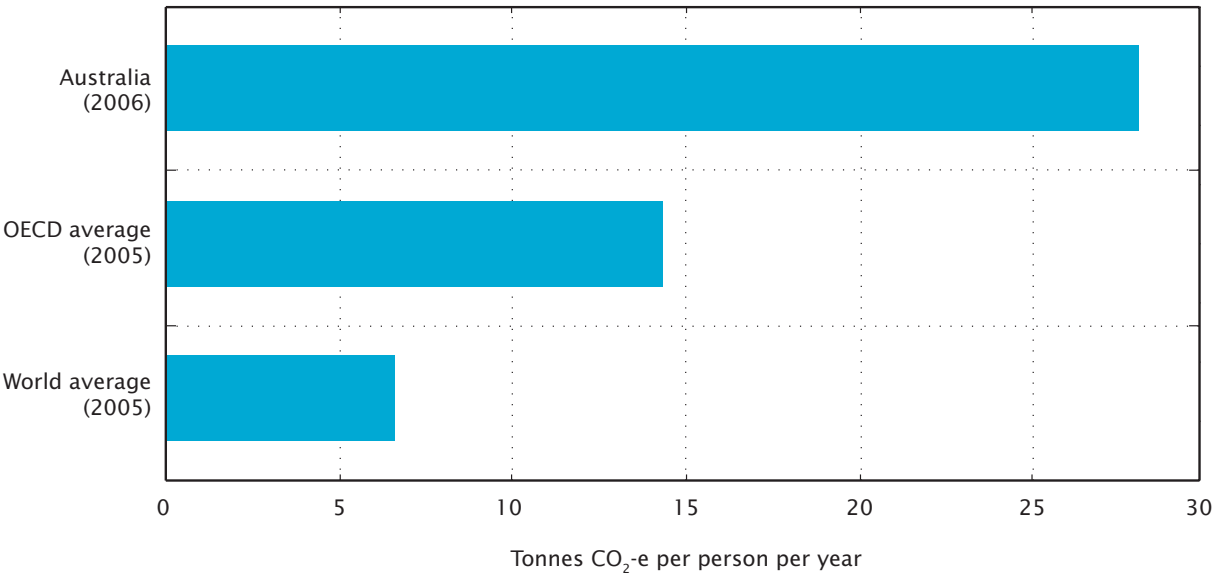
Mitigation strategies for energy and transport

By Jim Smitham, Jenny Hayward, Paul Graham, and John Carras

Key messages

- Australia has an abundance of clean energy options from which to choose. Its future will undoubtedly involve a wider range of different energy sources, which are suited to particular niches.
- Renewables are expected to feature more prominently in Australia's energy mix by the 2020s.
- Promising technologies exist for coal with carbon capture and storage for base-load power generation, but these will depend critically on the price society places on carbon. Prolonged uncertainty over carbon pricing could risk delays in investment, because generators will be reluctant to invest in any technology that may be 'stranded' by subsequent policy decisions.
- Energy saving technologies, demand reduction, and distributed power generation will help to lower national carbon emissions.
- Changes in the transport sector will be driven far more by oil prices than by carbon prices. Electricity may become the transport fuel of choice with Australian motorists and transport operators, with the use of some LNG gas, diesel, and biofuels. Hydrogen fuel cells may eventually replace batteries in electric vehicles.

Australia has a high per capita emissions intensity and has a higher energy use per unit of GDP than the OECD average (Figure 9.1). This is a function of the structure of the economy and Australia's international comparative advantages. Among these advantages are low-cost fossil fuel and mineral resource extraction and processing industries. The main disadvantage is large transport distances, both within Australia and to its overseas customers. The position of Australia relative to other countries in terms of emissions per person is shown in Figure 9.1 and in terms of energy sources in Table 9.1. This is the starting point for changes in mitigation strategies for Australia compared with the rest of the world.



▲ ***Figure 9.1**: Per capita greenhouse gas emissions.*[1]

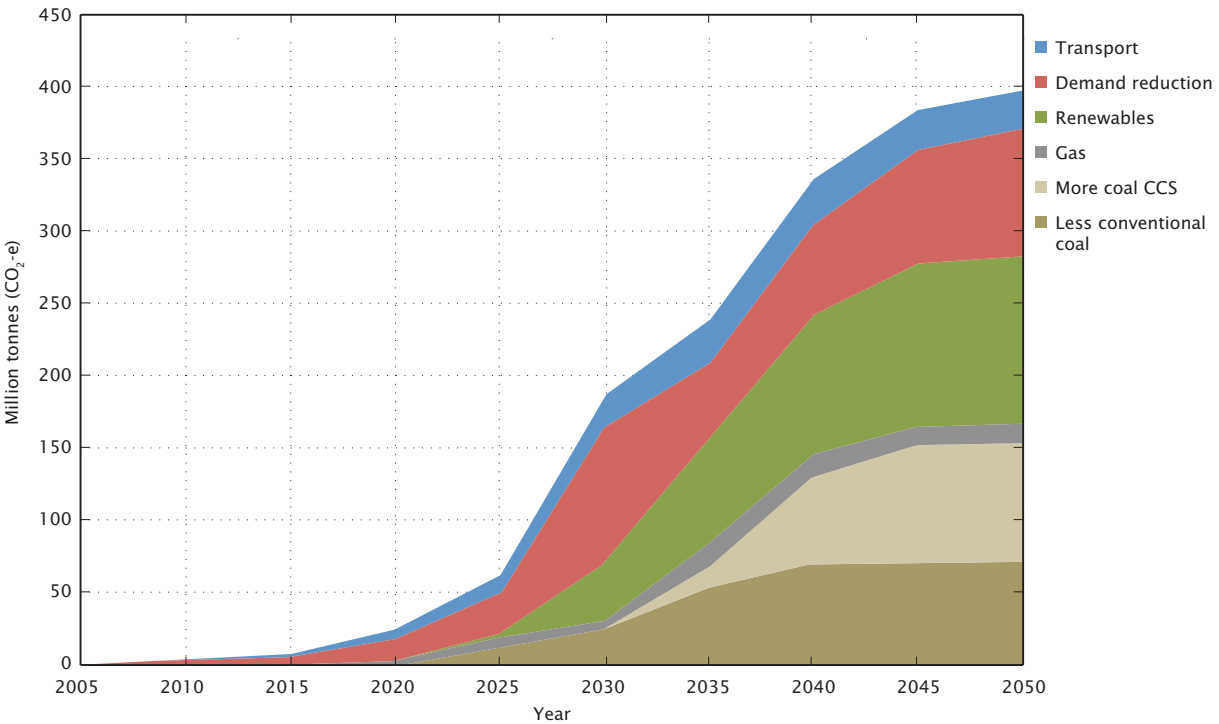
Table 9.1: Fuel mix contributing to primary energy supply[2, 3]

Fuel	OECD 2006 Share (%)	Australia 2007–8 Share (%)
Coal	20	37
Oil	41	36
Gas	23	22
Nuclear	10	0
Renewables	6	5
Total	100	100

Australia's use of oil primarily reflects the transport sector, which is dependent on oil for 94% of its energy usage. The remaining oil is used in the agriculture, mining, and chemical industries. Coal is mainly used for electricity generation, which is dependent on coal for 80% of its energy generation. This is in contrast to the average for the OECD, which uses proportionately less coal, but generates 10% of its electricity using nuclear power.

For electricity production, Australia has over three times the greenhouse gas emissions per capita than the OECD average, while for transport Australia's per capita emissions are some 30% higher. Consequently, a significant portion of the future reductions in greenhouse gas abatement will need to come from these sectors.

Taking into account a variety of drivers discussed further below, CSIRO's modelling has produced a number of scenarios, one of which is shown in Figure 9.2. This shows how much of, and where, the greenhouse gas savings may be found in energy and transport in trying to achieve 550 ppm CO_2-e in the atmosphere by 2100.



▲ ***Figure 9.2**: The projected level of emissions to be saved by different mitigation strategies (compared with expected 'business as usual' emissions, which includes 20% renewables by 2020 – as mandated by government). (CCS = carbon capture and storage)*

In broad terms, the modelling shows that, after taking into account the retirement of existing coal plants and some adoption of efficient vehicles and low-emission fuels, around one-third of the nation's energy greenhouse emissions savings could be expected to come from energy efficiency plus demand reduction, one-third from renewables, and one-third from carbon capture and storage (CCS).

Major drivers for change, uncertainties and implications

There is no simple path to selecting the most effective technologies for mitigation. It is a complex interplay between uncertain technology costs, future energy prices, and policy options.

The main drivers of innovation and the rate of take-up of new energy technologies are the cost of petroleum for the transport sector, the price of carbon for the power generation sector, and the uncertainty of future technology costs. These factors are also fraught with the greatest uncertainty.

Recent projections from modelling by the Australian Treasury Carbon Pollution Reduction Scheme suggest a gradual increase in the price of carbon of around 4% per annum over several decades to 2050.[4] If this rate of increase was built into a cost for carbon emissions, such as a national emissions trading scheme or similar, it would imply a gradual, rather than a rapid, shift to new technologies. Gradual adjustments make the transitions for the economy easier. That means that it will take longer for carbon prices to reach the break-even point whereby some low-emission power station investments recoup the cost of emissions reduction, compared with a power station without emissions reduction. Investors need a high level of confidence that a project will be viable, given that the normal life of a power plant is several decades. In the absence of a clear indication of a carbon price in the near term, the only certain policy driver for the sector is the 20% renewables target.

Complicating the picture is a consistent trend in public opinion favouring renewables over coal or nuclear energy. Meanwhile, due to strong worldwide interest in demand for energy and improved energy technologies generally, the cost of all forms of energy generation has risen. This combination of factors may cause hesitation and impose further delays on decisions in Australia to invest in base-load power generation. Unless plant costs fall – or electricity prices rise – to reduce the level of investment risk, it is plausible that investment in base-load power generation will be delayed for one to two decades, with consequent energy shortages.

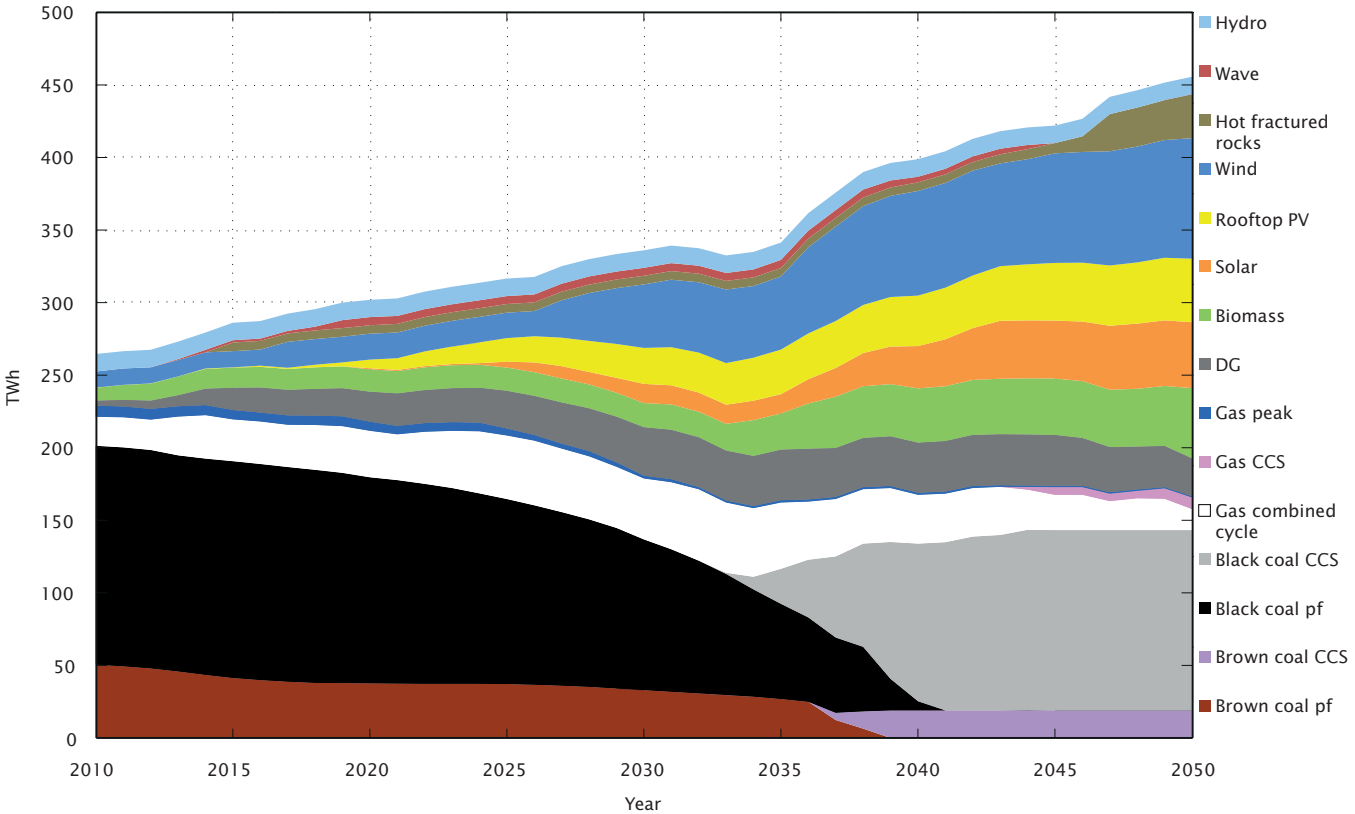
Oil prices, rather than pressure to reduce emissions, are likely to be the main influence on the evolution of Australian transport technology in the foreseeable future. The impact at the pump of an oil price above US$200 a barrel – as anticipated by the US Energy Information Administration (US EIA) in one of its higher-range scenarios – is some 10 times larger for motorists and transport operators than a carbon levy, which may add no more than 10–25 cents a litre (depending on the carbon price), and even this would be over three to four decades. High world oil prices, driven by resuming economic growth and concerns about global peak oil and energy efficiency regulation, will be the main signals to shift to fuel and transport alternatives, and these signals are likely to occur within the next two decades.

There remains significant uncertainty about the future price of oil, which is volatile on both daily and multi-year scales. Although current oil prices are high enough to encourage significant investment in new oil field production, it is unclear how long new oil production will be able to

offset the decline in production from existing oil fields. If a global production peak occurs in the near term, and alternative fuels are unable to fill the gap sufficiently rapidly, fuel prices may at times increase by several dollars a litre in order to curtail global demand.

The role of innovation

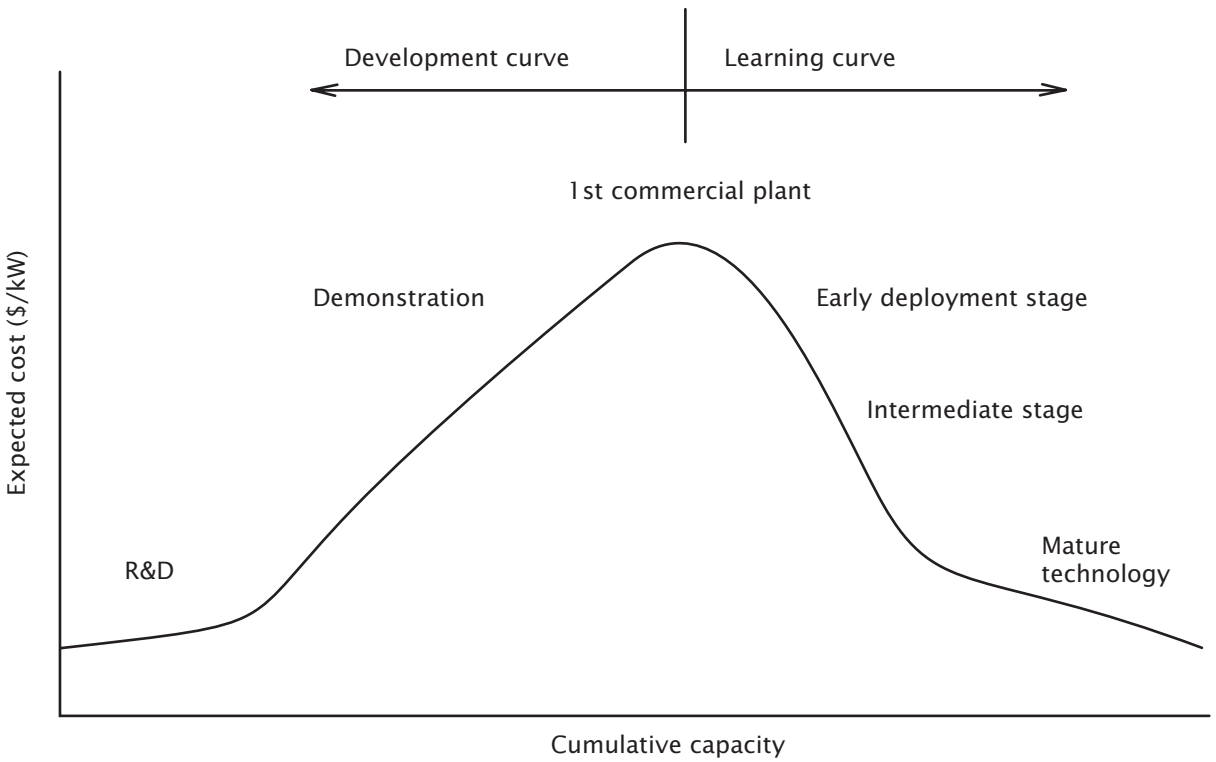
Australia has an abundance of clean energy opportunities, many of which must feature in our diverse energy future. Figure 9.3 illustrates the result of modelling by CSIRO, which shows one possible (but not the only) scenario of the adoption of a number of the electricity generation technologies most commonly considered.



▲ ***Figure 9.3**: CSIRO projection of potential mix of Australian clean energy sources for electricity production out to 2050 showing the changes in technology mix to achieve emissions reduction. (CCS = carbon capture and storage, pf = pulverised fuel, DG = distributed generation)*

Each of these technologies faces obstacles to its continued use and/or future deployment – including cost, state of development, environmental issues, government policy, the need for storage technologies, and public acceptability. The energy mix we achieve by the mid-century will thus depend on which technologies are best able to overcome the various barriers facing them and prove to be most adaptable to the Australian policy environment.

As they progress through R&D to development, demonstration, and adoption, most new technologies follow a similar path. Figure 9.4 shows how cost estimates rise as a technology approaches its first deployment, then fall as it begins to be more widely adopted and costs stabilise. However, there is no guarantee that the cost declines demonstrated by one technology will be replicated by all technologies.



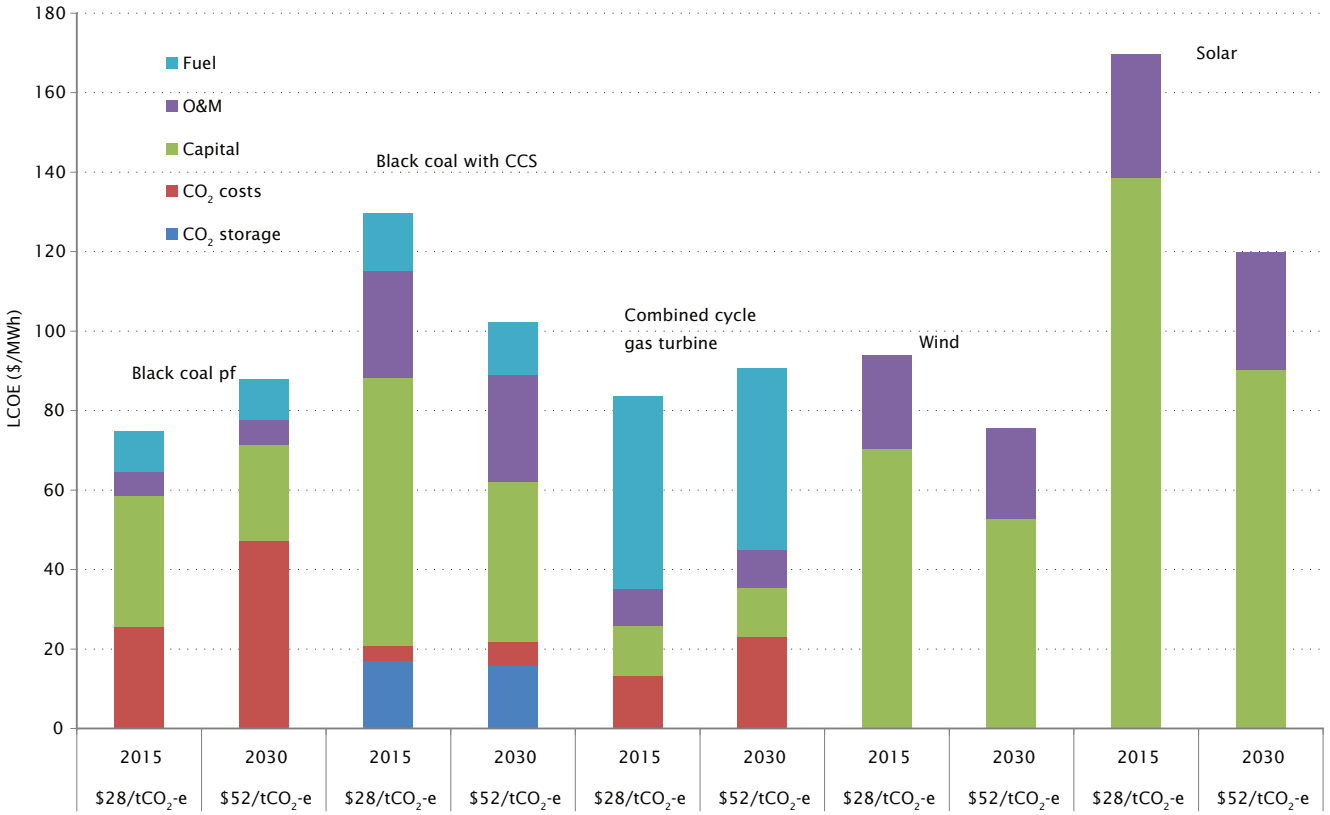
▲ ***Figure 9.4**: Generalised curve showing the rising cost of technology as it is developed from the research and development phase, then the fall in cost as it is deployed.*

Basically, learning curves indicate that the more of a particular technology that is built and used, the cheaper it becomes. However, many factors can alter the shape of the curve – for example, when demand for a technology exceeds supply, it temporarily drives up prices (as has happened with wind power in recent years). Government policies – such as Australia's 20% Mandatory Renewable Energy Target – can also drive the adoption of technologies faster along the learning curve nationally and internationally. Technologies can be accelerated down the learning curve when they share components or have components that interlink, and learning also can be accelerated by technology diffusion between countries. A technology may also undergo a step-wise change due to a new research discovery that drops the price – as thin film solar photovoltaic (PV) technology is expected to do.[5]

Figure 9.5 shows CSIRO's near- and longer term projections of the electricity generation costs of different energy options when a carbon price is added, and the learning curve methodology applied, to an economic model of electricity generation. The model shows investment in capital when required to meet demand and generate electricity at the lowest price, up to the year 2050. Investing in capital pushes technologies 'down' the learning curve so they become cheaper (Figure 9.4). This then encourages further investment in the now-cheaper technology. In the model, technologies compete in terms of price, and the cheaper technologies will then generate the most electricity.[6] In this particular scenario, by 2030 – and with a carbon dioxide price of AU$52 per tonne – wind could be more competitive than the fossil fuel technologies, even though its capital cost is still relatively high.

Figure 9.5 shows the need to balance decisions about capital costs for plant, fuel cost, and carbon dioxide storage costs on a comparative basis. Renewable technologies have high capital cost but no fuel costs, while gas turbine technologies have the lowest capital cost but high fuel cost.

Companies planning investment in generation assets, which may have a useable life of decades, also need to model specific site costs, market behaviour, capital service costs, fuel contracts, and the impact of policy options in specific locations.



▲ ***Figure 9.5**: CSIRO simulations of the cost of electricity (represented as levelised cost of electricity LCOE) for different technologies for two CO_2-e prices. (CCS = carbon capture and storage, pf = pulverised fuel, O&M = operations and maintenance)*

Energy and transport technologies

The following section summarises the state of development and role of key electricity and transport technologies and processes important to reduce CO_2 emissions.

1. Efficiency, demand reduction, and distributed power generation

Energy efficiency gains can come from all sectors. The *First Opportunities* report for the Federal Energy Efficiency Opportunities Program[7] reported that 199 large companies have identified energy saving opportunities equivalent to 1.1% of Australia's greenhouse gas emissions, with savings to boilers, furnaces, kilns, chemical processes, and electrical equipment and mobile equipment. Other savings may come from non-industrial sectors, where there have been low incentives for improvements in the past. Prospective areas for improvement include the building sector, commercial air-conditioning, residential water heating, improved insulation, and commercial and domestic lighting, with a more complete breakdown provided in the *IPCC Fourth Assessment Report*.[8] These will save energy, and so reduce costs for businesses and households, if non-financial barriers to the implementation of energy investments can provide win–win opportunities. However, they may have disadvantages such as loss of function, convenience, and performance. Furthermore, the uptake of energy-efficiency opportunities may be hindered by lacking or misaligned incentives and market failures.

Demand reduction can be achieved in many ways, such as the use of 'smart agents' and 'intelligent grids'. Here, sensors monitor and report information about energy use that can be used to manage supply and demand to a central controller. For example, systems that sense whether rooms are occupied – and that can regulate lighting, heating, and cooling accordingly – can reduce overall demand for power.

Many modern buildings are designed with considerations of reduced energy use in mind, such as natural lighting, thermal load management via the use of appropriate building materials, siting of buildings, and the use of shading, breezes, and vegetation. Demand reduction can be stimulated by government incentives and regulation, and is very often another case of win–win: making sense for both the economy and climate.

Distributed power generation seeks to achieve energy savings by generating electricity close to the point of use – even inside the actual building that uses the energy. Small generators that burn fossil fuels are more efficient overall and are less greenhouse gas intensive if their waste heat is captured and used locally for heating and cooling. Combining heating, cooling, and power production can potentially double the efficiency of fuel use. Small-scale generation is more responsive to local demand and, in some circumstances, can achieve greater cost savings overall when the network costs are considered.

Although distributed generation achieves even greater greenhouse gas reductions when the source of energy is renewable, such as solar, wind, or geothermal power, there is another aspect that must be considered. The current Australian electricity grid was designed to supply power to consumers from a small number of large centralised power stations. In order to achieve a reliable and stable supply from a significant number of distributed generators along with the current large centralised power stations, the electricity grid will require significant augmentation and capital investment.

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2. Renewables and nuclear

Solar power holds great promise as the energy source of the future. There are two categories of solar power that may play a role in future electricity generation: photovoltaics and solar thermal.

Photovoltaic (PV) technologies convert sunlight directly to electricity through the properties of photoactive materials. The main challenge for PV developers is to find the ideal combination of low production cost, optimum conversion efficiency and output, the cost of greenhouse gases emitted in making the materials, and the longevity of the cells in the environment. Silicon-based PV technology has developed over the past three decades, with significant gains in efficiency, and units have been commercially available for some time. However, the cost per kilowatt hour and the need to store electricity for night-time use remain barriers. Second-generation thin-film PV technologies such as CdTe have been introduced, with higher efficiencies and lower costs for large-scale PV power plants, while third-generation PVs, such as organic solar cells (PV or dye), are early stage technologies that promise rapid and cheap production, but their efficiency is still significantly lower than for silicon units.

Solar thermal technologies concentrate the Sun's rays to produce heat that can then be used to heat water, induce chemical reactions, or drive other energy processes. The main technologies include:

- domestic solar hot water systems
- 'trough' collectors that focus the Sun's rays along a single axis where the receiver is

located and which tracks with the Sun. They are cheap to make and produce steam at up to 300ºC, which can be used to produce electricity or heat for industry.

- linear Fresnel technology in which the linear receiver is stationary and is heated by tracking mirrors to provide outputs similar to the 'trough' collectors
- dish collectors that track the Sun and focus the Sun's rays on a receiver
- 'heliostat' and tower collectors that focus the Sun's rays to a single point to produce very high temperatures (of the order of 1000ºC) to drive chemical processes, and make steam or hot air to run electrical turbines.

Although solar technologies are still expensive, the technology is improving constantly, energy prices are changing, and the 'learning curve' promises more competitive solar thermal technologies within a decade or so.

Wind power is currently the most adoptable of the renewable energies and is being deployed on quite a large scale across Australia. Obstacles to its use include the high capital cost of the generators (driven by strong global demand), its intermittency, power fluctuations, the need to store power during calm conditions, and varying levels of local public acceptance. Many of the best wind sites in Australia are already taken. Those that remain may be more distant from the grid, have less favourable wind conditions, and may be less profitable for investors; these factors will eventually slow adoption, increasing the opportunities for other technologies.

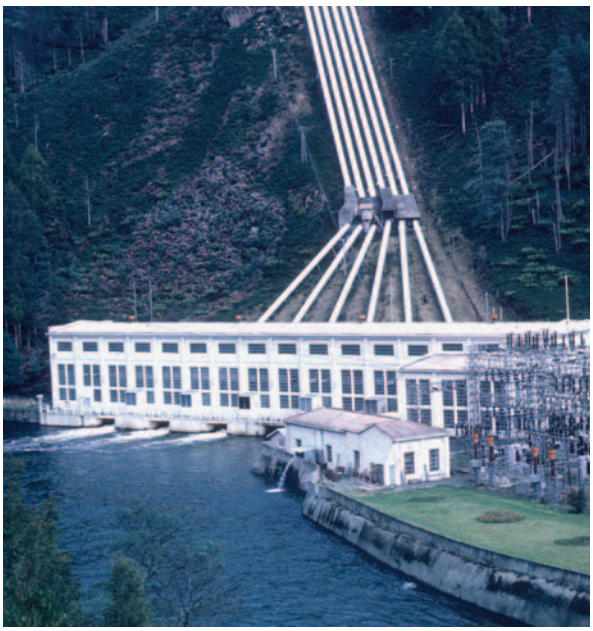
Nick Pitsas/CSIRO

Both solar and wind power require the development of cost-effective energy storage facilities to be able to mitigate power fluctuations, to provide energy at night-time for solar, or during periods of calm for wind power.

Biomass energy – for electricity or fuels – is seen as having considerable potential if sustainable use can be established and costs reduced through new technologies. CSIRO's assessment of bioenergy prospects is based on zero competition with food for agricultural resources. The best prospects occur when the biomass source is close to the place where the energy is consumed: for example, when the bagasse produced by the sugar cane industry is burned to produce heat and electricity used for sugar refining.

Hydro power has limited large-scale expansion opportunities in Australia due to public aversion to the large-scale impacts on river systems, limited accessible sites, and declining rainfall in the south.

Source: Adriana Downie, Pacific Pyrolysis



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Hot fractured rocks are still being developed as a potential base-load energy source for the future. Obstacles include current high drilling costs, geological uncertainty, low relative power efficiencies, the amount of water needed to access the heat which is lost in the process, and the proximity of the grid. If these can be overcome, hot fractured rocks could emerge as a reliable, low-cost source of base-load power.

Ocean energy – Australia has access to vast ocean resources: some of the best in the world for wave, current, and tidal energy, especially along the WA, Victorian and Tasmanian coasts. However, the technologies are still at an early stage in their development and, like some other renewables, suffer from intermittency, distance from the grid, and uncertainty about long-term maintenance and operational costs. Australia's ample resources of solar and wind energy mean that these may be fully developed before ocean power can become financially competitive.

Nuclear energy may become an economic option for power generation in Australia, but the main barriers to its adoption include high capital costs, long lead times, lack of a trained workforce, and current lack of public support.

3. Fossil fuel energy and carbon capture and storage

Although energy efficiency and renewable energy hold out great promise for a low-carbon economy, the world is heavily committed to the use of fossil fuels through its existing generation infrastructure, which will continue to provide the bulk of electricity generated for some time. In addition, many developing economies see coal use as the lowest-cost option to provide electricity for the growth of their economies and to increase the living standard of their people.

Carbon capture and storage (CCS) is the pathway for reducing greenhouse gas emissions from fossil fuels used for large-scale electricity generation. The aim is to capture the CO_2 released when coal is burned and then store it in stable geological formations, deep underground. It is worth noting that oil, natural gas, and CO_2 have been stored naturally in such formations for many millions of years.

The three most promising CCS technologies are gasification, oxyfuel combustion, and post-combustion capture.

- **Gasification** involves reacting coal with controlled amounts of oxygen and water at high temperature and pressure to produce raw syngas. When combined with syngas processing, the ultimate products are CO_2 and hydrogen. The pressurised CO_2 can be separated for storage and the hydrogen burned in special turbines to produce electricity, with water as the only emission.
- **Oxyfuel combustion** burns coal in a CO_2/oxygen mixture with recycled flue gas (instead of nitrogen/oxygen when air is used). The flue gas is predominantly CO_2. Some is removed, cleaned, dried, and pressurised for geological storage. Gasification and oxyfuel combustion are termed pre-combustion low-emissions coal technologies.
- **Post-combustion capture** involves reacting the flue gas from a conventional combustion power station with a chemical solvent to capture the CO_2 before the flue gas is emitted. The chemicals are regenerated and reused. The CO_2, now in concentrated form, can be cleaned, dried, and pressurised for storage. The potential advantage of post-combustion capture is that it can be retrofitted to existing coal plants.

Implementation of CCS in a timely and secure way faces a number of challenges. The principal challenge is that, although elements of the technology chain currently exist, there has as yet been no demonstration of an integrated process at a commercial large-scale power station. However, there are numerous programs worldwide, including in Australia, that aim to demonstrate CCS technology on a commercial scale.

Besides CCS, other ways to process bulk CO_2 so that it is 'locked up', or achieves savings elsewhere, are being investigated:

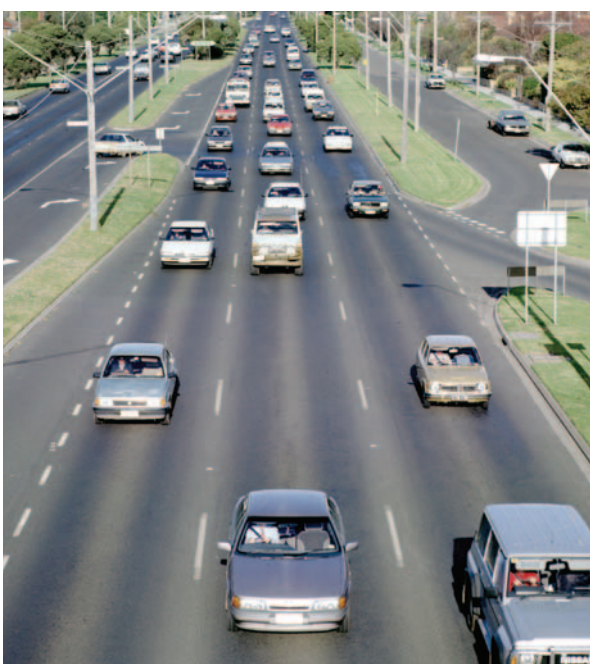
- **Mineralisation**, where CO_2 is reacted with naturally occurring minerals to form very stable carbonate rocks that can be stored in mines, or even used in building materials.
- **Algal cultures**, where the CO_2 and added nutrients are used to grow algae with a high lipid content for the production of biodiesel for transport fuels and thus displace petroleum fuels, with consequent greenhouse gas savings.

Other developments based on fossil fuels aiming to reduce CO_2 emissions include:

- **Gas**, which is seen largely as a 'transitional fuel' for peak power generation, bridging between today's systems and CCS or renewables in future. However, natural gas is in high demand worldwide and the power generators that use it are exposed to fluctuations in supply, demand, and price. There is also rapid development of coal seam gas in Australia which provides another source of this valuable resource.
- **Hybrid technologies** that combine fossil fuels, CCS, and renewables are also promising. These include: coal-fired power supplemented by solar thermal energy to reduce the amount of coal burned, reduce emissions, and boost efficiency; and solar/gas systems.
- The development of much more efficient ways of converting the chemical energy in coal to electricity. Two such promising technologies are large diesel engines fired with specially prepared slurries of fine coal and the direct carbon fuel cell.

4. Transport sector

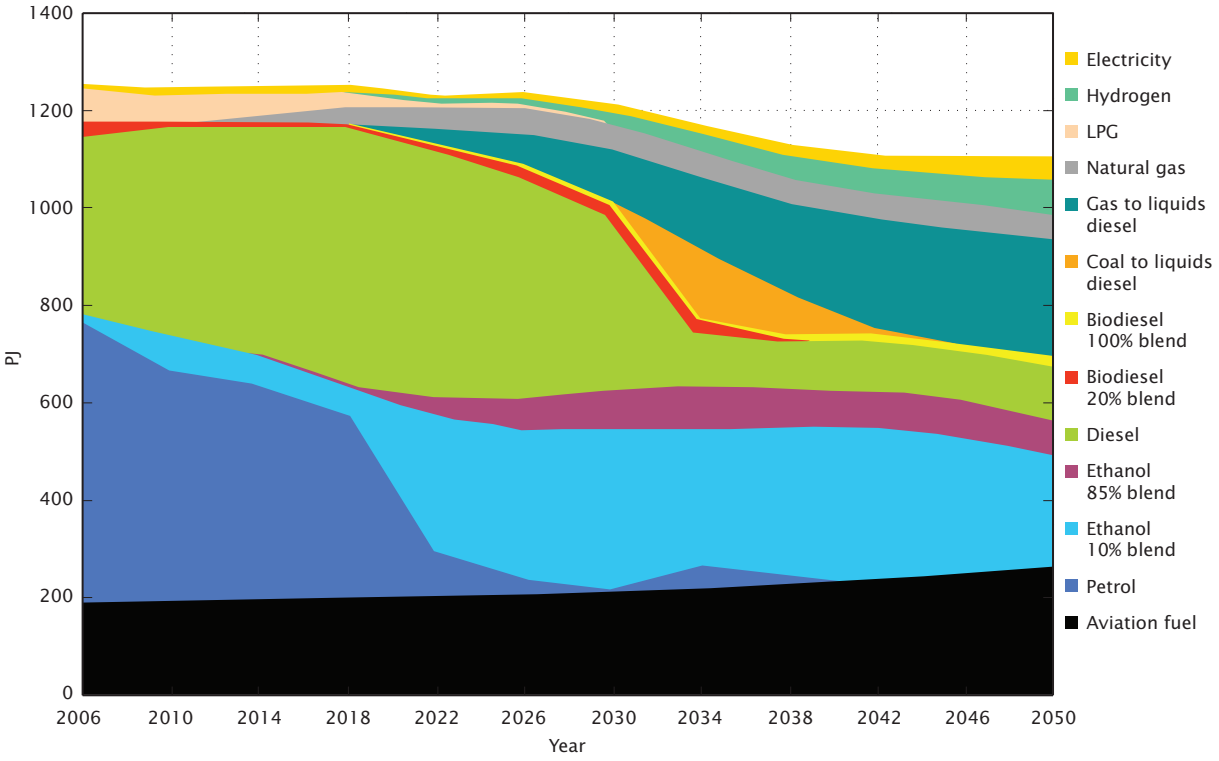
Over the next 10 years, and allowing for a cost for carbon, CSIRO modelling[9, 10] projects that diesel, electricity, liquefied petroleum gas (LPG), and natural gas (particularly in freight) will all increase their share of the transport fuel market (Figure 9.6). These fuels all have some existing production and distribution infrastructure, but will require more to make them readily accessible.



Tracey Nicholls/CSIRO

In the longer term, beyond 2020, advanced biofuels that do not compete directly with food production, and synthetic fuels derived from gas and coal, are also expected to come into wider use once production infrastructure has had time to scale up. How widely they are adopted will depend on primary fuel prices and greenhouse gas emission targets.

Realistically, only four additional transport fuel options are capable of being produced in large enough volumes to satisfy a significant part of the needs of the transport sector in the next two decades and supplement traditional fossil transport fuels – biofuels, liquefied natural gas (LNG), compressed natural gas (CNG), and electricity.

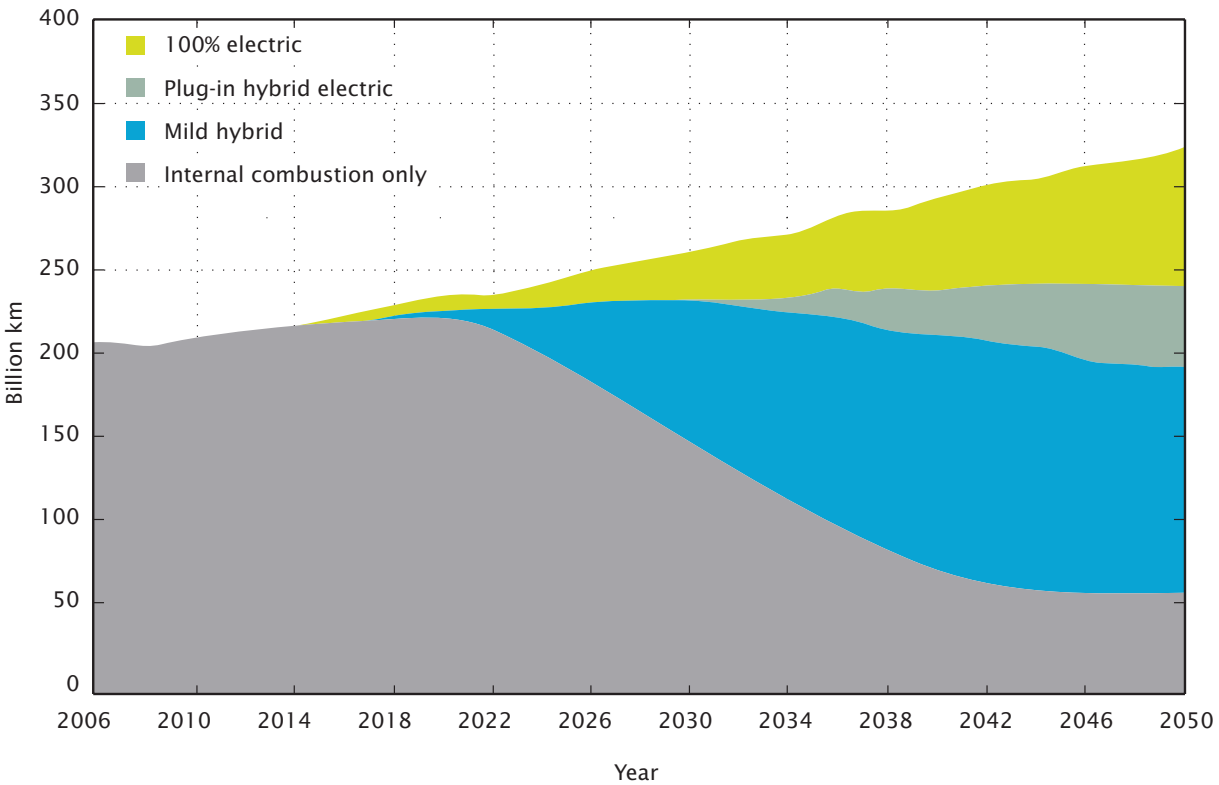


▲ ***Figure 9.6**: Likely changes in share of different transport fuels under a high oil price scenario.*

Biofuels could, in theory, supply around one-quarter of transport needs without having a significant impact on food production or soil nutrient quality. In the short term, ethanol and biodiesel blends will continue to be available, using crop wastes, tallow, and cooking oil. However, from around 2020–25, the principal future sources of biofuels will be lignocelluloses and plant oils (from crop stubble and forestry residues or special energy crops such as algae), thereby improving both Australia's balance of trade and greenhouse gas emissions. Biofuels are not completely emission-free because, among other inputs, they use fossil fuels in the biomass feedstock production process. However, in the long run, agriculture will probably move to lignocellulose-based biofuels and algal biodiesel for its motive energy.

LNG is a niche fuel more likely to suit long-distance transport operators, because the cost of converting vehicles is high and can only be re-couped by significant fuel savings. LNG is cheaper than diesel at present. However, in the longer term its costs are likely to follow those of oil as Australia's domestic gas industry becomes increasingly exposed to rising international oil and gas prices.

Electricity may emerge as the Australian transport fuel of choice for the majority of motorists and transport operators in the longer term. It is expected that the share of vehicles drawing electricity from the grid will increase from a handful today (excluding rail, which currently draws 8 petajoules) to at least 10% by 2030 (Figure 9.7). As hybrid vehicle technology matures, it will enable drivers to achieve 80% of their (city) mileage using electricity: using fossil fuel only for the 20% of trips that are outside battery range. The rate of electrification will depend critically on world oil prices relative to electricity prices and battery costs.



▲ ***Figure 9.7**: Projected increasing electrification of road transport vehicles, based on mid range oil prices and a carbon price.*

A challenge for electrification of the transport fleet will be the source of electricity. If this is provided by coal-fired power stations, a large increase in CO_2 emissions will ensue. Therefore electrification of the transport fleet in response to rising petroleum prices may constitute another driver for the commercial introduction of CCS and/or renewables.

Although synthetic fuels made from coal and natural gas are among Australia's possible transport energy options, the fact that they involve large greenhouse gas emissions means they are not likely to attract large-scale investment in the medium term: certainly not before carbon capture and storage (CCS) has been fully demonstrated. Synthetic fuel plants also suffer from the same investment risks as large-scale coal power generation, being multi-billion-dollar investment projects dependent on uncertain revenue drivers (in this case, the international oil price, rather than carbon prices).

Hydrogen is a clean fuel that can be made from fossil fuels or by splitting water into its constituents, hydrogen and oxygen. However, the development of a cost-effective vehicle fuel cell to convert hydrogen into electrical power is lagging behind other sources of power for electric and hybrid vehicles: as of 2010, there were no hydrogen-fuelled cars commercially available anywhere in the world, and only a very few demonstration models. The fuel cell's acceptance as a technology will depend on its price relative to competing sources, consumer preferences for the range of hydrogen vehicles compared with electric vehicles, and the lead/lag time of the roll-out of refuelling infrastructure. In the medium term, however, the option exists to replace the batteries in an electric vehicle with a hydrogen fuel cell. The availability of hydrogen fuel could be fairly easily achieved by locating small units that use electricity to split water into hydrogen and oxygen at service stations, car parks, and elsewhere.

Conclusion

Making the right energy choices for Australia's future from among our abundant resources and technologies is profoundly complex. Often it will be an issue of which energy source, or combination of sources, best suits a particular context – rather than trying to pick a single 'winner'. Australia's greatest need is for low-emissions technologies that are competitively priced, resilient, and flexible enough to cope with a range of possible future energy challenges and demands. Technologies whose costs fall quickest will tend to predominate, even though they may be more expensive at present. All options are still in the mix for a future energy system, with many niches and opportunities. Rather than advocating a single solution, it will be important for us to have the skills to identify the most advantageous combinations of solutions.

Australia has more energy options than almost any other country – and the systems we develop ought logically to reflect that diversity. The technologies we choose will not necessarily be invented or developed here: instead we can become a leading-edge user of the best the world has to offer.

Further reading

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