy Agency, 2009b). Further, coal and other fossil fuel exports represent our biggest source of export income. A global move to a low-carbon economy, with decreased demand for coal, is likely to have impacts on our terms of trade (*Sections 4.1 and 4.2*).

- Australian cities, industries and agriculture are between them using almost all the available water in southern regions. This is creating demand for additional water sources and increased water efficiency (*Section 4.3*), and also raising the need for good governance and market mechanisms to share finite water resources adequately (*See Section 5, Recommendation 1*).
- Energy-water-carbon intersections in land systems also interact with food production (*Section 4.4; Section 5, Recommendation 3*). Domestic responses to mitigate climate change and a high cost for imported oil are both likely to increase the economic attractiveness of bioenergy. Noting that Australia is a net food exporter, this would have both domestic and global impacts on the cost and availability of food. Food stress in developing nations could impede global efforts to reduce GHG emissions if land is cleared to meet increased demand for food production.
- Australia is a highly urbanised nation, implying that sustainable energy and water use in our cities is central to our future (*Section 4.5; Section 5, Recommendation 4*).

3.2 Resilience

Key points

- The fundamental energy-water-carbon challenge for Australia is to find pathways which combine a low-carbon economy, the ability to thrive under water limitation, social wellbeing and economic sufficiency—all in the presence of global uncertainties and shocks.
- A core concept that can guide the necessary integrative perspective is that of resilience. A resilient system can (1) recover from shocks and disturbances, (2) adapt through learning and (3) undergo transformation when necessary.
- Challenges at energy-water-carbon intersections confront Australian society with the need for both incremental and transformational changes.
- Transformational change requires ongoing innovative experiments by individuals at local scales, with support from government at the national scale, to provide the diversity essential for finding new pathways.

The need: The fundamental energy-water-carbon challenge for Australia is to find pathways which combine a low-carbon economy, the ability to thrive under water limitation, social wellbeing and economic sufficiency—all in the presence of global uncertainties and shocks. Some of the necessary changes may occur incrementally (relatively slowly and in small steps), while others will call for transformations (rapid changes in large jumps).

This fundamental challenge calls for an integrative approach to the system shown in *Figure 2.1*, because of the deep connections between system components. Several previous studies have used a variety of methodologies to examine the Australian economy, society and biosphere from an integrative perspective. These include (1) the triple-bottom-line analysis of *Balancing Act* (Foran et al, 2005), (2) an analysis of the physical economy (Turner, 2008), and (3) qualitative system-dynamics approaches (Proust et al, 2007).

Resilience: The Expert Working Group believes that a core concept that can guide the necessary integrative perspective is that of resilience (Walker et al, 2009; Folke et al, 2010). This way of thinking has the potential to unite the above methodologies and translate their implications into actions.

Three critical attributes of a resilient system are:

- the ability to recover from shocks and disturbances
- the ability to adapt through learning
- the ability to undergo transformation when necessary.

These attributes greatly increase the chances of making the both the incremental and transformative changes that are needed to meet the fundamental energy-water-carbon challenge.

Examples: Recent Australian history offers many examples of changes that illustrate how adaptation toward resilience can occur and some of the factors that assist or impede it.

First, a large-scale example is the economic reforms of the 1980s, especially tariff removal. These changes seeded a transformation of the Australian economy, with manufacturing shrinking steadily as jobs moved overseas and the service sector growing to a large fraction of the Australian workforce. Although there were winners and losers in the short term, it is generally agreed that the changes underpinned steady growth in national per capita wealth.

Second, an example at sectoral scale is the wool industry. The share of the fibre market held by wool has declined steadily over the last five decades, leading to incremental change in sheep grazing across Australia and also a transformative shock through the removal of the wool floor price in the early 1990s. The floor price had been introduced earlier to protect wool growers from international market shocks. While it did this in the short term, over the long term it led to declining resilience at the scale of the entire wool industry, and the transformative shock to individual growers when it was removed was severe. Many regional centres have not fully recovered from these two events.

Third, at an even more localised scale, towns built around a single industry have suffered different fates when those industries have moved on—as in the case of ‘timber towns’ in north Queensland and, more recently, along the lower Murray due to losses and changes in River Red Gum forests. In contrast, the loss of BHP Steel jobs from Wollongong was countered by growth in the higher education sector, through Wollongong University.

These examples demonstrate important and contrasting attributes of resilient and non-resilient systems. The Australian economy overall has replaced manufacturing with new service industries, helped in part by parallel changes in technology such as IT and the internet. In contrast, farming systems optimised for sheep grazing or forestry, for example, have struggled to find viable alternatives. In successful transformations, the systems are made resilient by having the ability to diversify through access to alternative options, through either serendipity or foresight. For instance, Wollongong and Newcastle now have access to diverse economic foundations, including education, as alternatives to their former main support in secondary industry. Before the change occurred, these diverse alternatives could have been seen as costly redundancies which stood in the way of economic efficiency. When shocks arrived, diversity became an essential attribute conferring the ability to recover.

An important point about transformational change is that it requires ongoing innovative experiments by individuals at local scales, and this requires support from government at a national scale. Such approaches are vital to move beyond a ‘state of denial’ about the need for change (‘we can keep doing what we’re doing if we just get a bit more efficient’). Getting beyond this state requires a change in higher-scale support, away from subsidies to not change (to keep on doing the same thing—drought relief for agriculture can be an example of this) and towards support for necessary change.

Hallmarks of resilient systems: Both resilience theory (Walker et al, 2009) and many practical examples indicate some important shared characteristics of resilient systems and the process of adaptation toward resilience:

- Resilient systems involve both the environment and the people (*Figure 2.1*), as both are interdependent.
- Resilience is achieved not by preventing disturbances and shocks—which is impossible—but by ensuring the ability to adapt and recover.
- A resilient society explicitly supports the evolutionary process of knowledge generation and applies knowledge effectively in support of natural, economic and societal goals. As with all evolutionary processes, three elements are involved: diversification (searching for successful strategies), sieving (selection of successful strategies) and amplification (convergence on successful strategies) (Dennett, 1995).
- Resilience perspectives provide the tools needed to turn potential crises into opportunities for transformation, because these are the times when the flexibility of the system is highest, or when ‘windows of opportunity’ are most open. At such a threshold point, the system can be guided in alternative directions with minimum effort.
- At energy-water-carbon intersections, adaptation towards resilience takes advantage of potential synergies and uses tensions as opportunities for change. Pathways consistent with such adaptation will reduce GHG emissions, lower overall water demand, maintain overall environmental quality and maintain or increase social and economic wellbeing. In contrast, there are many other pathways which have the potential to satisfy only some essential goals while worsening the outcomes for others, and may also lead to undesirable states from which recovery is difficult—for example, lock-in to high-emissions pathways.

- Because successful adaptation towards resilience involves evolutionary learning through diversification, sieving and amplification (see the third dot point, above), risk-taking and 'safe failure' at small scales are essential for overall success at large scales. The notion of 'learning by doing' requires an environment in which systems can fail safely and adapt.

3.3 Knowledge and learning

Key points

- The resilience perspective defines key roles for knowledge and learning, which are central to success under incremental and transformative change.
- Australia has a highly effective knowledge system at disciplinary and sectoral levels.
- This system must meet massive new challenges created by the connections between energy, water, carbon and beyond to ecosystems, the economy and society. These connections, together with the need for overall resilience, demand integrative perspectives.
- There is a need to strengthen Australia's capacity for integrative knowledge. The existing focus is on knowledge generation and application in specific sectors. Integrative perspectives require a new, overarching component in the knowledge system.

The critical role of knowledge and learning: The resilience perspective defines key roles for knowledge and learning, which are central to success under incremental and transformative change. Economic historians describe several 'long waves of innovation' that have, in the past, resulted in large scale transformations in modern economies (Freeman and Louca, 2001). Examples include the emergence of steam power and mechanisation; the associated industrial production of cotton, iron and other goods; railways; the age of steel and heavy engineering; electrification; the Great Depression; the age of oil; automobiles; automated mass production; and the emergence of new techno-economic paradigms around information and communication technology. The need to adapt to a resilient energy-water-carbon future will engender transformations that are just as profound. As in previous transformations, instability and threshold crossings will be hallmarks of the process. New paradigms will emerge as society, science and technology, social structures, institutional frameworks and cultural standards respond to rapid change.

Australia's knowledge system: Australia has a knowledge system which is populated by talented, dedicated people and performs better than world average by many measures (Productivity Commission, 2007). This system must meet massive new challenges created by present demands for new knowledge and applications in energy, water, carbon and related domains, including food, agriculture and ecosystem health.

The knowledge system must explicitly support the evolutionary process of knowledge generation and must apply knowledge as effectively as possible in support of natural, economic and societal goals. To fulfil these roles, an effective knowledge system:

- embraces basic science, foresighting, integration, and design and engineering
- facilitates the dialogue between research providers and users in policy, management and the private sector
- has rational priority setting which balances diversification, selection and amplification
- is adequately funded on time scales consistent with the innovation cycle
- is nurtured at the highest levels of government
- is integral to society
- interacts with the global knowledge system, as purely national approaches are proving insufficient to cope with the confluence of challenges arising from climate change and the need for sustainable growth.

Evolution in the knowledge system: Australia's learning and knowledge systems have already adapted to global opportunities and challenges. Indigenous knowledge preceded European settlement and has endured. Major adjustments to the European-derived knowledge system occurred as a result of its transfer to the Australian colonies, and also through the Great Depression and war. The 'modern' innovation system was formalised nationally in 1916 with the establishment of an Advisory Committee for Science and Industry, chaired by the Prime Minister, W.M. Hughes (National Archives of Australia, 2010). The Council for Scientific and Industrial Research (CSIR) was established in 1926, becoming CSIRO in 1949. Industrial science was required to develop the primary and secondary industries that would generate national wealth for a growing population. These industries developed under changing conditions and were based on the resources that were available at the time.

More recently, sustained growth—including rapid growth in the higher education sector and a desire for stronger research-industry linkages—has resulted in the addition of new components to the knowledge system, such as Cooperative Research Centres and Centres of Excellence that work across government, academic and private institutions. There is increasing interest in balancing public and private investment in research and development as total demand for innovation has increased. Today, technological 'supply' includes gross (public and private) expenditure on research and development of more than \$20 billion per annum (ABS, 2007a).

The application of knowledge varies across different domains—for example, through the relative reliance on public and private funds, the profile of underpinning disciplines, scale of technology-adopting enterprise, domestic capacity and the global R&D environment. Australia's rapid industrialisation has resulted in advanced capabilities in energy, transport, water, land use and urban development. These achievements are testimony to Australia's underlying scientific and technological strengths, including areas of world leadership.

The need for integrative perspectives: The knowledge system as a whole is generally market-based. Australian Government-funded agencies and programs must comply with Innovation Priorities (see DIISR, 2009) and National Research Priorities (*an environmentally sustainable Australia; promoting and maintaining good health; frontier technologies for building and transforming Australia; and safeguarding Australia*; DIISR, 2010a) as well as program-specific objectives. Similar priority-setting frameworks exist at the state government level. This 'purchaser-provider' approach to public funding can support incremental (and transformative) sector-level change *if* program-level objectives adapt to energy-water-carbon intersections and the resulting constraints. Business-sector innovation priorities will adapt as pricing structures for carbon, energy and water take effect. Hence, systems that can support the generation and application of *sectoral* energy, water and carbon knowledge are well-established.

However, twenty-first century problems also need *integrated* knowledge (*Figure 3.1*). Large cross-disciplinary projects are not readily accommodated in the current system. Institutional arrangements in some cases act against the generation of the integrated, cross-disciplinary knowledge that is now required. If funded, such projects tend to be relatively short-term or relatively small. Industry-specific requirements and fragmentation of responsibilities across government departments act against a coherent 'pull' for integrative knowledge. Such impediments prevent the Australian innovation system from functioning to best effect to meet contemporary, rapidly evolving challenges. *Appendix B* shows the multiplicity of Commonwealth portfolios currently involved in energy, water and carbon research (and the absence of a specific reference to water research policy carriage, in contrast to equivalent references for energy and carbon) and *Appendix C* lists a number of research provider programs. This multiplicity confounds the potential of the system—as it is now structured—to achieve a competitive and contestable market for integrative research.

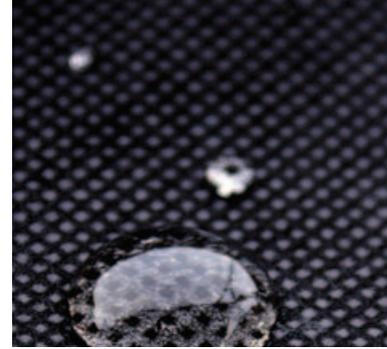
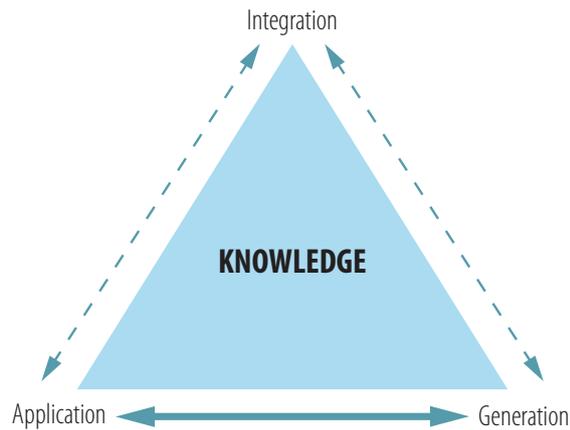


Figure 3.1: There is a need to strengthen Australia's capacity to integrate energy, water and carbon knowledge. Existing processes focus on the relationship between knowledge generation and application in specific sectors, often through purchaser-provider relationships (the bottom side of the triangle). Energy-water-carbon challenges also demand an integrative perspective, which requires a new, overarching component in the knowledge system.

Additional action will be required to promote knowledge integration: There is an immediate need (see Section 5, Recommendation 5) for PMSEIC to signal that energy-water-carbon and associated connections require a focused research effort in their own right—they should not simply set the environment within which specific disciplinary or sectoral work is pursued. This will require significant human capital (DIISR, 2010b). Such reforms are important because the present forces pulling towards essential integration are patchy and inconsistent. In an era of rapid transition it is critical to understand the whole as well as its parts.

Global alliances for interdisciplinary research are fostering integrative learning and knowledge systems across disciplines. Examples include the World Climate Research Program (www.wcrp-climate.org), focused on the physical climate system; the International Geosphere-Biosphere Program (www.igbp.net), with biophysical and ecological focuses; the International Human Dimensions Program (www.ihdp.unu.edu), with a focus on social research; the biodiversity program Diversitas (www.diversitas-international.org); and the fully integrative Earth System Science Partnership (www.essp.org) embracing all of the foregoing four programs.

The absence of comparable programs at the national scale in Australia is striking. Three steps are necessary to rectify this. First, the institutional barriers that foster research segregation must be removed and replaced by factors that promote generation of integrated knowledge. Second, a focused initiative to increase the rate of integrated knowledge generation is necessary, if lost ground is to be made up. Third, systems that ensure continuing, long-term collection of the data that allow integrated analysis of the energy-water-carbon system must be guaranteed. These issues are addressed in Section 5, Recommendation 5.

4. Outlook: Challenges and Opportunities

This section analyses five sectors that play central roles in energy-water-carbon intersections: stationary energy, transport energy, water systems, land systems and urban systems. The analysis provides the evidence base to support the recommendations described in *Section 5*, noting that all recommendations are trans-sectoral.

4.1 Stationary energy systems

Key points

- The future outlook for the Australian stationary energy sector involves a major energy-carbon tension, as reduction of its greenhouse gas emissions is critical. There is also an energy-water intersection through the need to ensure that its significant water requirements are met.
- Many technical options are available to meet this challenge, but no single technology can fulfil all requirements alone.
- Power generation costs will tend to increase if greenhouse gas emissions are limited. However, these costs will be offset by two major benefits: reduction of risks from climate change impacts, and export opportunities in a changing world.
- Consistent principles for the pricing and accounting of carbon emissions and water will be crucial to guide the necessary technological transformations (*see Section 5, Recommendation 1*).
- Smart distribution networks have great potential to enhance efficiency and effectiveness throughout the energy production, distribution and consumption system (*see Section 5, Recommendation 2*).

Situation and outlook: By world standards, Australia has a low-cost stationary energy system. In 2007–08, 76 per cent of Australia's electricity production (925 PJ or 257 TWh) was generated by the combustion of black and brown coal, with the remainder from gas (16 per cent) and renewable sources (hydro, wind, solar, biomass; 7 per cent) (ABARE, 2010a; Geoscience Australia and ABARE, 2010).

Because of its high reliance on coal, Australia has a relatively high GHG emission intensity in its domestic stationary energy sector compared to other industrialised economies, which have historically made use of greater available hydroelectric resources or deployed nuclear power on a significant scale (*see Table 2.1*). The stationary energy sector is also a significant water user, consuming about 4 per cent of non-agricultural water (ABS, 2006).

Australia is also a major exporter of fuel for stationary energy: around two-thirds of Australia's primary energy production is exported, mainly as black coal and uranium (ABARE, 2010a). Since 1986 Australia has been the world's largest coal exporter, and since 1989 has become one of the largest exporters of natural gas and uranium (ABARE, 2009a; International Energy Agency, 2009b; ABARE, 2010a). In 2008–09, the value of Australian coal and liquefied natural gas (LNG) exports amounted to around \$55 billion and \$10 billion, respectively (ABARE, 2010a). Both these exports are rising rapidly, largely from global demand spurred by growth in developing countries. Despite the high energy content of exported uranium, its monetary value was significantly lower at about \$0.9 billion.

The energy sector is capital-intensive, accounting for around 13 per cent of Australia's total capital stock. The sector generates 8 per cent of Australia's Gross Domestic Product (GDP) and employs between 1 and 2 per cent of the Australian work force (ABARE, 2010a).

The future outlook for the Australian stationary energy sector involves a major energy-carbon tension, as reduction of its GHG emissions is critical. There is also an energy-water intersection, through the need to ensure that the significant water requirements for energy generation are met.

Box 4.1 briefly surveys the main technical options available to meet this challenge. Together, these technologies offer a wide choice of possible scenarios, but no single technology can fulfil all requirements alone. The future stationary energy mix will be shaped by wide range of factors including energy-water-carbon intersections and also other economic, environmental and social concerns.

Pathways to meet the energy-carbon challenge: Figure 4.1 illustrates a possible pathway for the Australian stationary energy sector to reduce its GHG emissions to an extent consistent with eventual stabilisation of global atmospheric GHG concentrations at 450 parts per million (ppm) CO₂eq. This GHG mitigation scenario involves cuts in Australia's emissions to 75 per cent of 2000 levels by 2020 and to 10 per cent of 2000 levels by 2050 (Garnaut, 2008). The scenario analysis by the CSIRO Energy Futures group (Paul Graham, pers. comm.; Wright, 2009) determines the minimum-cost pathway to meet the emissions constraint. The scenario shows strong growth in renewable energy technologies (such as wind, solar and geothermal), which make up around three-quarters of Australian stationary energy by 2050 in this scenario. No significant growth is foreseen in the contribution from hydroelectricity because potential Australian resources are essentially already committed. The scenario has a progressive increase in carbon capture and storage from coal and gas from 2020 onward, to make up most of the remaining quarter of stationary energy by 2050. Nuclear energy was not included in this scenario, but similar scenarios which do include nuclear indicate that it becomes cost-effective only after several decades, and even then contributes only a small fraction of total stationary energy. It should be noted that such scenario analysis depends on assumptions about the evolution of technology costs and input costs over time, and is not a prediction of what will actually happen.

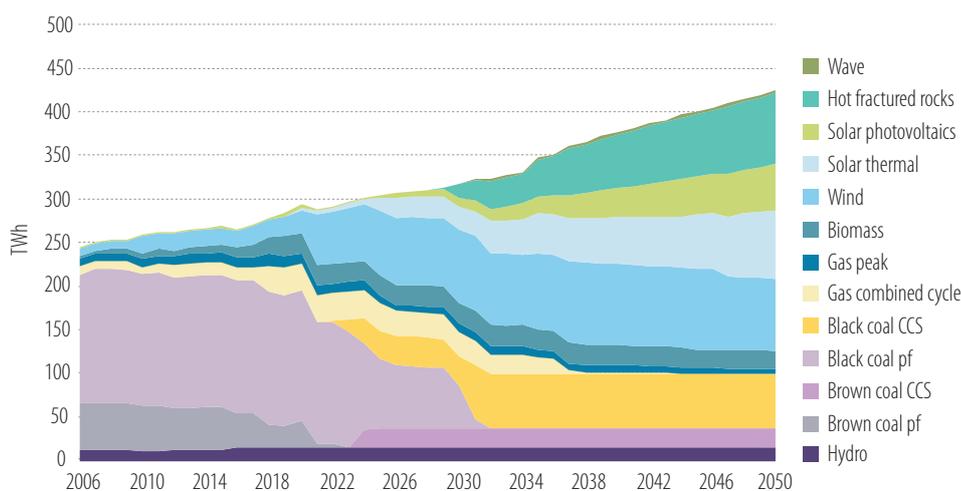


Figure 4.1: Scenario to 2050 for a mix of stationary energy technologies consistent with stabilising GHG concentrations at 450 ppm CO₂eq. Scenario analysis using the CSIRO Energy Sector Model by the CSIRO Energy Futures group (Paul Graham, pers. comm.). CCS is carbon capture and storage. TWh is terawatt-hours (10¹² watt-hours; a unit of energy).

Changes like those indicated in Figure 4.1 will tend to increase power generation costs. For example, a cut in Australia's GHG emissions to 25 per cent below 2000 levels by 2020 is projected to cost A\$185 per household per year (ClimateWorks Australia, 2010), about 0.3 per cent of the average annual income in Australia for full-time employed adults (about \$65 000 in 2010). Economic modelling suggests this strong mitigation scenario would have an overall cost to the Australian economy of around 0.1 per cent of annual economic growth to 2020 (Garnaut, 2008).

It is critical to note that cost increases to support emissions reduction are modest relative to growth rates in the economy and can be economically affordable with appropriate development pathways (McKinsey & Company, 2008; Daley and Edis, 2010). These increases in costs must also be seen in the context of two major benefits that they would bring: improved resilience through mitigation of climate change as Australia plays its part in a global effort, and positioning Australia at the leading edge of global changes in the stationary energy sector, with associated opportunities for export of technologies and knowledge.

Box 4.1 Stationary energy options (in alphabetical order)

Bioenergy from solid biomass such as wood waste is already used to fire thermal power stations. Liquid biofuels are used mainly for transport. The use of bioenergy could grow rapidly if the price of energy rises sufficiently. Bioenergy is, in principle, CO₂-neutral, but not GHG-neutral, because of non-CO₂ emissions from fertiliser use and other sources. Increased bioenergy production would introduce pressures on water use and compete for land with food production and natural forests.

Coal is currently Australia's main source of stationary energy. Advanced power stations employ supercritical steam pressures to boost efficiency. Integrated Gasification Combined Cycle systems with even higher efficiencies are near deployment. These higher efficiencies reduce GHG intensities, but not enough to meet the GHG emission constraints outlined in *Section 2*. Investment in new large-scale stations locks in the associated emissions pattern for many decades. Further, all thermal power options require cooling: wet cooling with fresh water is water-intensive, but other options (air cooling or sea water cooling) are available in some circumstances (Smart and Aspinall, 2009).

Clean coal requires the addition of Carbon Capture and Storage (CCS) technology to advanced coal plants. CCS is yet to be demonstrated on a utility scale and will increase generation costs. CCS processes will likely have energy and water penalties.

Gas combined cycle uses a gas turbine, followed by the use of the hot exhaust to operate a steam turbine system to get the highest conversion efficiencies available in commercial power plants. The high conversion efficiency and lower carbon content of gas leads to CO₂ emissions only one-third those of coal. Australia already has a number of these systems and a price on carbon would likely lead to wider adoption. Cooling water use is also reduced. Emissions are still significant and investment locks in future emissions.

Geothermal energy has promise but is yet to be demonstrated commercially in Australia. Most potential sites are in remote areas with limited access to cooling water. This is significant, because geothermal system operating temperatures and hence efficiencies are low, increasing cooling water needs. There may also be significant water needs associated with recirculation of water through the bore holes.

Nuclear energy is free of direct CO₂ emissions but remains prohibited in the Australian stationary energy sector. It is the subject of significant community concern. It has potentially high cooling water requirements, commensurate with its use of relatively low-temperature, low-efficiency power cycles. A recent report on nuclear power in Australia (Australian Government, 2006) noted that 'the earliest that nuclear electricity could be delivered to the grid would be 10 years, with 15 years more probable' and costs are significantly higher than for coal-fired electricity, including a high capital cost of plants. The time to implementation and cost mean that nuclear has low potential to contribute to rapid emissions reductions.

Solar photovoltaics use silicon wafers to generate electricity directly from sunlight. Australia has huge, though widely spread, solar resources. Solar photovoltaic systems generate electricity with no direct CO₂ emissions or water consumption. Their disadvantages are a high capital cost and the fact that they only generate when the sun is shining. Costs, however, are decreasing. If implemented on a large scale, the panels will affect runoff. There may be a small water requirement for cleaning.

Solar thermal power systems are commercially available and use mirrors to focus sunlight to create heat for steam turbine-based power generation. Like photovoltaic systems they offer emission-free generation and use of our huge solar resource. Their advantage over photovoltaics is that thermal energy storage can be built in to allow generation on demand. Costs are high but expected to drop rapidly as the industry expands. Being thermal systems, they also have significant water consumption if wet cooling is used, together with water for mirror cleaning. Local runoff will be affected by large installations.

Wave and tidal energy are emission-free renewable sources at very early stages of commercial deployment. In good sites they have potential to be economically attractive in the future, but are unlikely to make major contributions in a 20-year time frame. There are some intriguing proposals to operate desalination systems directly with wave power.

Wind energy is the largest global renewable energy success story of the past two decades. Sustained growth of around 20 per cent per year has raised installed capacity worldwide and in Australia to around 1.5 per cent of electricity generation. Continued exponential growth would mean that the contribution over the next 20 years could be substantial. Much of Australia's expanded Renewable Energy Target is expected to be met with wind power. Wind power has no direct emissions, no notable water issues, but is limited in its maximum contribution by its inability to generate on demand and by site choice issues.

The challenge in finding a pathway like that in *Figure 4.1* will be to develop the appropriate mix of technologies, locations and demand management to maximise cost-effectiveness and minimise GHG emissions, against a background of rising demand for energy. Forecasts (Syed et al, 2007; Geoscience Australia and ABARE, 2010) suggest that total primary energy demand in Australia will increase by 35 per cent to 2030, and electricity demand by 50 per cent, at a growth rate of nearly 2 per cent per year, which is faster than population growth. This increasing demand, combined with the need to restrict carbon emissions, puts even more urgency on the need to rapidly decarbonise Australia's stationary energy systems.

Energy-water intersections: An important consideration in the stationary energy sector is the water requirement for electric power generation. Lower water availability in southern Australia in coming decades (see *Section 2.2*) will increase the risk that there will be insufficient water for this purpose, particularly as energy demand increases. Currently, around 270 GL is consumed by the electricity and gas sector, mostly for steam make-up and cooling of coal and gas fired power stations (ABS, 2006; Smart and Aspinall, 2009). When evaporative cooling is employed, 90 per cent of the water consumption of a power station is used for that purpose, as occurs in 65 per cent of the power stations supplying the Australian electricity market. The consumption of 271 GL in 2004–05 is around one-eighth of the water consumed by Australian households (2108 GL) and constitutes 4 per cent of total non-agricultural water consumption (6523 GL; ABS, 2006), making the power generation sector a significant water consumer. Consequently, there are concerns about water availability, quality and location as the power generation industry grows to meet increased demand (Smart and Aspinall, 2009). A non-consumptive water use by the sector is for in-stream flow for hydroelectricity generation, but this flow is returned to the environment after use and is therefore not defined as consumption. In 2004–05 the hydroelectric industry used around 59900 GL of water for this purpose (ABS, 2006).

Major further growth in hydroelectricity in Australia is unlikely (*Figure 4.1*), so most growth in water demand will come from thermal power stations: coal, gas, solar and geothermal (plus nuclear, if adopted). Each of these technologies will have its own water requirements (Ikeda et al, 2007a; Ikeda et al, 2007b; Smart and Aspinall, 2009). In particular, new-generation, water-cooled, low-emission thermal plants incorporating carbon capture and storage (CCS) are likely to be up to one-third more water-intensive than current technology. Solar thermal and geothermal power plants are also likely to have significant water intensities.

There are many opportunities to address the energy-water challenge, including increasing water use efficiency, recycling plant waste water, dry cooling, use of purified recycled water, saline water cooling, desalination and regional water management schemes (Smart and Aspinall, 2009). The potential for increasing the water efficiency of electricity generation is shown by the fact that the industry has already implemented programs that have reduced water use by up to 15 per cent per MWh (Smart and Aspinall, 2009) without compromising the efficiency of electricity yield.

The available options present different opportunities and challenges. Recycling plant storm water and operational run-off water is a low-energy option (0.002 kWh of electricity per kL of recycled water) that has minimal effect on sent-out electricity efficiency. Greater use of dry cooling can reduce water consumption in thermal power plants by up to 90 per cent. However, dry cooling also reduces the sent-out electricity efficiency by around 2–3 per cent, leading to an increase in GHG emissions per MWh of up to 6 per cent. For a solar thermal power station, the effect of the efficiency penalty is seen in a higher cost of electricity. By their nature solar thermal stations are likely to be sited in high-sunshine areas, which often have low water availability. Use of saline water cooling does not affect sent-out power efficiency, but is usually only economically feasible near the coast. Use of water from coal seam methane extraction may be a future option. Use of purified recycled water as an alternative source of freshwater is becoming more prevalent in Australian power stations and the use of treated sewerage effluent has been studied. Use of desalinated water is an option, but carries with it an energy penalty (with associated GHG emissions) of between 3 and 4.5 kWh of electricity per kL of freshwater produced (GHD, 2003; Watson et al, 2003; Australia Institute, 2005). This means that if desalination were to be used to supply water to a large coal-fired power station, about 1 per cent of the electricity generated would be used by the desalination plant (Smart and Aspinall, 2009).

Where water is used for evaporative cooling, the implied monetary value for that water arising from the extra electricity generated is around \$1500 per ML, or even higher for solar thermal systems. This is higher than either urban or irrigation water prices. Coupled with the relatively small fraction of total water consumption involved, this argues against simply phasing out evaporative cooling. Rather, appropriate decision-making methodologies are needed (see *Section 5, Recommendation 1*).

Given the predicted increase in power demand, the likely overall increase in water consumption of new, lower-GHG generation technologies and the likelihood that Australia will face evermore limited water supplies, research priorities need to include the development of low water-use energy technologies.

4.2 Transport energy systems

Key points

- Transport systems need to become much less greenhouse gas-intensive over the next 20 years if greenhouse gas emission reductions are to be achieved.
- The dominant role of transport in urban environments creates major opportunities when combined with the possibility of increasing urban amenity and resilience (see Section 5, Recommendation 4).
- Many options for reducing the greenhouse gas intensity of transport carry implications elsewhere: for example, increased use of electricity for transport will require decarbonisation of stationary energy, while increased use of biofuels has implications for water use and food production (see Section 5, Recommendation 3).
- In the absence of a price on carbon there is potential for a major increase in emissions if rising oil prices lead to the adoption of more greenhouse gas-intensive alternatives.

Situation and outlook: Australian roads are host to about 15 million vehicles, 77 per cent of which are passenger vehicles with an average age of 9.7 years. The fleet has been growing at 2.9 per cent per year since 2003. The transport sector is the largest user of final energy in Australia at around 35 per cent (ABARE, 2010a). It is also responsible for approximately 14 per cent of Australia's total GHG emissions (DCCEE, 2010b).

Australia's current transport fuel mix is shown in Figure 4.2. Petrol is the dominant fuel used by passenger and other light vehicles, while diesel dominates the heavy vehicle sector (trucks and buses). The other significant fuels are liquefied petroleum gas (3 per cent) used by high distance vehicles such as taxis, a growing supply of E10 (10 per cent ethanol in petrol) and compressed natural gas used by bus fleets. Average fuel consumption has not changed greatly over the last decade (ATC and EPHC, 2008): as engine efficiency has increased, so too has engine size. In 2005, the overall fuel efficiency of Australia's passenger vehicles was 11.2 L per 100 km compared with the European average of around 8 L per 100 km. However, with the entry of smaller, more fuel efficient vehicles into the Australian market, overall fuel efficiency is starting to improve (ATC and EPHC, 2008).

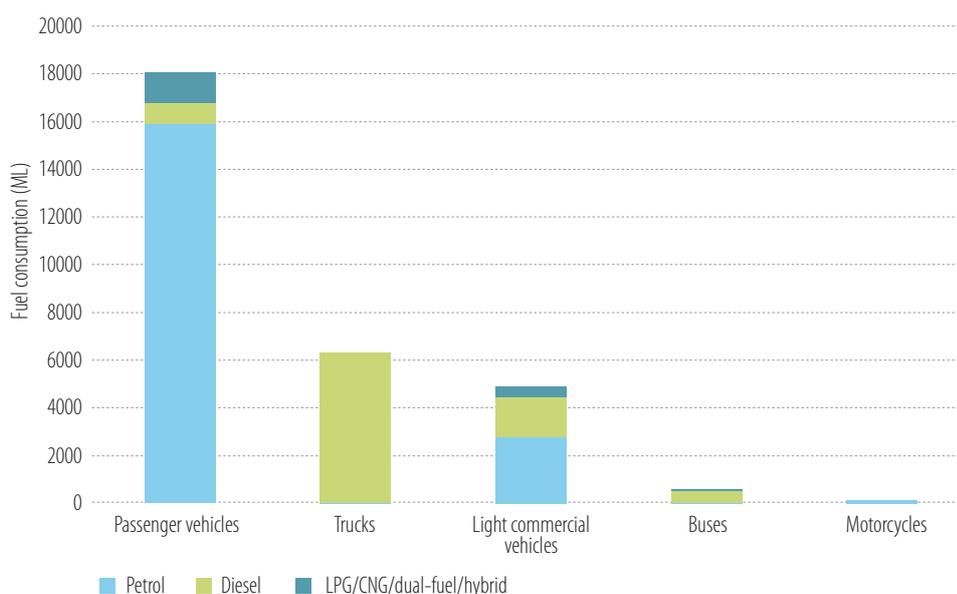


Figure 4.2: Australia's transport fuel mix in 2006 (ABS, 2007b). Trucks include rigid, articulated and specialised trucks. LPG is liquefied petroleum gas, CNG is compressed natural gas, ML is million litres.

Australia's transport fuel supply: The gap between Australian oil production and imports has been widening over the last two decades, particularly as our petroleum demand has increased. While the gap has not been a major issue so far, it becomes a concern when the oil price rises, due to changes in global prices and/or exchange rates. In the June quarter of 2008, Australia's oil trade balance was a deficit of 1.8 per cent of GDP, with an increasing trend. Since oil is an internationally-traded commodity and Australians pay world oil prices for the shortfall between demand and domestic production, our vulnerability to rises in the oil price will increase as our domestic supply diminishes. This will continue while we remain dependent on petroleum products as our major source of transport fuels.

Changing vehicle and fuel technology: Figure 4.3 illustrates possible changes in vehicle technology for the Australian transport sector to reduce its GHG emissions consistent with stabilisation at 450 ppm CO₂eq, and to simultaneously reduce its dependence on imported oil. As in Figure 4.1, this scenario analysis determines the minimum-cost pathway to meet the emissions constraint while also taking account of increases in the world oil price. In the scenario the Australian fleet will become increasingly electrified, with growing use of hybrids, plug-in hybrid electric vehicles (PHEVs) and pure electric vehicles. Despite the strong predicted trend to electrification, it is anticipated that ongoing use of hybrid, plug-in hybrid and fully internal combustion engines will cause on-board combustion of liquid fuels to remain the dominant source of energy for transport until 2050.

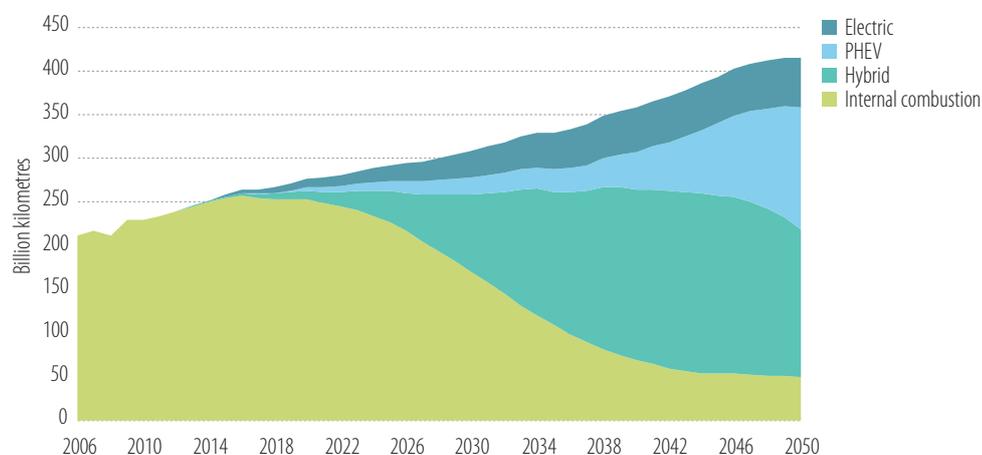


Figure 4.3: Scenario to 2050 for a mix of vehicle technology types consistent with stabilising greenhouse gas concentrations at 450 ppm CO₂eq. Scenario analysis using the CSIRO Energy Sector Model by the CSIRO Energy Futures group (Paul Graham, pers. comm.). PHEV is plug-in hybrid electric vehicle.

Figure 4.4 shows the changes in the transport energy mix that accompany the vehicle technology scenario in Figure 4.3. In this scenario there will be greater use of alternative fuels such as ethanol from bio-sources (biofuels, see Section 4.4), diesel from gas and coal (combined with CO₂ geosequestration), and liquefied or compressed natural gas (LNG or CNG; particularly for heavy transport).

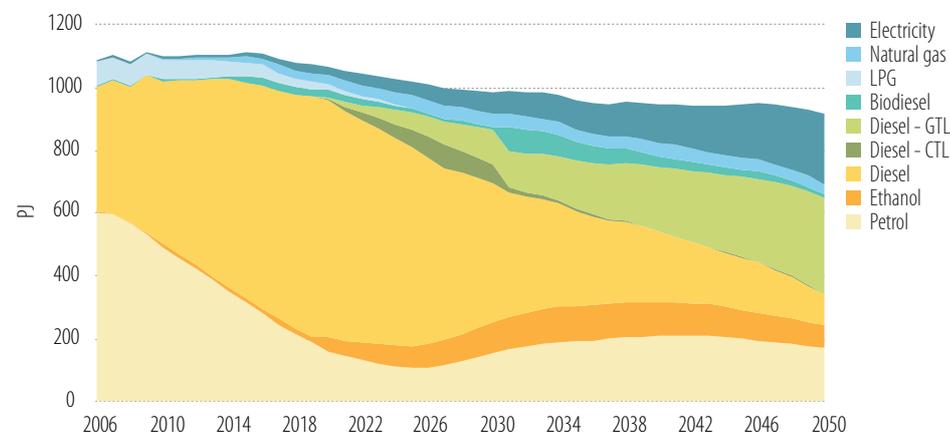


Figure 4.4: Scenario to 2050 for transport energy sources (in Petajoules (PJ) per year) consistent with stabilising greenhouse gas concentrations at 450 ppm CO₂eq. Scenario analysis using the CSIRO Energy Sector Model by the CSIRO Energy Futures group (Paul Graham, pers. comm.). LPG is liquefied petroleum gas, GTL is gas-to-liquid, CTL is coal-to-liquid.

The scenario also indicates a strong increase in the demand for electricity to power plug-in hybrids and electric vehicles. This would have to be supplied by the electricity grid, which would need to be progressively decarbonised from a current GHG intensity of around 0.9 tCO₂eq/MWh (IEA, 2009a; Climate Group, 2009; DCCEE 2010c) to around 0.2 tCO₂eq/MWh by 2050. Until 2030 the increase in electricity consumption due to electric vehicles is likely to be relatively small, but demand is expected to increase strongly from then until 2050, implying a 12 per cent increase in total electricity production to service demand. People are likely to charge their cars overnight, which will assist in smoothing out electricity demand and may increase generation and distribution efficiencies. Electric vehicles' stored energy could be used to return power to the grid at times of high demand. The management of the charging process and possible two-way flows will require the advancement of smart grid technology to maximise these benefits (see Section 5, Recommendation 2).

The projections of technology and fuel mix in Figures 4.3 and 4.4, along with those for stationary energy in Figure 4.1, are based on an assumption of global mitigation of greenhouse gas (GHG) emissions to keep concentrations to 450 ppm CO₂eq. In the absence of such mitigation, it is likely that the stationary energy technology mix will change little from the present. However, a low-mitigation scenario could also see a changing transport energy mix that causes a major increase in GHG emissions because of global oil shortages as resources are exhausted. Expensive alternatives to conventional oil supplies (such as the conversion of coal to liquid fuels and the use of shale oils) will become economically viable if international oil prices rise sufficiently and there is no price on carbon. These alternatives have much higher GHG emissions per unit of energy: for instance, the use of shale oil produces two to three times more CO₂ than the use of conventional oil (International Energy Agency, 2009c). Figure 4.5 shows the production costs and resources for all the main oil options. Those that become economically viable above an oil price of US\$50 to \$60 a barrel, (to produce petrol and diesel products equivalent to conventional oil) have considerably higher GHG emissions per unit of energy.

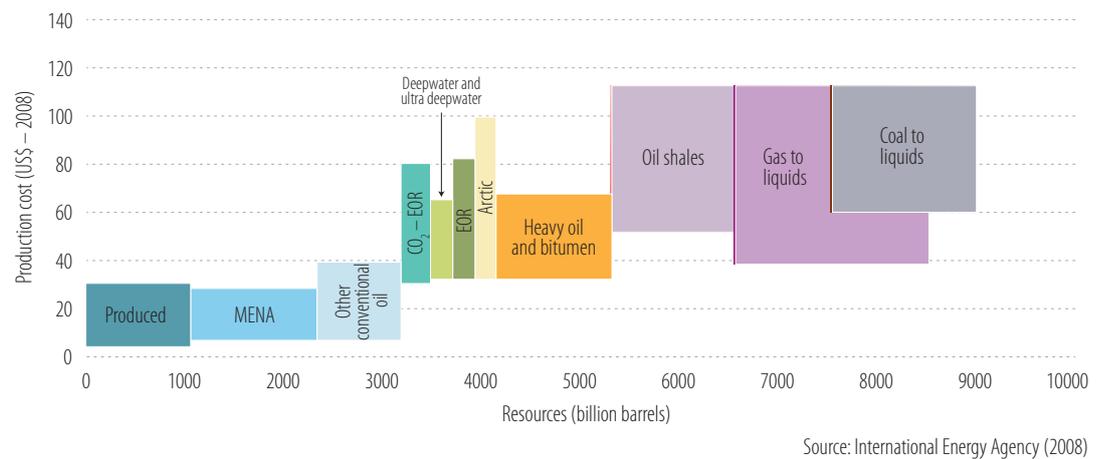


Figure 4.5: Long-term oil supply cost curve. The height of the boxes represents the estimated range of production costs for each oil resource; the width shows the estimated availability of the resource. Gas-to-liquids and coal-to-liquids are overlapping to indicate the range of uncertainty surrounding the size of these resources, with the combined width showing a best estimate of the likely total availability of the two. There is also a significant uncertainty on oil shale production cost, as the technology is not yet commercial. Cost associated with CO₂ emissions is not included. MENA is the Middle East and North Africa; CO₂-EOR is carbon dioxide enhanced oil recovery; EOR is enhanced oil recovery (International Energy Agency, 2008).

The role of hydrogen in Australian transport needs to be clarified, especially in the light of the huge investments being made by most overseas car and bus companies in fuel cells, hydrogen generation and distribution systems.

Adopting the changes in vehicle technology and alternative fuels shown in Figures 4.3 and 4.4 would result in the Australian transport sector playing its role in reducing overall Australian GHG emissions by around 20 MtCO₂eq/year by 2030 and up to 40 MtCO₂eq/year by 2050, against a backdrop of increasing population.

Energy-water-carbon intersections: Australia's transport future depends on many factors, including requirements for environmental sustainability, technological innovation and cost effectiveness.

Constraints on GHG emissions, together with rising world oil prices, are likely to drive changes in transport technology (*Figure 4.3*). The necessary alternative fuels (*Figure 4.4*) are likely to require increased water use in production and processing, particularly those from bio-sources and those using carbon capture and storage.

There is encouragement coming from both government and industry through voluntary fuel efficiency measures for both light and heavy duty vehicles, building more fuel-efficient vehicles in Australia through the \$6.2 billion 'A New Car Plan for a Greener Future' with its Green Car Innovation Fund and public education initiatives such as the 'eco-driving' program.

Public preference and choice will also play a role in deciding Australia's transport future. Choices will be driven by a complex mix of vehicle technology, cost (both of new vehicles and the fuel) and travel convenience. Public transport will also be a major factor in urban amenity and needs to take into account the various population growth scenarios and links with city planning strategies. Greater use of rail for the transportation of goods will be important and also needs to be factored into our transport future.

Australia is fortunate to have a range of resources for the development of alternative transport fuels that can use our existing liquid fuel distribution infrastructure. Options include greater use of gas in the form of CNG and LNG, potential second-generation biofuels and the conversion of gas and coal into liquids (bearing in mind the implications of all these strategies for water and GHG emissions, for example the high emission costs of coal-to-liquid conversion). The use of electricity for transport will also become more important. Crucial to these developments will be low-emission, low-water-use technologies and distribution systems to go with them. While energy and GHG emission analyses are well advanced, similar studies of future transport-related water requirements are needed to properly define parallel water sector implications.

4.3 Water systems

Key points

- There is increased competition for limited water resources between cities, irrigation, industry and the environment, caused by declining surface and groundwater resources in southern Australia, increasing populations and growing community awareness of the environmental impacts of over-extraction of water.
- Measures to ensure urban, industrial, agricultural and environmental water security include (1) reducing demand, through education and efficiency programs; (2) increasing supply, through recycling and desalination; and (3) making better use of available water, through proper pricing and ensuring adequate environmental flows.
- Some measures to increase supply, such as recycling and desalination, have significant energy costs, but can be environmentally viable options provided that the full implications of their costs (particularly for the environment) are properly recognised and met. With such recognition of costs, desalination (for example) is preferable to destroying river systems by over-extraction.
- Water is a local resource. Large-scale pumping from northern to southern Australia would have prohibitive energy costs compared with desalination.
- Water and energy efficiency measures often act on the same systems and appliances, so there is scope for a National Energy and Water Efficiency Target scheme to combine state and federal rebates, incentives and regulations (*Section 5, Recommendation 1*).
- There is scope for improving the efficiency of urban water use and the water productivity of agricultural water use through smart network technology (*Section 5, Recommendation 2*).

Situation and outlook: Rainfall in southern Australia has decreased over recent decades (*see Section 2.3*). Pronounced drying trends have been evident in southwest Australia since the 1970s and in southeast Australia since the 1990s. This drying is consistent with trends expected from human-induced climate change and may be at least partly caused by climate change, in addition to natural climate variability (*Section 2.2*). An important feature of rainfall patterns over the last few decades in southern Australia has been the absence of very wet years to replenish deep soil moisture and provide the large runoff events that boost reservoir levels.

Because of limited (and decreasing) water availability, the growth in water consumption in southern Australia has been much slower than the growth in energy consumption. Water consumption per person has fallen in response to decreases in water availability (*Section 2.3*).

Insurance is required against the severe social and economic damage resulting from storage levels falling to critically low levels. Doing nothing except waiting for rain is no longer a viable option for managing security of water supplies for urban, industrial and agricultural uses. Continued effort is needed to respond to three challenges: urban water, food production and ecosystem repair.

Challenge 1—Urban water: Australia's cities have responded to water stress with demand management and with measures to increase supply. Reduction of demand has already been significant (*Section 2.3 and Figure 2.10*). On the supply side, urban water authorities are turning to alternative, less rain-dependent water sources—principally desalination and recycling—and are building pipe networks to interconnect city and irrigation supply systems. Through these measures, future water supply for Australia's urban population can be assured. In effect, cities are achieving security of supply by building a more diverse portfolio of water sources. These alternative water sources, particularly desalination and recycling, are more energy-intensive than traditional gravity-driven supply from reservoirs. Increased diversion of water for urban uses (particularly in the Murray–Darling system) either contributes to environmental water stress or must be offset by reductions in use for agricultural irrigation.

The costs of desalination are steadily declining as technology improves, such that it is now a viable option for city water supplies (*Box 4.2*). There has been criticism of recently constructed desalination systems on the grounds that the increased electricity demand contributes to increasing Australia's GHG emissions. The energy and GHG emission costs of desalination are significant, as reviewed in *Box 4.2*. However, consistent principles for the use of finite resources (*see Section 5, Recommendation 1*) can ensure that these costs are properly handled. Desalination can be then be an appropriate technology for meeting urban water needs, with less environmental impact than options which do not properly recognise full costs, such as over-extraction from stressed river systems.

Box 4.2 Desalination

There are a range of proven technologies for desalination, the conversion of saline water (seawater or terrestrial water containing salts) into freshwater. All require substantial amounts of energy. Currently the desalination industry is dominated by 'reverse osmosis' systems, the technology used in all Australian systems to date. Reverse osmosis involves forcing saline water at high pressure through membranes that allow water molecules to pass but reject salt ions. Only a fraction of the water can be processed and around half of the saline water flow is discarded as high-salinity brine, generally to the ocean.

The costs of desalinated water, which are steadily declining as technology improves, have fallen sufficiently to make desalination a viable option for city water supplies. The cost range is \$1.15 per kL to \$3.50 per kL for desalinated water, compared to a range of \$0.15 per kL to \$3.00 per kL for dams or surface water (PMSEIC, 2007).

Plants have been built in Sydney, Perth and the Gold Coast, while plants in Victoria, South Australia and Western Australia are under construction.

There has been considerable community criticism of recently-constructed desalination systems on the grounds that the increased electricity demand contributes to increasing Australia's GHG emissions. This criticism is valid if the mix of stationary energy supply technologies does not change. Desalination requires between 3 and 4.5 kWh of electricity per kL of freshwater produced (GHD, 2003; Watson et al, 2003; Australia Institute, 2005). If all 2100 GL per year of household water use (ABS, 2006) was supplied by desalination, electricity demand would increase by approximately 8000 GWh per year. Assuming a GHG intensity for electricity of around 0.9 tCO₂eq/MWh (currently typical for Australian electricity generation; IEA, 2009a; Climate Group, 2009; DCCEE, 2010c), GHG emissions would increase by approximately 7.2 MtCO₂eq/y, or about 1.3 per cent of Australia's total emissions in 2008 (excluding land use change) of around 550 MtCO₂eq/y (DCCEE, 2010b).

Some desalination projects incorporate additional renewable (often wind) energy capacity to offset the energy used by a particular desalination plant. This *ad hoc* approach successfully restricts the increase in emissions to low levels, in the absence of a more holistic overall approach. For example, the Capital windfarm near Bungendore, NSW was built to offset the electricity consumption of Sydney's Kurnell desalination plant (www.sydneywater.com.au/Water4Life/Desalination).

If an integrated approach to energy, water and carbon is taken, then desalination is a very useful technology for sourcing new urban water supply, with considerably less environmental impact than many other options (*see Section 5, Recommendation 1*).

There are a number of minor but useful opportunities for maximising the production of renewable energy from water systems themselves. Water supply systems with pressure heads in excess of supply flow needs have already been largely retrofitted with small hydroelectricity systems. Generation of biogas (methane from sewage) could be beneficially exploited further, with the added benefit of simultaneously reducing GHG emissions from the water system.

Challenge 2—Water for food production: The production of food through irrigated and rain-fed agriculture in a drying climate is a major challenge (PMSEIC, in press). If Australia is to prosper as a major supplier of food and fibre to the growing world population, major initiatives are required to improve the water productivity of Australian agriculture (water productivity is the economic value produced per unit of water used). While this is a daunting challenge, Australian farmers have a long history of adaptation to increase agricultural productivity in the face of a highly uncertain climate. Research and development have been key factors in their success. However, the research capacity that underpins improvement in economic water productivity in irrigation is currently at risk with the closure of Land and Water Australia and the Cooperative Research Centre for Irrigation Futures, and an uncertain future for the National Program for Sustainable Irrigation. These gaps need to be filled (see Section 5, Recommendation 5).

Challenge 3—Repairing riverine ecosystems: The third challenge is to repair the substantial environmental damage caused by historically unsustainable levels of water allocation and diversion. A start has been made in facing up to this challenge by investing in water use efficiency, purchase of water from irrigators and transforming water allocation priorities (Water Act of 2007). However, much remains to be done to ensure that these strategies are ultimately successful in restoring environmental flows and the health of rivers and aquatic ecosystems.

Moving water over long distances: When society is faced with regions under severe water stress and unmet demand for water for urban and agricultural use, it seems natural to look to Australia's wetter regions. Periodically, proposals are mooted for transporting water very long distances from the northern, high-rainfall parts of the continent to drier regions. This option appears even more attractive under climate change scenarios with decreasing rainfall in the south and increasing rainfall in the north (Section 2.2). Long-distance piping of water is expensive from several viewpoints. A water pipeline is a major and expensive piece of infrastructure which must be continually maintained. A significant continuous consumption of electricity is needed to operate the pumps required to drive the water against the frictional losses within the pipe. Summing the amortised capital cost of the pipeline, the maintenance cost and the energy cost yields a total cost of transporting water; the water at the end of the pipe is more valuable than what enters the pipe by this amount. Costs for water piped over long distances are up to \$9.30 per kL, compared to a range of \$1.15 to \$3.50 per kL for desalination. For example, the cost of water piped nearly 600 km to Kalgoorlie is about 10 times higher than the typical cost of locally supplied water in Australian cities (PMSEIC, 2007). Adelaide currently has the highest capital city consumption of energy for water pumping, since much of its water comes via pipelines from Murray Bridge and Mannum, an average distance of around 70 km. The resulting energy cost is in the middle of the range for modern desalination plants (PMSEIC, 2007).

These considerations reinforce the view that water is essentially a local resource that can be moved over long distances only at a cost which is larger than the cost of desalination. Thus, the option of moving water from the wet north to the dry south of the continent is not economically viable.

Opportunities for end-use efficiencies at energy-water intersections: A 2008 report on energy use in urban water systems (Kenway et al, 2008) found that 'the total energy use by water utilities in Sydney, Melbourne, Perth, Brisbane, Gold Coast and Adelaide in 2006–07 represents about 0.2 per cent of energy use in the total urban system. The total energy use by water utilities is less than 15 per cent of the energy used for residential water heating'. Heating water is some four to five times more energy-intensive than desalination using membranes. Reducing hot water use through more water-efficient washing machines, shower roses and dishwashers, combined with a shift away from electrical hot-water heaters to solar and instantaneous gas units would make a substantial reduction in the GHG emissions from energy use by urban water systems.

A 2008 report by the Department of Environment, Water, Heritage and the Arts on energy use in Australia (DEWHA, 2008) found that water heating is the only major residential energy use predicted to decline over the period 2005 to 2020, principally as a result of various energy programs undertaken by federal and state/territory governments. The anticipated decline is about 10 per cent. The key drivers of this change are an increase in the share of gas and solar technologies, with a corresponding decrease in electric storage hot water, and some additional impact from the introduction of electric water heater minimum energy performance standards in 1999. This illustrates that efficiency

standards can be effective in improving the energy or water efficiency of individual appliances or items. A more systemic strategy is needed to improve the end-use efficiency of both energy and water use, combining efficiency and demand management measures, especially those that address energy and water use together.

The Victorian Energy Efficiency Target (VEET) scheme provides incentives to replace items like lights, refrigerators, space heaters and water-heaters, and will be expanded to include air conditioners and televisions. This scheme has been successful in its first two years of operation in Victoria.

A scheme such as the VEET could be extended nationally to include both energy and water efficiency (see Section 5, Recommendation 1). Such a National Energy and Water Efficiency Target scheme would include incentives to:

- replace low efficiency water heaters, ducted heating and lighting with high efficiency models
- install insulation, window seals and energy-saving windows
- install insulation cladding on hot water pipes
- upgrade to low-flow shower roses
- purchase high energy efficiency refrigerators
- purchase washing machines, dishwashers and clothes dryers with higher energy or water efficiency
- upgrade to switchable power boards.

Large retailers of consumer products, such as lighting and whitegoods, could be encouraged to become accredited under this scheme to simplify the generation of energy and water efficiency certificates at the point of sale. For whitegoods, these would be verifiable upon installation of new items and removal of old ones. For products such as lighting, certification could involve a trade-in mechanism whereby consumers would bring inefficient lights to stores and swap them for efficient ones. By allowing consumers to choose products in stores instead of relying on 'door knocking' by contractors, consumers can exercise their own choices over products and have the reassurance of retailers' brand presences.

A single point of access for the public can be developed that encompasses the wide variety of state and federal rebates, incentives and regulations affecting purchase decisions. This can address the barrier of 'information overload' that leads to inaction from consumers and would allow all possible opportunities to be accessed.

4.4 Land systems

Key points

- Energy, water and carbon in rural Australia underpin five major landscape functions:
 - (1) food, fibre and wood production
 - (2) water production and use
 - (3) bioenergy production and biosequestration
 - (4) conservation of environmental assets
 - (5) economic and social wellbeing.All of these linkages can create both tensions and opportunities.
- To maximise opportunities and resolve tensions, these functions and their underlying energy-water-carbon intersections need to be integrated to achieve long-term resilient land systems (see Section 5, Recommendation 3).
- There is an immediate opportunity to establish joint development goals for food/fibre and fuel production, focusing on linked biomass, energy and water planning to increase productivity while supporting Australia's move to a low-carbon future.
- Opportunities exist to combine better soil carbon management with carbon sequestration, both through natural and engineered solutions, and for a shift to non-land-based sectors

Situation and outlook: Approximately 30 per cent of Australians live in rural and regional Australia, including the populations of regional centres outside the major state capital cities. Rural (farm-dependent) economies account for 17 per cent of national employment (ABARE, 2010b) and contribute 12 per cent of GDP. Rural Australia contains and supports almost all of the environmental assets upon which the entire nation depends for food, water and environmental amenity, so the contribution of rural Australia to national wellbeing far exceeds its contribution to GDP.

Australia has long been subject to climate variability, and projections of future climate change indicate rainfall decline in much of southern Australia in coming decades (Section 2; CSIRO and Bureau of Meteorology, 2007; CSIRO, 2008).

Energy-water-carbon intersections in rural Australia: Population growth throughout the nation will place increased demands for rural Australia to meet five goals simultaneously (Figure 4.6): to increase food and fibre production; to maintain water production in catchments; to contribute to the decarbonisation of the Australian economy through biosequestration, bioenergy production and emissions reductions; to preserve environmental assets and natural heritage; and to maintain thriving, diverse rural communities.

These five goals are linked. Energy-carbon-water intersections in rural Australia underpin all the landscape functions indicated in Figure 4.6 and thus involve interactions between industries, communities and environmental assets. This implies that most activities in landscapes involve energy-water-carbon intersections, leading to a proliferation of consequences in addition to the intended direct outcome of the activity. Some of these additional consequences are beneficial, while others may be adverse. Table 4.1 provides some examples of relational opportunities and risks that need to be considered.

It follows that the enhancement of resilient land systems in rural Australia requires that water, energy and carbon—together with food production, protection of environmental assets and socio-economic development—are not managed in isolation but as interacting parts of a coherent system. This theme is addressed in Recommendations 3 and 5.

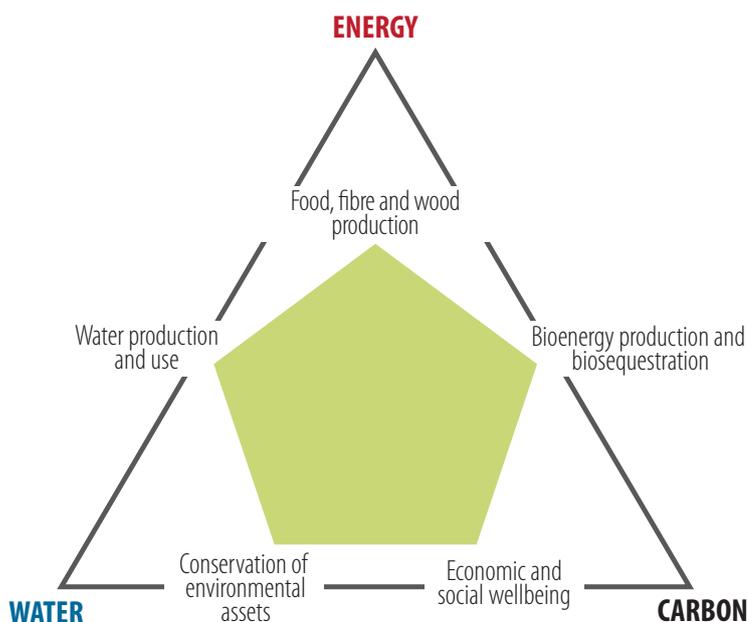


Figure 4.6: Energy-water-carbon intersections in rural Australia (the underlying triangle) underpin five major landscape functions (the superimposed pentagon). All points of the triangle are linked directly or indirectly with all points of the pentagon.

Activity	Environmental effects	Socio-economic effects	Energy-water-carbon intersections	Risks/uncertainty
Expand biofuel production	(1) Less reliance on fossil fuels (2) Climate change mitigation	(1) Development of rural bioenergy industries (2) Less reliance on global energy markets	Potential to induce land clearing elsewhere (leakage); biomass production requires water and possibly fertilisers	Conversion of fertile cropland to bioenergy harvests
Diversion of waste biomass to bioenergy and biochar production	(1) Fossil fuel substitution (2) Biomass stabilisation (3) Less pressure on landfill systems (4) Lower GHG emissions from landfills	Local economic activity from bioenergy production systems (potentially mobile units)	Energy production instead of GHG production	Ensure sustainable management (e.g. retain some stubble)
Biochar application to agricultural soils for productivity increase	(1) Likely increased water-holding capacity (2) Greater soil resilience (3) Potential increase in crop productivity (4) Nutrient retention (5) Carbon sequestration	(1) Local biochar production and consultation (2) Knowledge required in carbon accounting and markets	(1) Potentially less fertiliser use (2) Lower energy and water requirements (3) Production and distribution may require long distance transport	(1) Un-regulated production and application of biochar to farmland may disturb nutrient balances (2) Need for certification (3) Transport costs (4) Uncertainty over permanence
Biochar application to agricultural soils for sequestration	Build up of soil carbon in agricultural soils with benefits as listed above	(1) Potential income from C credits (2) Connection with bioenergy production (3) Need for expertise	Other forms of soil carbon may be lost during drought.	(1) Exposure to carbon markets (2) Limited production of biochar (3) Inflated prices
Afforestation for carbon credits and bioenergy	(1) Increase in soil carbon and biomass carbon (2) Decreased runoff and stream flow	(1) Growth in carbon forest industry (2) Development of new tree species and harvest management	(1) No net CO ₂ emissions (2) Less dependence on fossil fuels.	(1) Transport costs (2) Possible displacement of food production areas (3) Decreased water flow to catchments
Retirement of unproductive cropland and conversion to native pasture or woodland	(1) Revegetation of degraded land (2) Biodiverse and resilient landscapes (3) Retention of natural heritage	Government incentives may be required to convert from conventional to new land stewardship practices	Potential increases in carbon stores in soils and vegetation	Loss of employment in conventional rural sector jobs

Table 4.1: Examples of activities in landscapes, their energy-water-carbon intersections and their interactions with other landscape functions. Note that many of the listed effects are based on unpublished data and need to be further investigated as part of Recommendation 3. CO₂ is carbon dioxide, GHG is greenhouse gas.

The carbon challenge in rural Australia: Bioenergy production and the managed biosequestration of GHGs are two emerging activities that can make significant contributions to the future decarbonisation of the Australian economy. Both have the potential to reduce Australia's net GHG emissions. In addition, increased use of bioenergy can reduce Australia's dependency on fossil oil and gas (IEA Bioenergy, 2009), and biosequestration can increase soil resilience and productivity (Krull et al, 2004; Chan et al, 2008). However, both activities also have major implications for water availability, food and fibre production, nutrient balances, biodiversity and socio-economic structures.

Biomass production for bioenergy, biofuel or biochar production has collateral effects through competition with food production for land and ancillary GHG emissions which have to be managed effectively to ensure that the whole system has a significant overall benefit for GHG mitigation. Likewise, factors that favour increased food and fibre production, for example nutritional requirements, consumer preferences, environmental constraints, global price signals and trading systems, are not always also favourable for water production, energy efficiency and low GHG emissions.

Managed biosequestration can be achieved in several ways: through afforestation and reforestation, through increasing soil carbon by farming practice and through the use of biochar. Among the important additional consequences to be considered are reductions in stream flows in afforested catchments (Zhang et al, 2004), alterations in nutrient balances and the need for ongoing management of landscapes to preserve high carbon levels in soil and/or biomass, so that the sequestered carbon is not returned to the atmosphere.

Management of soil carbon levels as a biosequestration strategy has been promoted as offering significant technical GHG mitigation potential in Australia (e.g. Garnaut, 2008; ClimateWorks Australia, 2010). Australia has vast areas of land under agricultural management, and small increases in soil carbon levels across Australia would indeed result in substantial mitigation of GHGs (CSIRO, 2009; Walcott et al, 2009). However, there is much uncertainty about the response of many Australian soils to a change in management practice (Sanderman et al, 2010) and evidence suggests that observed increases in soil carbon are volatile and can be easily lost during drought or after a change in management practice (Sanderman and Baldock, 2010). Use of irrigation or nitrogen fertilisers to increase productivity and thus soil carbon accumulation (Sanderman et al, 2010) has obvious water, energy and GHG implications.

Achieving effective integration of rural Australia into a future low-carbon economy will require changing priorities in land management, adopting new farming practices (soil carbon management, water conservation) and maximisation of research, development and learning opportunities—particularly, but not only, in bioenergy and biosequestration.

Emerging challenges: With a growing population, agricultural food productivity must be increased. This suggests that high-productivity agriculture should increasingly occur in more productive climates and soils, and that marginal lands, especially those under the threat of increased drying, should increasingly be managed for alternative uses such as bioenergy production. The corollary of this constraint is the need to achieve domestic food security, together with an ongoing food export contribution to the Australian economy and global food security, within similar land availability limits to those effective now and with lower resource inputs (PMSEIC, in press).

The main constraints for increase in bioenergy and biochar production are biomass availability and limits on the availability of productive land (O'Connell et al, 2009), while the dominant constraint for both biosequestration (in soils and trees) and also for increased food production is water (Sanderman et al, 2010). Future constraints in all these areas have the potential to be exacerbated by population pressures: global modelling indicates that these tensions are directly related to population growth (World Bank, 2009). As awareness of these limitations increases it will be important for the population-food-fuel tension to be replaced by sensible, long-term land planning and resource strategies (Glover et al, 2008) which exploit emerging technologies.

Emerging opportunities: Future bioenergy production and biosequestration are likely to be less energy- and water-intensive than current technologies (*Table 4.1*). Significant advances are occurring in large-scale biorefinery technology and biofuel production, such as energy production from algae (Pienkos and Darzins, 2009). Global projections suggest that by 2050, sustainable sourcing of biomass for bioenergy production could contribute between a quarter and a third of the future global energy mix (IEA Bioenergy, 2009). Australia has the opportunity to plan and prepare for these global trends. Emerging opportunities for bioenergy production and biosequestration can be linked to new bioenergy production systems—particularly in the area of biorefineries—that are based on smaller-scale production, mobile production units, technology advancement and bioenergy-specific carbon accounting services.

There is an immediate opportunity to establish joint development goals for food/fibre and fuel production, focusing on linked biomass, energy and water planning to increase output per hectare while supporting Australia's move to a low-emissions future. A forward-looking approach needs to be adopted to cope with climate-related changes to Australia's rural sector. Opportunities exist to combine better soil carbon management with carbon sequestration, both through natural and engineered solutions, and for a shift to non-land-based sectors (Walcott et al, 2009). Examples include:

- development of water-tolerant forage for ruminants (Cullen et al, 2010)
- genetic modification of productive biomass to achieve greater energy-water-carbon efficiency
- increased focus on regional integration of biophysical and productivity drivers (*Section 3.3*)
- better use of waste (DEWHA, 2009)
- greater diversification in rural industries, for food and fibre production and in response to the globally recognised need for bio-based replacements for petrochemicals (Gregory, 2010)
- development of non-land-based biomass sources for biofuels (such as algae) and biorefinery products (aquaculture, fisheries, kelp) to decrease pressure on land use (IEA Bioenergy, 2009).

4.5 Urban systems

Key points

- Australia's high and increasing level of urbanisation means that energy-water-carbon intersections in cities and towns are critical, presenting both opportunities and challenges.
- In Australia as well as overseas, many local and state governments are endeavouring to take a holistic and practical approach to urban sustainability, including adaptation to climate change, mitigation of urban greenhouse gas emissions and reduction of urban ecological footprints.
- There are major opportunities to meet urban energy-water-carbon challenges, for example through: increased energy and water efficiency, water recycling with associated energy cogeneration, local climate improvements through urban design and changing lifestyles to facilitate transport and increase amenity (*see Section 5, Recommendation 4*).
- These efforts, which are mainly locally based at present, need strong augmentation and national support (*see Section 5, Recommendation 4*).

Situation and outlook: Australia has one of the world's most urbanised populations (UN DESA, 2010), with around 90 per cent of Australians living in urban settings and 69 per cent in the major cities (ABS, 2010). The trend for a progressively greater fraction of the Australian population to live in cities and towns is likely to continue, according to the Intergenerational Report (Australian Government, 2010).

Urban environments are points of confluence for the exchange of goods, money and ideas. They are industrial, commercial and transport hubs, with accompanying intense usage of energy and non-agricultural water. Urban environments are also points of confluence for vulnerabilities, because of the closely connected nature of water, energy, transport, food, health, education, social and other vital systems for urban life support. Increasing connectedness increases the risk that a failure in one of these systems can cascade through to others, leading to consequences which greatly amplify the initial problem. Great damage can be caused by cascades, which may be rapid and highly visible, such as gridlock in a major city caused by a single failure in a transport system, or slow and often unnoticed, such as the pressures on services and quality of life caused by uncontrolled urban sprawl.

Energy, water and carbon, with carbon a driver of climate change, intersect in the urban environment through several key vulnerabilities, many of which also indicate opportunities for transformation:

1. Current and expected warming trends increase the frequency, and probably the duration, of extreme events such as heatwaves (CSIRO and Bureau of Meteorology, 2010). In the context of an ageing and thus more vulnerable population, this places pressure on services such as emergency medicine, through greater incidence of heat-related illnesses, and highlights the need for adaptive strategies for local climate control (O'Brien and Baime, 2010). Such strategies could include rooftop lawns and gardens.

2. More intense and longer heatwaves increase the risk of catastrophic bushfires, which will have increasingly devastating consequences as more urban Australians inhabit forested rural environments on the fringes of cities. The Victorian Black Saturday (7 February, 2009) bushfires, which were essentially uncontrollable firestorms in the record fire weather of that day, provide a vivid picture of events which are likely to become more frequent.
3. The cities and towns of southern Australian regions are projected to experience decreasing rainfall as climate change proceeds (*Section 2*), putting urban water supplies under pressure from both demographic and climate trends (*Section 4.3*). These pressures increase the viability of energy-intensive water sources such as desalination and recycling (*Figure 4.7*), with associated energy and social implications.
4. The largest Australian urban centres are coastal, so critical infrastructure will be affected by rising sea levels (DCC, 2009b).
5. Efforts to move away from fossil-fuel powered vehicles towards electric vehicles will place increased pressure on stationary energy supplies, which are currently dominated by coal-powered plants (*Sections 4.1 and 4.2*).
6. Increasing urban populations are driving a high demand for affordable housing. This demand is largely being met by expansion of urban areas at the fringes of cities and towns, increasing the dependence of urban Australians on private vehicles and the freeway systems necessary to avoid congestion.
7. Rapid growth of cities and associated energy demand is increasing the urban 'heat island' effect and demand for cooling. Together with the general warming trend from climate change, this is leading to increasing dependence on air conditioning, which is a prime example of maladaptation—an immediate, local response to a problem which actually makes the problem worse at large scales and in the long term.

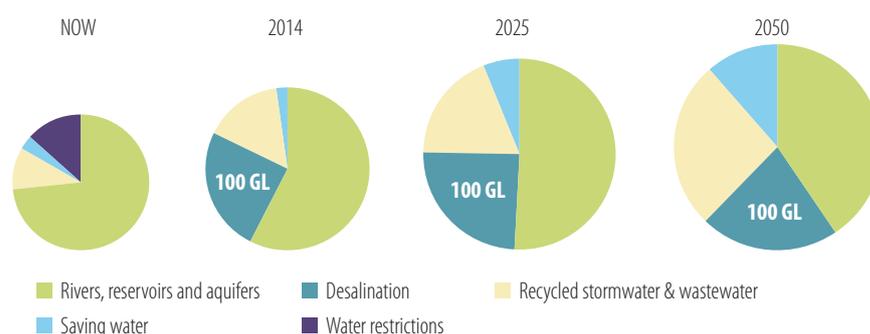


Figure 4.7: Greater Adelaide's current and projected water supply from all sources for both drinking and non-drinking purposes, showing expected increased reliance on recycled stormwater and wastewater (Government of South Australia, 2009).

Efforts to increase urban resilience and sustainability: Prompted by considerations such as those above, local and municipal governments are increasingly endeavouring to take a holistic approach to urban sustainability and to translate this into practical measures in urban design and function. This includes adaptation to climate change, mitigation of urban GHG emissions, and many other steps toward environmental sustainability and the reduction of urban ecological footprints (for example, City of New York, 2007; Dhakal and Betsill, 2007; Dhakal and Shrestha, 2010; Rosenzweig and Solecki, 2010). *Table 4.2* indicates some international organisations dedicated to providing networking and support to assist these efforts.

Organisation and URL	Focus
The Urban Climate Change Research Network (www.uccrn.org)	Integrating climate risk into city development policies
Climate Mayors (www.climatemayors.com/index.php?id=22)	Building local government capacity for adaptation and mitigation (includes a number of Australian and New Zealand cities)
ICLEI, the Local Governments for Sustainability Network (www.iclei.org)	International association of local governments and organisations who have made a commitment to sustainable development, providing technical and information services to build capacity for sustainable development at local level, with a focus on intersections between energy, carbon, water and society.
Global Carbon Project, Urban and Regional Carbon Management Theme (www.globalcarbonproject.org ; www.gcp-urcm.org)	Place-based and global research on carbon management and sustainable development in urban environments

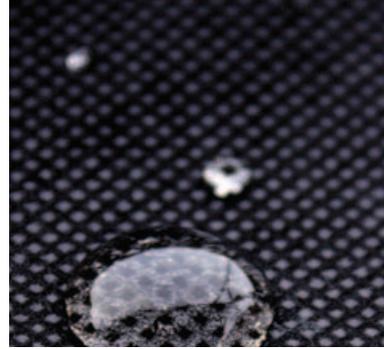
Table 4.2: Some international networks providing support for urban sustainability efforts by local and municipal governments.

Opportunities: Energy-water-carbon intersections in urban environments create many opportunities for enhancing urban sustainability (see Section 5, Recommendation 4).

1. *Planning regulations:* Urban planners have the opportunity to create spaces which minimise energy consumption and water runoff, through attention to issues such as building density, green space and transport. Similarly, reform of revenue regimes such as stamp duty can encourage purchase of more efficient housing by lowering barriers to relocation.
2. *Building standards:* Appropriate building standards can encourage design which maximises energy and water efficiency. Proposals for efficient buildings in the residential and non-residential sector include the Lend Lease Efficient Building Scheme (www.lendlease.com/sustainability/pdf/EfficientBuildingScheme.pdf) and the Building Efficiency Disclosure Scheme of the Australian Government Department of Climate Change and Energy Efficiency (www.climatechange.gov.au/what-you-need-to-know/buildings/commercial/disclosure.aspx). This measure was passed by the Australian Parliament in June 2010 and mandates efficiency disclosure, initially for commercial structures and later for other non-residential buildings such as hotels, schools and hospitals.
3. *Engineering and design of sustainable buildings:* Because residential and commercial energy consumption is such a significant proportion of Australia's overall energy profile (around one-fifth in 2007-08; ABARE, 2010a), urban buildings represent an opportunity for energy and emissions minimisation (New York Academy of Sciences, 2010). Sustainable buildings can provide multiple benefits through a wide range of technologies, for example:
 - local climate control from reflective surfaces and vegetated roofs
 - reduced energy demand through insulation and building design to promote the use of passive solar winter heating and protection from summer solar heat loads
 - use of below-ground thermal inertia for both cooling and heating
 - replacing inefficient (electric resistive) residential hot water systems with more efficient or renewable energy sources (DEWHA, 2008; Kenway et al, 2008; also see Section 4.3)
 - local collection of rainwater and minimisation of stormwater runoff.
4. *Demand reduction:* Social and behavioural adaptation in energy and water consumption can be encouraged by making information available to consumers through smart networks (see Section 5, Recommendation 2) and education campaigns.
5. *Public transport and alternative transport options:* Increasing access to affordable, safe and regular public transport is a key means of reducing vehicular GHG emissions, local pollution and congestion. Similarly, increasing the availability of bicycling and walking as transport options through urban design and road planning increases amenity and brings health benefits. Reducing reliance on cars also means less valuable city space has to be devoted to parking. Some transition from car-dependence can be achieved through car-share (www.environment.gov.au/settlements/transport/publications/carsharing.html) and short-

term car-hire schemes (www.zipcar.com). Fee-based measures such as tolls and parking can further reduce car dependence, and (if the measures are time-sensitive) can also reduce congestion, itself a source of energy use and emissions (see London congestion charges—www.tfl.gov.uk/roadusers/congestioncharging, and peak and off-peak tolls for New York bridges and tunnels—www.panynj.gov/bridges-tunnels/tolls.html).

6. *Integration of electric vehicle use with the electricity grid:* Initiatives such as ‘Smart Garage’ (move.rmi.org/move-news/what-is-the-smart-garage.html) can manage the charging of electric vehicles from the electricity grid, together with their use as sources of stored energy when needed.
7. *Flexible work patterns:* ‘Teleworking’ and staggering of working hours can reduce transport congestion (Council of Australian Governments, 2006) and can also reduce the need for expensive, possibly fossil-fuel-intensive, peak stationary power. A pilot flexible work hours program in Brisbane showed a reduction in peak-hour travel and an overall reduction in vehicle kilometres travelled (Queensland Government Department of Transport and Main Roads, 2009).
8. *Urban design and layout:* Opportunities are present in urban design to maximise access to non-motor transport, and place services and amenities strategically to increase the overall energy efficiency of urban living (e.g. City of Sydney, 2007). Through urban renewal and creative use of options, some redesign is possible, even in already densely-developed cities.
9. *Urban cooling with vegetation:* Strategic placement of vegetation in urban environments provides one means of providing local climate control, as a well as a use of stormwater (Coutts et al, 2010; O’Brien and Baime, 2010). This strategy presents a possible tension because it requires water for irrigating vegetation, but use of local stormwater runoff can provide a solution.
10. *Recycling of energy and water, and reduction of GHG emissions:* The concentration of stormwater and sewage streams provides opportunities for water, energy and materials recovery from waste (e.g. Project Neptune, www.awmc.uq.edu.au/index.html?page=115447&pid=61320). GHG emissions associated with water supply also arise from CO₂, methane, and nitrous oxide escape from reservoirs and wastewater facilities (Hall et al, 2009).



5. Recommendations

This section describes in detail the recommendations of the Expert Working Group.

Key points

- The five recommendations of the Expert Working Group address major components of an overall path to energy-water-carbon resilience for Australia. These include:
 - (1) Consistent principles for the use of finite resources of water and carbon emissions;
 - (2) Improving the distribution and use of energy and water with smart networks in urban and agricultural settings;
 - (3) Enhancing the resilience and sustainability of Australian landscapes in meeting energy-water-carbon challenges;
 - (4) Enhancing the resilience and sustainability of the built environments in Australia's cities and towns; and
 - (5) Enhancing Australia's knowledge and learning capabilities to meet not only sectoral challenges, but also new demands for integrative knowledge about the whole system formed by energy, water, carbon, ecosystems, the economy and human society.
- Each of these recommendations spans sectors and industries. Our focus is on developing the knowledge, systems and approaches needed to address challenges that demand long-term transformations, rather than advocating particular solutions in particular places.
- The recommendations cover a range of time scales, from short-term and focused, to long-term and transformational. While the recommendations are designed as a complete set, implementation begins with short-term steps. This does not lessen the importance of long-term recommendations, but it does mean that not everything has to be done at once.

5.1 Consistent principles for the use of finite resources

Background: Water is a finite, renewable resource. Emissions of CO₂ to the atmosphere also constitute a finite, essentially non-renewable resource, because there is a global cap on the amount that can be emitted before risks from climate change become unacceptable (see Box 2.1).

Energy, water and emerging carbon markets already exist, each with the potential to foster desired technological and behavioural adaptations. However, energy-water-carbon linkages require that these markets, and their non-market environments, all function under consistent guiding principles for the use of finite resources. These consistent principles are needed to ensure that markets, regulations, institutional arrangements and decisions about infrastructure reflect the full costs and benefits accruing from societal uses of energy, water and carbon.

Recommendation 1

The Expert Working Group recommends that consistent principles for finite resource use be developed and implemented for energy, water and carbon. These principles will ensure that (1) markets transmit full, linked, long-term costs to society; (2) accounting is comprehensive and consistent with natural constraints and processes; and (3) markets work together with non-market strategies, including implementation of robust governance arrangements, promotion of behavioural change and effective regulation of use.

Outcomes: The goal is to ensure that finite resources are used effectively, efficiently and in ways that are consistent with long-term sustainability and resilience.

Markets and pricing: Consistent pricing principles will ensure that the costs of using finite common resources are properly recognised and met, rather than being hidden and deferred to cause problems in the future. To do this, it is necessary that markets, regulations, institutional arrangements and decisions about infrastructure reveal full costs and benefits implied by energy-water-carbon linkages. These costs and benefits can then be shared efficiently throughout cycles of production, distribution, consumption and re-use. Important linkages that can be recognised by market mechanisms include: the energy use and associated carbon emissions resulting from water supply through desalination or energy-intensive recycling; the water requirement of some biosequestration strategies, such as the reduction in catchment run-off from carbon forestry; and links between energy consumption, emissions and water consumption in urban environments.

It follows that an essential foundation for the consistent principles envisaged here is a price on carbon, as for water and energy.

Accounting: Comprehensive, rigorous and transparent accounting for energy, water and GHGs (both sources and sinks) is critical to enable administrative systems to properly regulate the use of finite resources and to identify and avoid perverse effects.

Accounting systems need to: (1) identify interactions—for example, plantation forestry to sequester carbon can reduce catchment water availability; (2) recognise constraints on water availability and GHG emissions; and (3) be consistent with the biophysical processes that determine resource availability—for example to ensure hydrological integrity and to avoid double counting in surface water and groundwater accounts.

An additional foundation for this principle is a set of adequate national monitoring and accounting systems for energy, water and carbon which are comprehensive, consistent, inclusive of both natural and human components, and appropriately linked. This is addressed in *Recommendation 5*.

Non-market strategies: Markets alone cannot overcome impediments to change such as social barriers, institutional distortions, technological inertia and lock-in, and failure of research and development to deliver appropriate knowledge or to be implemented to full potential. Therefore, market strategies require parallel non-market strategies. These may include:

- a regulatory environment that sets the availability of public-good resources such as water and limits GHG emissions
- administrative arrangements that govern market processes
- promotion of behavioural change through communication, including the provision of real-time information, and through education programs that are designed to assist communities and businesses to understand the consequences of their actions (see *Recommendation 2*)
- regulated standards that influence investment decisions, such as appliance efficiency criteria, building codes and planning controls.

Steps to implementation: Implementation of this recommendation begins with (1) an assessment of the essential principles for finite resource use that need to underpin energy, water and carbon management policies. This will lead to (2) development and agreement on a set of consistent guiding principles for pricing, accounting and non-market strategies; (3) evaluation of the consequences of these principles for governance and regulation; and (4) a timetable for transition from the existing set of arrangements to one that can be relied upon to send clear pricing, accounting and other information to users.

The principles established by this process will ensure consistency for many possible initiatives. Examples include:

- The establishment of a National Energy and Water Efficiency Target scheme. This scheme would combine state and federal rebates, incentives and regulations affecting purchase decisions under a single point of entry, making price and incentive signals consistently visible to the public. The design of such a scheme would be shaped by the consistent principles called for in this recommendation.

- The updating of the Australian Energy Regulator’s National Electricity Objective to specifically reflect the principles called for in this recommendation. The current objective is ‘To promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to (a) price, quality, safety, reliability, and security of supply of electricity; and (b) the reliability, safety and security of the national electricity system’. The update would ensure that environmental, water and emissions reduction goals are placed on an equal footing with economic and consumer-oriented objectives. Such a step would embed environmental concerns into the organisational culture that implements the regulatory framework.
- The establishment of an ‘Environment and Sustainability’ panel. This panel would complement the ‘Reliability’ and ‘Consumer Advocacy’ panels that are currently hosted by the Australian Energy Market Commission (AEMC). The ‘Environment and Sustainability’ panel would monitor, review and report on sustainability concerns such as efficiency, GHG reduction, renewable energy and cogeneration, and water use.

5.2 Smart networks to link demand and supply

Background: Applied to electric power, a ‘smart grid’ uses information and communication technology (ICT), together with sophisticated instrumentation and power control devices, to improve the efficiency of electricity use, distribution, transmission and generation. A \$100 million commercial trial of a smart urban electricity grid has recently commenced under the federal government’s ‘Smart Grid, Smart City’ program. Based in Newcastle, the trial will identify and correct faults; manage voltage levels and fluctuations; optimise load sharing, including a small fleet of electric cars and battery storage installations; integrate variable renewable energy from wind and solar power generation; and provide customers with real-time energy costs to encourage user-load management.

Similar concepts can also be applied to gas and water to bundle power, gas and water supply and management into integrated ‘smart networks’. The goals of these networks are to optimise overall system performance, to recover from outages and, importantly, to empower users to respond to readily accessible information. Smart network technologies and systems can reduce GHG emissions, increase reliability of supply, maximise energy, gas and water delivery efficiency, and provide higher levels of user choice and flexibility. These networks could eventually extend right across the delivery spectrum, from the extraction or collection of the resource, through the chain of processing and distribution at the highest possible efficiency, to its eventual use and recycling. All of this would be enabled by taking advantage of leading-edge ICT systems.

Smart networks also have applications in irrigation systems and can be used to improve the energy efficiency of water supply. They could also be utilised to reduce river operating losses of water and to maximise economic water productivity. To improve economic water productivity, it is important to supply water to irrigated crops at the right time and in the right quantities for the particular growth stage of the crop. This could be achieved with wireless sensor networks that connect soil, atmospheric and plant sensors to smart control systems to control irrigation water delivery. Early research being undertaken by the University of Melbourne indicates that this technology can achieve on-field improvements in economic water productivity of 25 to 75 per cent. Smart network technology can also improve the efficiency of the water distribution network by ensuring stable pressures in piped systems or appropriate water levels in channel systems. For this purpose, smart networks have been implemented in the Colleambally Irrigation District in NSW and are being implemented in the Goulburn–Murray Irrigation District as part of the \$1 billion Food Bowl Modernisation Project in northern Victoria. While recovering water losses was the initial driver of these investments, the major benefit will be improved economic water productivity.

In both the urban and irrigation domains, smart networks will optimise network efficiency and effectiveness, and encourage social and behavioural adaptation in energy and water consumption.

Recommendation 2

The Expert Working Group recommends (1) the design, testing and assessment of smart networks for electricity, gas and water, through a research and implementation program leading to commercial demonstration; and (2) the application of smart network technology to improve distribution efficiency and water productivity in irrigation.

Outcomes in the urban domain: Integrated smart networks for electricity, gas and water offer the following main outcomes:

- *Integration of renewable stationary energy sources into grids:* Smart network technology can optimise the integration of intermittent and distributed renewable energy sources, such as solar and wind, into existing electricity networks.
- *More effective management of fluid distribution systems:* Improved pressure management in urban water and gas supply networks can lead to more efficient use of energy for pumping, reduced leakage and extended life of distribution pipes.
- *Facilitation of behavioural change:* Smart networks can provide consumers, suppliers and planners with direct, real-time information on usage rates and costs of energy, water and associated carbon emissions. This will empower users to see and respond to energy, water and other costs, providing them with opportunities to exert more informed control over their own usage. Evaluation of the social and psychological aspects of customer responses will be essential.
- *More effective markets:* development of market systems, together with smart networks, will allow real-time information to be conveyed to customers. This will assist in providing incentives at appropriate times.
- *Cost reductions by sharing of ICT infrastructure:* There is potential to reduce costs by sharing ICT infrastructure between electricity, gas and water networks. This is particularly the case for metering and communication protocols.

While there are many smart grid trials being conducted around the world, preliminary exploration has indicated that there are no activities that combine electricity, gas and water in an integrated way. This combination is especially pertinent to Australia, given our need to reduce our GHG emissions from the power sector by the addition of more variable renewable energy sources, the increased availability of gas on the east coast through coal seam methane developments and our precarious long-term water supply situation. We also have an added degree of difficulty in that our supply networks tend to be long and narrow, reflecting our coastal population. Australia does not have the denser, compact supply grids of most other developed countries. All these characteristics provide incentives for Australia to become a world leader in the development of smart networks.

Outcomes in the irrigation domain: It is now possible to connect farm irrigation operations, channel and pipe networks, and river operating systems to create a complete smart water supply chain from the water source to the crop. Such smart water supply chains can lead to the following outcomes:

- *Improved energy efficiency of the water distribution network:* This is achieved by ensuring stable pressures in piped systems and appropriate water levels in channel systems.
- *Reduction in river operating losses of water:* This is achieved through more accurate forecasts of demand and more responsive operation of the reservoir releases.
- *Improved economic water productivity:* This is achieved by supplying water to irrigated crops at the right times and in the right quantities for optimum growth.

Various pieces of a smart water supply chain have been implemented (see examples above), but the full potential cannot be realised until the complete smart water supply chain is implemented from the source to the crop.

Steps to implementation in the urban domain: Implementation of this proposal can begin with a pre-deployment study. This would involve an extension of the existing 'Smart Grid, Smart City' trial program for a smart electricity network to include gas and water in parallel. Such a pre-deployment study was very successful in the design of the Smart Grid program. The recommended study would involve government, industry and researchers, including both physical and social-science disciplines. The outcome of the study would be an examination of the benefits, both engineering and behavioural, of combined smart networks for electricity, gas and water. If the study shows significant benefits, gas and water can either be added to the existing Smart Grid program for electricity, or run parallel to it with cross-flow of information and outcomes.

Steps to implementation in the irrigation domain: A demonstration project in a selected set of irrigation systems would be a sound investment. Given that on-farm systems are an important link in the supply chain, funds could be sourced from the \$5 billion committed to on-farm water efficiency in the Water for the Future Initiative.

5.3 Resilient landscapes

Background: The challenges facing rural Australia over coming decades include production of significantly more food with less water, contribution to reductions in GHG emissions and restoration of stressed land and river ecosystems. These challenges require an integrative approach, because all of them constitute intersection points between energy, water and carbon, together with landscape productivity and ecosystem health.

Requirements for integration arise both within and between many activities and functions. These include (1) food and fibre production; (2) bioenergy production; (3) soil carbon sequestration; (4) carbon sequestration through forestry; (5) management of water availability and runoff (especially in the presence of water demand from forests and crops); (6) ecosystem health; (7) exploration of alternative production technologies, such as algal biofuels; and (8) rural social development leading to healthy socio-ecological systems. Energy-water-carbon intersections appear directly in the first five of these activities and functions, and indirectly, but significantly, in the other three.

A framework for shaping a response to these challenges is provided by the concept of resilience (see Section 3.2): the ability to recover from disturbances and shocks, the ability to adapt to change through learning and the ability to undergo transformation when necessary.

Recommendation 3

The Expert Working Group recommends a national Resilient Landscapes Initiative, to support the evolution of land systems as resilient producers, watersheds, carbon storages, ecosystems and societies. The initiative will assist communities to resolve tensions and take advantage of emerging opportunities presented by these diverse roles, in the context of the transformational changes demanded by environmental constraints. The initiative will operate through a diverse set of regional projects.

Outcomes: This initiative seeks to develop an integrative, resilience-based approach to challenges at the intersections of energy, water, carbon, productivity, and environmental, economic and social health in Australian landscapes. Outcomes include:

- Development of bioenergy and food systems which complement one another, support healthy ecosystems, and are sustainable and commercially viable as carbon, water and energy markets evolve.
- Engagement with both market-based and non-market-based measures for sharing finite resources (complementing *Recommendation 1*).
- Soil carbon sequestration strategies which sustain soil fertility and nutrients while conserving water and energy.
- Evaluation and resolution of tensions between water availability, ecosystem health and carbon sequestration.
- Exploration of alternative production technologies, such as a shift from land-based bioenergy crops to aquatic bioenergy production with algae.
- Full water and GHG accounting for both managed and natural landscapes.
- Rural social development leading to healthy socio-ecological systems.

Steps to implementation: This is a long-term, transformational initiative involving staged implementation over many years, probably decades. Structurally, its core is envisaged as a set of regional projects, large enough in number to represent the diversity of Australian landscapes, rural industries and social systems, and to provide opportunities for learning and diffusion of successful strategies between projects. A model for the application of resilience concepts in this way is provided by work in the Goulburn–Broken catchment in Victoria (Walker et al 2009). These demonstration projects will be aimed not only at transformations within their focal regions, but also at subsequent diffusion of ideas and approaches to other regions.

Steps to implement this vision may include four elements:

- *An initial development and scoping study*, involving key stakeholders from governments, industry, community and the innovation system, centrally supported by a Commonwealth Government authority. This scoping step would be modestly funded for a period of around two years and would lead to a detailed plan including selection of focal regions and determination of specific regional goals.

- *Initial trials of goals and methods* in a limited number of regions, to integrate the landscape activities and functions listed above in *Background*. These trials would ensure, through adaptation and learning, that goals and methods are appropriate, robust and capable of evolving to meet changing needs.
- *Extension to a wider set of focal regions*, spanning the diversity of Australian landscapes, rural industries and social systems, and including ongoing evaluation, learning and adaptation.
- *Fostering of learning and diffusion of successful strategies*, both between focal regions and throughout Australian landscapes and stakeholder communities.

The projects will utilise a variety of existing and developmental systems for water, carbon and other natural resource information in landscapes. The Expert Working Group notes a need for improved integration across these systems. This is addressed in *Recommendation 5*.

Success of the initiative will require a whole-of-government perspective, building on existing developments, farm sector linkages and basic research. Importantly, government-level involvement will be necessary at several levels:

- This initiative will work to common national (Council of Australian Governments; COAG) principles, building on the work of the Natural Resource Management Ministerial Council and the Primary Industries Ministerial Council, established to better integrate Australia's conservation and sustainable production objectives (www.mincos.gov.au).
- The initiative will also recognise the work of the Senate Standing Committee on Rural & Regional Affairs and Transport, which considered 'the capacity for regional Natural Resource Management (NRM) groups, catchment management organisations and other national conservation networks to engage land managers, resource users and the wider community to deliver on-ground NRM outcomes'. The committee made recommendations for 'long-term land care scale strategic planning and action' (Senate Standing Committee on Rural & Regional Affairs and Transport, 2009).
- Other national strategic activities addressing landscape resilience will also be recognised, including the work of Regional Development Australia (www.rda.gov.au), established in 2008 as a partnership between the Australian, state and territory, and local governments to support the growth and development of Australia's regions; and the work of the Rural Research and Development (R&D) Council, established by the Minister for Agriculture, Fisheries and Forestry in 2009 to develop a National Strategic Rural R&D Investment Plan (www.daff.gov.au/agriculture-food/innovation/council).

In the environment formed by the programs listed above, the central offering of the initiative proposed here is an integrative perspective.

5.4 Resilient cities and towns

Background: Australians inhabit built environments from great cities to the Red Centre. Meeting the combined energy, water and carbon challenges in our cities and towns will require technological innovation for energy and water supply, the development of shock-resilient systems, astute investment in infrastructure, and reduction of demand for constrained natural resources (particularly water and GHG emissions). These developments need to occur together.

As for our recommendation on the corresponding issues in landscapes (*see Section 5.3*), the Expert Working Group advocates a resilience approach to these challenges.

Constraints on water availability and GHG emissions, together with population pressures, are generating new challenges for Australia's built environments. For our economy to decarbonise over coming decades, urban environments will need to play a leading role because most Australians live there. This will require transformations in stationary energy supply (*see Section 4.1*) and transport (*see Section 4.2*), together with changes to promote energy conservation and efficiency (*see Section 4.5*). Urban water consumption needs to continue to decrease at least as rapidly as has been achieved over the last few decades (*see Section 4.3*), implying an even more rapid decrease in per capita household and industrial water consumption.

The Expert Working Group views a resilience approach (Walker et al, 2009; Folke et al, 2010) as providing an appropriate framework for addressing these challenges, as for landscapes (*see Section 5.3*). Underlying this approach are (1) the need for connected, transformational changes; (2) the need for local action; and (3) the importance of combining physical, engineering, economic, environmental and social perspectives in a complete view of urban systems.

Recommendation 4

The Expert Working Group recommends the development of a national Resilient Cities and Towns Initiative. This will foster resilient, low-emission energy systems, water systems and built environments by focusing jointly on technological developments in supply and on adaptation in demand as the Australian urban population grows. The initiative will operate through a set of regional demonstration projects. Commonwealth leadership is needed.

Outcomes: The aim of this initiative is to incubate the design of resilient energy, water, transport and related urban systems which meet human needs with minimum emissions and environmental impact, and enhance urban quality of life. These systems can achieve adequate energy and water supply through (1) the reshaping of energy and water supply; (2) recycling to use energy, water and carbon resources presently discarded as waste; and (3) efficiency, conservation and demand management measures. The initiative will engage with the economic, social and physical processes driving demand; capitalise on industrial and employment opportunities made available by sustainable technologies; and manage trade-offs in the decarbonisation of the energy economy.

Specific activities will focus on opportunities for enhancing urban sustainability at energy, water, carbon and related intersections, as detailed in *Section 4.5*:

1. *Planning regulations* to reduce urban sprawl, create green space and improve transport options, including reform of revenue regimes.
2. *Building standards* to maximise energy and water efficiency.
3. *Engineering and design of sustainable buildings* to reduce energy consumption.
4. *Demand reduction* by making information available to consumers through smart networks (see *Recommendation 2*) and education campaigns.
5. *Public transport and alternative transport options* to increase access to affordable, safe and regular public transport.
6. *Integration of electric vehicle use with the electricity grid* to manage the charging of electric vehicles and utilise them as sources of stored energy.
7. *Flexible work patterns* to reduce transport congestion and ease demand for fossil-fuel-intensive peak stationary power.
8. *Urban design and layout* to maximise access to non-motor transport and services, and increase the overall energy efficiency of urban living.
9. *Urban cooling with vegetation* for local climate control and amenity.
10. *Recycling of energy and water* to recover materials and energy from waste water, including turning waste organic carbon into energy as usable methane.

Major communities of interest include local governments of cities and towns, federal and state regulatory agencies, energy producers and retailers, energy innovators (for distributed renewable energy and technologies such as smart networks), the building industry, urban planners and architects, the education sector, community organisations representing special needs such as homelessness and aged care, and the research community, comprising the government, university and private sectors.

Steps to implementation: As for *Recommendation 3*, this is a long-term, transformational initiative involving staged implementation over many years. The demonstration projects at the core of the initiative would encompass the diversity of Australian urban environments from major cities to small towns, with links to technological developments such as smart networks and their extension to gas and water (see *Recommendation 2*).

Steps to implementation would be similar to the four elements outlined in *Recommendation 3*, starting with a scoping and evaluation process involving key stakeholders from governments, industry, community and the innovation system, centrally administered by a Commonwealth Government authority. This scoping process would not be the same as in *Recommendation 3* because the stakeholders and options are significantly different, but it could be centrally supported by the same government structure.

This initiative would build upon several existing federal activities to focus on intersections between energy, water and carbon. Relevant activities include:

- the Renewable Energy Futures Fund
- the Prime Minister's Task Group on Energy Efficiency
- the 'Smart Grid, Smart City' program (*see Recommendation 2*)
- national initiatives operating in individual sectors.

The initiative would also connect with a number of relevant international activities, including those listed in *Table 4.2*.

This initiative is significant in the overall framework being developed in this report in placing technical developments such as smart networks (*see Recommendation 2*) into a whole-system context, including people.

5.5 Enhanced knowledge and learning system

Background: All of the foregoing recommendations place high demands on new knowledge and innovation, particularly for integrative understanding of whole-system behaviours. There is a growing gap between the largely compartmentalised knowledge provided by our current innovation system and the kind of cross-disciplinary, cross-sectoral understanding that is needed to enable innovation across energy, water, carbon and related domains. We cannot manage what we do not understand, and we cannot manage what we do not measure.

Recommendation 5

The Expert Working Group recommends enhancing the development of integrative perspectives across the Australian knowledge system, by (1) establishing a core research effort in integrative systems analysis, to understand and map the connections between energy, water, carbon, climate, agriculture, ecosystems, the economy and society; (2) including incentives for integrative analysis in existing academic, government and sectoral innovation investment structures; and (3) enhancing support for stable, ongoing delivery of essential information.

Outcomes: Through both short-term and long-term actions, this recommendation will improve Australia's ability to develop resilience through adaptation and learning. It will address the rapidly emerging need for integrative perspectives that can overcome the ongoing compartmentalisation of research funding and organisations into silos representing traditional disciplines and sectors.

In keeping with the principle 'we cannot manage what we do not understand', this recommendation will lead to better understanding of the whole-system characteristics that emerge from energy-water-carbon intersections, including resilience, adaptability, transitions and thresholds. Understanding of these characteristics will lead to identification of potentially successful and unsuccessful pathways—particularly the dead-end pathways which lead to long-term problems for society if action is not taken early and from which escape is difficult. Examples of integrative issues for this effort include the implications of climate change and population growth for the economy, urban amenity, agricultural productivity, ecosystem health and societal wellbeing.

In keeping with the principle 'we cannot manage what we do not measure', the recommendation will lead to stable, ongoing and continuous operational delivery of essential biophysical, ecological, geographic, economic and social information, through greatly enhanced support and integration. These kinds of information are crucial for both research and operational goals in integrative frameworks.

Steps to implementation: The first part of the recommendation can be initialised relatively quickly, but is long-term in its ultimate time frame and in its intent of catalysing a transformation of the innovation system to generate an enhanced focus on integration. This part of the recommendation proposes the establishment of a national program for integrated systems analysis. This program will encompass both natural and physical science disciplines (for example hydrology, agricultural science, climatology and engineering) and also human sciences (for example economics, demography, social science and psychology). Its focus will be upon linkages and connections rather than on disciplinary components.

The integrated systems analysis program can be built around a dedicated central research agency, linked to nodes based on existing institutions. Its governance would be structured to ensure a high level of user engagement, through a board that includes key national and state agencies and embraces both research users and providers. The program will have extensive international linkages to institutions in other countries that carry out related work, such as the International Institute for Applied Systems Analysis in Laxenburg, Austria (IIASA; www.iiasa.ac.at), the National Science Foundation (NSF) Advisory Committee for Environmental Research and Education in the USA (AC-ERE; nsf.gov/geo/ere/ereweb/advisory.cfm) and the Global Systems Dynamics and Policy initiative of the European Union's Framework Science Program (www.globalsystemdynamics.eu).

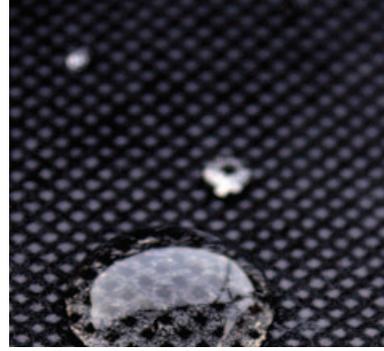
A significant part of the mandate of the program will be education and training of researchers and practitioners in integrated systems thinking. There is an acute need for researchers with these skills at all levels, from research assistants to leaders. International demand for these research skills is very strong. In time, an Australian education and training program in these areas has the potential to operate not only nationally, but also regionally and globally.

The second part of the recommendation addresses the compartmentalisation of research funding and organisations into silos representing traditional disciplines, such as physical sciences, earth sciences and biology, or into research sectors, including the natural sciences, social sciences, economics and the humanities. Implementation involves two specific components:

- We propose adding a National Research Priority which will promote cross-disciplinary and cross-sectoral synthesis, as required by the close connections between energy, water, carbon, agriculture, ecosystems and society. This would be reflected in long-term funding criteria by the Australian Research Council (ARC) and in other government research funding initiatives.
- We propose a research-coalition model for linking the diverse existing providers of energy, water and carbon research with the users of that research. Such a model can encourage both fundamental and applied research with appropriate overall priority setting and selection. This can be implemented in the energy, water, climate and other sectors by building upon existing arrangements (for example the ARC, Rural Research and Development Corporations and Cooperative Research Centres), in a sector-appropriate manner.

The third part of the recommendation proposes enhanced support for and integration of essential biophysical, ecological, geographic, economic and social information. These kinds of information are presently supplied by numerous systems with varying levels of continuity and linkage to other systems. In a rapidly changing world, this monitoring is needed not just as occasional audits or snapshots (as provided in 2000 by the National Land and Water Resources Audit, for example) but as continuous data streams to track trends and provide early warning of changes. Increasingly, the supply of suitably integrated and connected information is an innovation challenge in its own right. It is essential to have better coordination and stable support for these activities, which are currently spread across numerous agencies, including the ABS, ABARE-BRS, the Bureau of Meteorology, CSIRO, Geoscience Australia, National Research Facilities such as TERN (the Terrestrial Ecosystem Research Network) and IMOS (the Integrated Marine Observing System), several federal and state government departments, and universities. The important need is not to bring all of these processes under a single framework, but rather to ensure stability of funding, effective delivery of information and effective connectivity between different kinds of information.

From a government perspective, the research system is the natural custodian of cross-portfolio research leadership. The changes envisaged here can therefore complement the recent proliferation of national research programs administered by government departments (Department of Finance and Deregulation, 2009).



6. Conclusions

There are deep connections between energy, water and carbon, which together play essential and intersecting roles in the total system formed by the natural environment and human society. To recognise these connections, this report is based on two underpinning themes: the need for an integrative perspective and the need for system resilience.

These two themes are the foundation for our five recommendations: (1) the governance and sharing of finite resources of water and GHG emissions; (2) the distribution of energy and water with smart networks; (3) enhancing the resilience of Australian landscapes; (4) likewise, enhancing the resilience of built environments; and (5) enhancing Australia's knowledge and learning capabilities to meet the need for integrative knowledge about the whole system formed by energy, water, carbon, ecosystems, the economy and human society. All of our recommendations span sectors, focusing on developing the knowledge, systems and approaches needed to address challenges which will demand long-term transformations.

In working on a topic as vast as this, many aspects inevitably emerge that require further intensive effort. An indicative list of such issues includes the following:

- *Risk analysis of climate change:* In the presence of uncertainty (both in climate science and more importantly in assessing future development pathways for the world and Australia) it is critical to improve the analysis and interpretation of risks from climate change, with full recognition of energy-water-carbon intersections. This includes several elements: (1) continued development of probabilistic climate projections; (2) better quantification of the impacts of climate change on Australia, its region and the world; and (3) replacement of 'damage functions' (now used in most integrative assessments to translate predicted changes in physical climate into economic costs) with more sophisticated measures acknowledging full economic, environmental and societal costs and benefits.
- *The international game of sharing emissions reductions:* It is possible that 'appropriate contributions' by nations to the global task of mitigating climate change will not be determined by a top-down approach (a universal international treaty), but rather by a bottom-up approach in which national contributions, and the overall extent of global emissions reductions, emerge from the responses of individual nations. Each nation will make its own assessment of threats from climate change and its impacts (for instance through water), and also the costs and benefits of various courses of action (for instance through energy supply and consumption). This means that over the coming century, the course of emissions reductions and of climate change itself will be the outcome of the actions of players in an international game. Understanding the dynamics and possible outcomes of this game will be fundamental.
- *Effects of coming global oil shortages:* Responses to coming oil shortages will be critical and there is a need to understand the full energy-water-carbon implications of all options. In the absence of a price on carbon there is potential for a major increase in emissions as oil shortages lead to the adoption of more GHG-intensive alternatives through rising oil prices. There will also be significant water and food implications from increases in biofuel production.

- *Reliability and longevity of land-based carbon sequestration:* Carbon sequestration in soil carbon, biochar or wood (through carbon forestry) is subject to many uncertainties, including risks from a variable and changing climate. Carbon in soils and forests is returned in large quantities to the atmosphere by droughts and fires, and likewise taken up by regrowth. The efficacy of land-based carbon sequestration as a mitigation strategy is therefore subject to the effects of climate variability. Given the present strong political moves toward making carbon sequestration a major part of Australia's emissions reduction strategy, it is important to have better determinations of: (1) real, achievable potential of carbon sequestration (rather than possibly optimistic assessments of theoretical potential); (2) the risks posed by climate variability; (3) implications for water and nutrients; and (4) measurement techniques and issues.

Australia and the world will change enormously in coming decades in population, technologies, economies, environments, societies and cultures. Throughout history, energy, water and carbon have underpinned the functioning of this integrated system. In coming decades they will also influence the system in new ways, as the world and Australia face the twenty-first century challenge of sharing a finite planet with limited resources that are approaching the point of being fully utilised by humanity.

While the challenges and uncertainties are great, so is the potential for response. We have attempted an integrated perspective on this potential, based on the concept of system resilience. The intent of our five recommendations is to explore pathways toward resilient responses to the many challenges at energy-water-carbon intersections. Our recommendations are broad in scope, but all have logical steps to implementation. Once the destination is known, the next step is always the most important.



Appendices

Appendix A Australia's future greenhouse gas emissions

There is a well-known gap between 'business-as-usual' (BAU) trajectories for greenhouse gas (GHG) emissions and the trajectories required for climate stabilisation (IPCC, 2007a). To have a 50 per cent chance of keeping global temperature rise above pre-industrial temperatures to 2 degrees or less, future global cumulative carbon dioxide (CO₂) emissions must be capped at a quota or 'budget' which is about the same as what has been emitted throughout the industrial era to date (Allen et al, 2009; Meinshausen et al, 2009; Raupach and Canadell, 2010). At current global emission rates, this cap will be reached in about 50 years. A small trickle of ongoing sustainable emissions is possible thereafter, but much lower than at present.

The global cap translates to a global CO₂ emissions reduction of about 60 per cent by 2050 (relative to emissions in 2000) and greater reductions, of 80 per cent or more, in developed nations like Australia.

To characterise these gaps between BAU emissions trajectories and biophysical constraints for Australia, we use a simple set of four scenarios defined by 'high' and 'low' population trajectories, and '2 degree' and '4 degree' scenarios for the evolution of global climate. The 'high' and 'low' population trajectories are, respectively, Scenarios A and C from the Australian Bureau of Statistics (ABS, 2008b), which yield Australian populations in 2050 of about 40 million and 30 million, respectively (the population in 2010 is 22 million).

BAU (with either high or low population) and climate-constrained (2 degree world or 4 degree world) trajectories for Australian fossil-fuel CO₂ emissions are shown together in *Figure A1* for the 130-year period 1970–2100. We focus on CO₂ emissions from fossil fuels both because they are the largest single emissions component (DCCEE, 2010b) and because the global mitigation challenge can be defined well by specifying a quota or 'budget' for future global cumulative CO₂ emissions (see above).

In detail, the trajectories in *Figure A1* are calculated as follows:

- The two BAU trajectories (red and orange lines) for CO₂ emissions depend only on the population scenario. They are obtained by multiplying population (from the high or low ABS scenarios) by Australian per capita emissions over the period 2000–07 (DCCEE, 2010b). Based on observed trends over this period, BAU per capita emissions of CO₂ from fossil fuels are assumed to decrease in future at 0.5 per cent per year, while per capita emissions of all GHGs are assumed to remain steady.
- The climate-constrained emissions trajectories for Australia in the 2 degree and 4 degree climate scenarios (green and blue lines) are calculated by ascribing to Australia a given share of allowed cumulative global CO₂ emissions. To stay below the specified global temperature increases with 50 per cent probability (from 2010 onward), these global quotas are 1470 GtCO₂ for the 2 degree scenario and 7330 GtCO₂ for the 4 degree scenario. These cumulative values fix the integral (area) beneath an emissions trajectory that smoothly merges present growing emissions with long-term exponential decay, which determines the entire trajectory.

- The primary climate-constrained emissions trajectories are shown as heavy blue ('2 degree compromise') and green ('4 degree compromise') lines. These are obtained by ascribing to Australia a share of 0.6 per cent of allowed cumulative global CO₂ emissions, which is a weighted average (a 'compromise' position) of the shares resulting from two extreme possibilities: sharing by current emissions ('current share') and sharing by population ('share by popⁿ'). Sharing by current emissions would give Australia a share of 1.3 per cent of cumulative global emissions, yielding the emissions trajectories shown as dashed blue (2 degree) and green (4 degree) lines. Sharing by population would give Australia a much lower share of 0.3 per cent, yielding the trajectories shown as thin blue (2 degree) and green (4 degree) lines. The 'compromise' share used here to determine the primary climate-constrained emissions trajectories (0.6 per cent) emerges from an analysis to determine the most achievable global weighting in a rule space for sharing cumulative CO₂ emissions (Raupach, 2007). Assuming a different weighting for each of the extreme possibilities would yield a different 'compromise' trajectory.

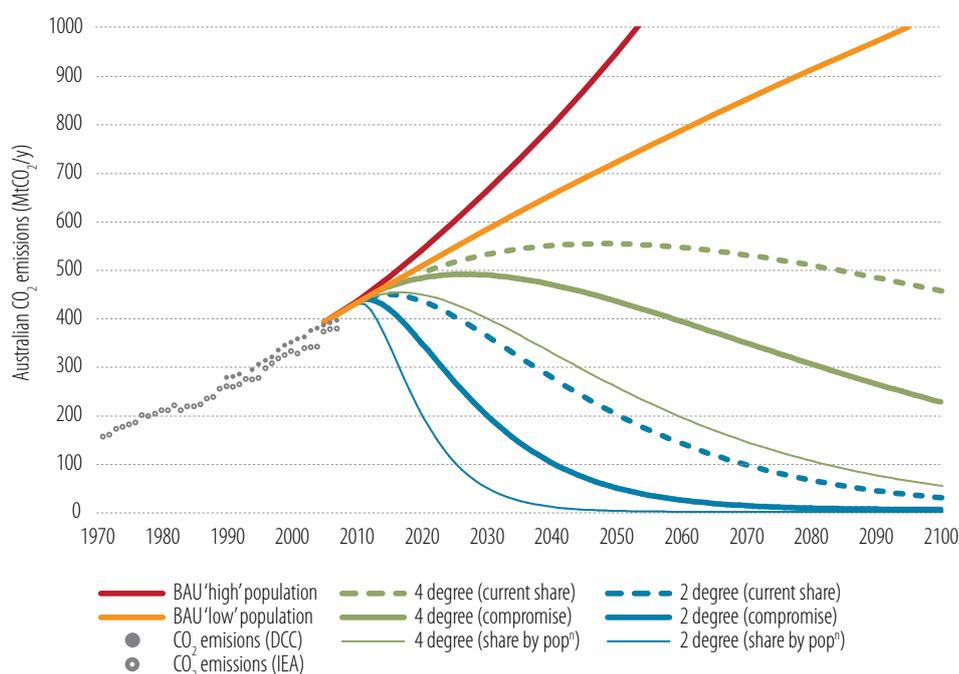


Figure A1: Business-as-usual (BAU) and climate-constrained trajectories for Australian CO₂ emissions over the period 1970–2100. Grey points show data for past CO₂ emissions to 2007 from the Australian National Greenhouse Gas Inventory (DCC, 2008; DCC, 2009a) and for past fossil-fuel CO₂ emissions from the IEA (International Energy Agency, 2009a). Red and orange curves are BAU trajectories corresponding to high and low population scenarios, respectively, from the Australian Bureau of Statistics (BAU 'high' population and BAU 'low' population; 40 million or 30 million in 2050, respectively). Heavy blue and green curves are climate-constrained trajectories consistent with peak global temperature rises of 2 degrees and 4 degrees above pre-industrial temperatures, respectively, with Australia having a 'compromise' share of 0.6 per cent of allowed global CO₂ emissions. The compromise share is a weighted average of shares resulting from two extreme possibilities: sharing by current emissions and sharing by population. Sharing by present emissions ('current share') yields the dashed blue (2 degree) and green (4 degree) lines; sharing by present population ('share by popⁿ') yields the thin blue (2 degree) and thin green (4 degree) lines.

Appendix B Examples of departmental responsibilities for energy-water-carbon matters

The following departmental responsibilities are extracted from the *Commonwealth of Australia Administrative Arrangements Order – 14 September 2010*. This list is indicative only.

Agriculture, Fisheries and Forestry

- Agricultural, pastoral, fishing, food and forest industries
- Soils and other natural resources
- Rural adjustment and drought issues
- Primary industries research including economic research

Climate Change and Energy Efficiency

- Development and coordination of domestic and international climate change policy
- Mandatory renewable energy target policy, regulation and coordination
- Greenhouse gas emissions and energy consumption reporting
- Climate change adaptation strategy and coordination
- Coordination of climate change science activities
- Renewable energy programs
- Greenhouse gas abatement programs
- Community and household climate action

Education, Employment and Workplace Relations

- Education policy and programs including schools, vocational, higher education and Indigenous education, but excluding migrant adult education
- Science awareness programs in schools

Families, Housing, Community Services and Indigenous Affairs

- Indigenous policy coordination and the promotion of reconciliation
- Community development employment projects

Foreign Affairs and Trade

- External affairs

Infrastructure and Transport

- Infrastructure planning and coordination
- Land transport

Innovation, Industry, Science and Research

- Manufacturing and commerce including industry and market development
- Biotechnology, excluding gene technology regulation
- Industry innovation policy and technology diffusion
- Science policy
- Promotion of collaborative research in science and technology
- Coordination of research policy
- Creation and development of research infrastructure
- Commercialisation and utilisation of public sector research relating to portfolio programs and agencies
- Food industry policy

Prime Minister and Cabinet

- Coordination of Government administration
- Intergovernmental relations and communications with State and Territory Governments

Regional Australia, Regional Development and Local Government

- Delivery of regional and rural specific services
- Regional development
- Matters relating to local government
- Regional Australia policy and coordination

Resources, Energy and Tourism

- Energy policy
- Mineral and energy industries, including oil and gas, and electricity
- National energy market
- Energy-specific international organisations and activities
- Minerals and energy resources research, science and technology
- Geoscience research and information services including geodesy, mapping, remote sensing and land information coordination
- Radioactive waste management
- Renewable energy technology development
- Clean fossil fuel energy
- Industrial energy efficiency

Sustainability, Environment, Water, Population and Communities

- Environment protection and conservation of biodiversity
- National fuel quality standards
- Land contamination
- Meteorology
- Natural, built and movable cultural heritage
- Environmental research
- Water policy and resources
- Ionospheric prediction
- Coordination of sustainable communities policy
- Population policy
- Built environment innovation

Appendix C Examples of existing activities

This is intended as an indicative, but by no means exhaustive or complete, survey.

Sectoral activities: Water

- a. The National Water Commission is within the Department of Sustainability, Environment, Water, Population and Communities (formerly DEWHA) portfolio and has an advisory and assessment role, advising COAG and auditing/assessing progress on the National Water Initiative (below) and the Murray–Darling Basin Plan. www.nwc.gov.au
- b. The National Water Initiative is an intergovernmental ‘blueprint for water reform’ set up in 2004 by COAG. Its goal is to create a national market, regulatory and planning regime for water, with each state and territory preparing its own implementation plan. www.nwc.gov.au/www/html/117-national-water-initiative.asp
- c. Water for the Future is the Department of Sustainability, Environment, Water, Population and Communities’ water program. Its structure includes initiatives such as the National Water Quality Management Strategy and the National Rainwater and Greywater Initiative. www.environment.gov.au/water/australia
- d. The Smart Water Research Facility has a strong focus on water quality though they also research water sources (e.g. coal-seam, recycling, condensate) and governance/demand management issues. www.smartwaterresearchcentre.com/smart-water-facility
- e. The eWater Cooperative Research Centre is developing some of the kind of integrated tools for water which could be applied to energy-water-carbon as an integrated system. They are developing tools for managing river systems, catchments as a whole and urban water systems. www.ewatercrc.com.au
- f. The Victoria Smart Water Fund is a joint initiative of five of Melbourne’s water utilities plus the Victorian Government. It funds water projects with a strong emphasis on water quality, but across the spectrum from water treatment for biosolids through to awareness programs for schools. www.smartwater.com.au
- g. The CSIRO Water for a Healthy Country Flagship Program is a national research program ‘addressing one of Australia’s most pressing natural resource issues—sustainable management of our water resources’. Its Sustainable Yields Projects ‘are undertaking a comprehensive scientific assessment of current and future water availability in all major water systems across Australia to allow a consistent framework for future water policy decisions’. www.csiro.au/org/HealthyCountry

Sectoral activities: Energy

- a. Smart Grid Australia is a mostly-industry consortium but includes some CSIRO, university and government partners. www.smartgridaustralia.com.au
- b. The CSIRO Energy Transformed Flagship is ‘developing clean affordable energy and transport technologies for a sustainable future—the first steps towards a hydrogen economy’. www.csiro.au/org/EnergyTransformedFlagship
- c. CSIRO ICT has been working on smart metering technology geared toward end-users to allow them to be alerted to (e.g. via SMS) and control energy usage remotely. www.csiro.au/multimedia/Smart-metering-benefits
- d. DCCEE ‘Smart Grid, Smart City’ initiative. A consortium based in Newcastle NSW will deploy a commercial-scale ‘smart grid’. The grid they implement will be geared toward utilities, though there will be end-user applications such as in-home displays of electricity usage. www.climatechange.gov.au/government/programs-and-rebates/smartgrid
- e. The Ministerial Council on Energy is responsible for the *National Framework for Energy Efficiency* including a set of national measures for energy efficiency. www.ret.gov.au/mce
- f. COAG’s *National Partnership Agreement on Energy Efficiency*. An agreement related to the framework above. www.coag.gov.au/coag_meeting_outcomes/2009-07-02/index.cfm#energy

Sectoral activities: Carbon and climate

- a. The National Carbon Accounting System accounts for land-based greenhouse gas emissions including those from livestock and crop production, land clearing and forestry. www.climatechange.gov.au/government/initiatives/national-carbon-accounting
- b. CSIRO basic climate change research 'provides comprehensive, rigorous science to help Australia understand, respond to and plan for a changing climate'. www.csiro.au/science/Climate-Change
- c. The CSIRO Climate Adaptation Flagship has the goal of 'equipping Australia with practical and effective adaptation options to climate change and variability, and in doing so creating A\$3 billion a year in net benefits by 2030'. www.csiro.au/org/ClimateAdaptationFlagship
- d. National Climate Change Adaptation Research Facility (NCCARF, funded in part by DCCEE). NCCARF's initiatives include climate change adaptation research plans for primary industries, terrestrial biodiversity, social, economic and industrial dimensions, and others relevant to energy-water-carbon intersections. www.nccarf.edu.au
- e. Climate Change Research Strategy for Primary Industries. Designed to equip primary industries to deal with climate change and variability. Has links to the DAFF Climate Change Research Program. www.ruralrdoc.com.au/Page/CCRSPI.aspx
- f. The Global Carbon Project is an international project aimed at developing an integrative picture of both the natural and human aspects of the global carbon cycle. www.globalcarbonproject.org

Integrated activities

- a. IIASA, the International Institute for Applied Systems Analysis, carries out 'policy-oriented research into problems that are too large or too complex to be solved by a single country or academic discipline.' IIASA is supported by member organisations (national science academies and foundations) and is related to *Recommendation 5's* call for integrated perspectives across the Australian knowledge system. IIASA's core theme areas— Environment and Natural Resources, Population and Society, and Energy and Technology—are related to energy-water-carbon intersections. www.iiasa.ac.at
- b. The Barbara Hardy Centre for Sustainable Urban Environments at the University of South Australia, has a focus on urban sustainability, including water, energy, and biodiversity. www.unisa.edu.au/barbarahardy
- c. The Carnegie Department of Global Ecology at Stanford University, with several projects focused on energy monitoring and greenhouse gas accounting. dge.stanford.edu
- d. The (US) NSF Advisory Committee for Environmental Research and Education report on tipping points emphasises the importance of understanding interactions between social and physical sciences, as does this report. www.nsf.gov/geo/ere/ereweb/ac-ere/nsf6895_ere_report_090809.pdf
- e. The McKinsey/Swiss Re study on climate-resilient economic development has a strong focus on the financial aspects of climate-related risks. Studies like this are key to this report's *Recommendation 1*, which calls for prices that 'reflect long-term societal costs.' media.swissre.com/documents/rethinking_shaping_climate_resilient_development_en.pdf

Appendix D Glossary of terms and abbreviations

Term	Definition
AAS	Australian Academy of Science
A\$	Australian dollar
A2 scenario	A hypothetical future world scenario with a technological emphasis on fossil-intensive energy sources and rapid population growth
ABARE	Australian Bureau of Agricultural and Resource Economics
ABARE–BRS	In July 2010 ABARE merged with BRS to form ABARE–BRS
ABS	Australian Bureau of Statistics
AC-ERE	Advisory Committee for Environmental Research and Education
AEMC	Australian Energy Market Commission, the rule maker and developer for the nation's energy markets
AER	Australian Energy Regulator
ARC	Australian Research Council
BAU	Business-as-usual
biochar	Biochar is a stable form of charcoal produced by heating organic materials (crop and other waste, woodchips, manure) in a high temperature, low oxygen process known as pyrolysis.
biofuel	Liquid fuel derived from a living biological source, typically ethanol or oil
BRS	Bureau of Rural Sciences
carbon	Depending on context, the term 'carbon' in this report denotes: (1) a synonym, in accord with popular usage, for greenhouse gases that contribute to human-induced climate change; (2) a component of carbon dioxide, the most important greenhouse gas through which human activities influence climate; and (3) the element on which life is based and which moves through the earth system in the carbon cycle. The phrase 'energy-water-carbon intersections' uses 'carbon' in the first sense.
carbon sequestration	Removal of CO ₂ from the atmosphere and storage of the carbon in a land or ocean reservoir, thus lowering atmospheric CO ₂ . This reservoir may be in wood (carbon forestry), in the soil (as soil carbon or biochar), in a geological formation (as in carbon capture and storage, CCS) or in the ocean (an option not considered in this report).
CCRSPI	Climate Change Research Strategy for Primary Industries
CCS	Carbon Capture and Storage
CH ₄	Methane
CNG	Compressed Natural Gas
CO ₂	Carbon dioxide
CO ₂ eq	Carbon dioxide equivalents, a unit used to compare the warming effects of different greenhouse gases (mainly CO ₂ , methane, nitrous oxide and chlorofluorocarbons) over a 100-year period by converting to an equivalent quantity of CO ₂ .
COAG	Council of Australian Governments
CSIR	Council for Scientific and Industrial Research (predecessor of CSIRO)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry
DCC	Department of Climate Change (DCC became DCCEE in 2010)
DCCEE	Department of Climate Change and Energy Efficiency
decarbonisation	The reduction and eventual elimination of net greenhouse gas emissions
DEWHA	Department of the Environment, Water, Heritage and the Arts (DEWHA became the Department of Sustainability, Environment, Water, Population and Communities on 14 September 2010)
DIISR	Department of Innovation, Industry, Science and Research
E10	10% ethanol in petrol
Earth System	The fully coupled system formed by the natural world (including the atmosphere, oceans, water in soil and rivers, and ecosystems of plants and animals) together with human economies, societies and cultures
EOR	Enhanced oil recovery
ESM	Energy Sector Model
EWG	Expert Working Group
FAO	Food and Agriculture Organisation of the United Nations
fossil fuel	Coal, mineral oil and natural gas, burned to provide energy
GDP	Gross Domestic Product

Term	Definition
GHG/s	Greenhouse gas/es
GL	Gigalitre (1 gigalitre is 1 billion litres)
greenhouse gases	Gases which interact with heat radiation to cause the natural and enhanced greenhouse effects (<i>Section 2.2</i>)
GtCO ₂	Gigatonnes of CO ₂ (1 gigatonne is 1 billion tonnes)
GWh	Gigawatt-hour, a unit of energy corresponding to a power of 1 billion watts for 1 hour
ICT	Information and Communication Technology
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
kl	Kilolitre (1 kilolitre is 1000 litres)
km	kilometre, 1000 metres
kW	kilowatt, 1000 watts
L	Litre
LNG	Liquefied natural gas
lock-in	Occurs when there is no opportunity for a system to change its trajectory, even though change may be desired or required. Lock-in is often the result of much earlier decisions. An important example for energy-carbon-water intersections is the development of a new power station, which (if it is coal-fired) locks its generated energy to high emissions for the life of the station, typically several decades.
LPG	Liquid petroleum gas
MJ	Megajoule, 1 million joules
ML	Megalitre, 1 million litres
MtCO ₂	Megatonnes of CO ₂ (1 megatonne is 1 million tonnes)
MW	Megawatt (1 million watts), a unit of power or energy per unit time
MWh	Megawatt-hour, a unit of energy corresponding to a power of 1 MW for 1 hour
NRM	Natural Resource Management
NSF	National Science Foundation
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule, 10 ¹⁵ joules (a unit of energy)
PMSEIC	Prime Minister's Science, Engineering and Innovation Council
ppm	Parts per million, a measure of concentration
R&D	Research and Development
Rainfall-runoff amplifier	The amplification of fractional changes in rainfall into larger fractional changes in runoff and stream-flow in rivers, which is a general hydrological feature of landscapes in all but very wet climates. In these conditions a 1% change in rainfall (either up or down) produces approximately a 3% change in runoff in the same direction.
SDL	Sustainable diversion limit, e.g. for water
t	Tonne (1 thousand kilograms or 1 million grams)
t/year	Tonnes per year
TWh	Terawatt-hour, 10 ¹² watt-hours (a unit of energy)
VEET	Victorian Energy Efficiency Target
y	Year

Appendix E References

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