

Low Emissions Technology Roadmap

Executive Summary

June 2017



CITATION

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The energy sector is crucial for Australia's prosperity

Australia needs an energy sector that addresses the 'energy trilemma' – that is to say it must provide energy security, affordability and environmental sustainability. After a period of relative stability, significant change in the energy sector can be expected in coming years due to the need to reduce greenhouse gas (GHG) emissions, together with the rapid pace of technological development occurring in the sector.

This roadmap seeks to help policy and other decision makers navigate this change by highlighting the key technologies that Australia can draw on as it endeavours to address the energy trilemma. It also identifies the barriers to these technologies and the potential enablers that may be called on to overcome them. Lastly, the roadmap identifies the key commercial opportunities for industry that low emissions technologies in the energy sector can provide.

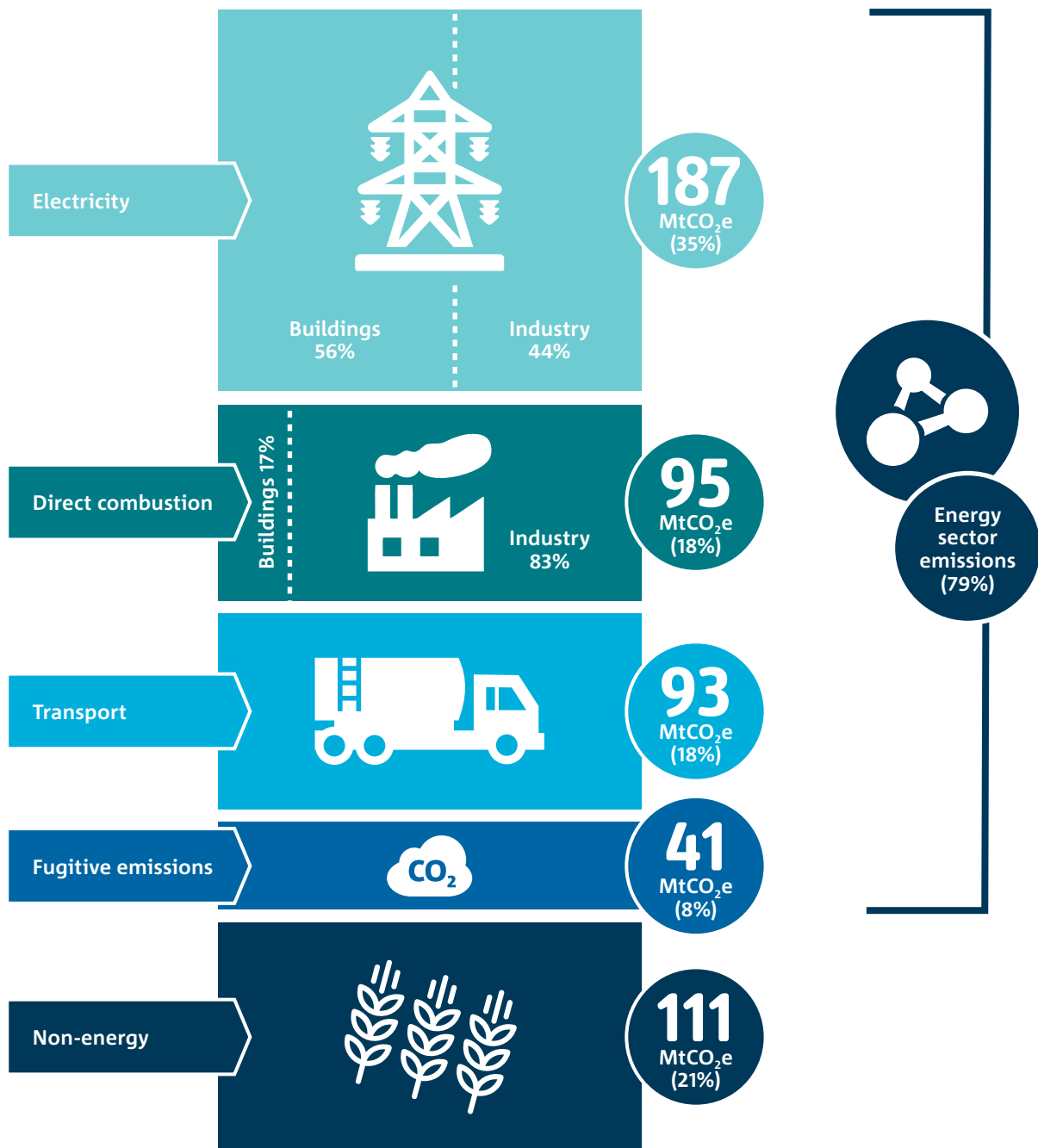
Australia's emissions reduction target

On 10 November 2016, Australia ratified the Paris Agreement, committing to achieve a 26-28% reduction in GHG emissions below 2005 levels by 2030. The Paris Agreement also requires signatories to strengthen their abatement efforts over time with the overarching goal of limiting the increase in global average temperature to well below 2°C above pre-industrial levels, with efforts to limit the temperature increase to 1.5°C. The Paris Agreement also recognises that the world will need to achieve zero net emissions in the second half of the century. To achieve this level of decarbonisation, Australia will need to adopt a multi-faceted approach, primarily targeting emissions reduction in the land and energy sectors. The energy sector, which is the focus of this roadmap, will play a key role given it accounts for 79% of Australia's emissions.



The roadmap identifies the key commercial opportunities for industry that low emissions technologies in the energy sector can provide.

Breakdown of Australia's 2015 emissions¹



¹ From (Department of Environment and Energy, 2016). Direct combustion includes emissions from burning coal and gas for industrial and building heat, steam and pressure as well as emissions from combustion of fuel for mobile equipment in mining, manufacturing, construction, agriculture, forestry and fishing. Fugitive emissions includes GHG released during coal mining, and oil and gas production and transport. The split of electricity between buildings and industry is approximated from electricity consumption of commercial and residential as percentage of total thermal electricity in 2014-15 from 2016 Australian Energy Statistics (Office of the Chief Economist, Table F). Split for direct combustion calculated from (Australian Government Department of the Environment and Energy, 2016).

Objectives of the Low Emissions Technology Roadmap

In light of the need for the energy sector to contribute towards Australia's carbon abatement target, to address the energy trilemma more broadly, and to continue to play a central role in growing Australia's prosperity, this roadmap has two key objectives:

1

The primary objective is to identify the emission reduction technology options within the energy sector that Australia could pursue in order to meet or exceed its 2030 target and achieve deeper decarbonisation post-2030. The report also considers what actions might be required to achieve rollout of these technologies, while continuing to maintain energy security and affordability.

2

The secondary objective is to identify the main opportunities presented by low emissions technologies, in terms of economic value and job creation. The transition to a low emissions economy is often framed in terms of cost; this roadmap seeks to broaden the discussion by also highlighting the opportunities and net benefits that the identified technologies and associated industries can provide.

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This roadmap seeks to help policy and other decision makers navigate this change by highlighting the key technologies that Australia can draw on as it endeavours to address the energy trilemma.

Approach

This roadmap was developed through a bottom up analysis of individual technologies, combined with a top down analysis of different pathways through which these technologies may be deployed.

In the bottom up analysis, a wide range of technologies were examined, considering criteria such as abatement potential, risk (including technological and commercial readiness), cost (both current and projected), and level of industry support. Based on this analysis, the technologies most likely to play a key role in addressing the energy trilemma were identified, and were further analysed to identify associated barriers, potential enablers and commercial opportunities.

This analysis included wide-ranging consultation with technology experts as well as government and industry stakeholders. Pathways were then constructed to illustrate how these technologies may be combined, and to demonstrate major options available to reduce emissions. Modelling was carried out to demonstrate potential rates of technology deployment, consistent with GHG abatement targets, and to inform how the deployment of low emissions technologies might impact energy costs.

In the context of this roadmap, a pathway is defined as a scenario that explores how a particular set of key technologies can contribute to decarbonisation of the Australian energy sector while maintaining energy security and affordability. Four pathways were developed in order to explore how major shifts in electricity generation and energy use in buildings, industry and transport could impact decarbonisation to 2050.

The key differences between pathways relate to the main options that exist across the different energy subsectors. In buildings, industry and transport, the key options relate to how fast energy productivity improvements take place. Pathways 1 and 4 examine the role that ambitious improvements in energy productivity

can play in reducing emissions, while Pathways 2 and 3 assume business as usual (BAU) productivity improvements. 'Ambitious' in this context refers to a rate of improvement at the higher end of what appears to be feasible given the barriers involved, and roughly corresponds to the full opportunity identified in the National Energy Productivity Plan (NEPP), equivalent to a doubling Australia's energy productivity by 2030². BAU roughly corresponds with existing NEPP targets of 40% improvement by 2030, which accelerates energy productivity above what has been achieved historically but does not achieve its full potential.

The other key difference between pathways relates to new build electricity generation technologies. In Pathway 1, given that the focus of the pathway is on energy productivity, new generation is restricted to technologies that have been recently deployed, namely wind, solar PV and gas, with limits placed on deployment of wind and solar PV. Pathway 2 examines the full extent of the role variable renewable energy (VRE) technologies such as wind and solar PV can play, with particular focus on the enabling technologies required to achieve a high share of VRE. Pathway 3 examines the role low emissions, dispatchable technologies can play, namely concentrating solar thermal (CST) with storage, high efficiency low emissions (HELE) fossil fuel technologies with carbon capture and storage (CCS), nuclear and geothermal.

All pathways assume uptake of cost-effective technologies for the abatement of fugitive emissions from coal mining, and oil and gas production. Pathways 3 and 4 also investigate the role hydrogen can play as an energy storage medium across the energy sector.

² See www.2xep.org.au

Summary of pathways

	<div style="text-align: center;"> 1 Pathway 1: Energy productivity plus </div>	<div style="text-align: center;"> 2 Pathway 2: Variable renewable energy </div>	<div style="text-align: center;"> 3 Pathway 3: Dispatchable power </div>	<div style="text-align: center;"> 4 Pathway 4: Unconstrained </div>
Buildings, industry and transport	Ambitious energy productivity improvements	Business as usual energy productivity improvements		Ambitious energy productivity improvements
New build electricity generation	Existing low emissions technologies: wind, solar PV (45% limit) plus gas	Cheap, mature, low emissions generation: mainly wind and solar PV plus enabling technologies e.g. batteries pumped hydro	Wind and solar (45% limit) plus low emissions, dispatchable generation: <ul style="list-style-type: none"> Concentrating solar thermal with storage High efficiency, low emissions fossil fuels with carbon capture and storage Nuclear Geothermal 	All low emissions technologies allowed, with no limit on wind and solar PV
Fugitive emissions	Uptake of cost-effective technologies			

It is important to recognise that the pathways are not intended as deterministic predictions. Rather, they are designed to illustrate some of the plausible combinations of technology options that arise based on assumptions on the rate of technology development and external drivers. They also enable an examination of

the associated trade-offs, costs, risks and opportunities and allow comparisons to be made between different choices. No one pathway is recommended as preferable; rather, they are intended to serve as a tool for policy and other decision makers to conceptualise possible futures in the face of considerable uncertainty.

Key findings

I. Australia is well positioned to benefit from innovation in low emissions technologies

- 1. Australia has many sources of comparative advantage for low emissions technologies to build on.** While the transition to a low emissions economy is often framed in terms of cost, this transition will also create demand for new products and services both in Australia and in export markets. Australia is endowed with some of the world's best energy resources, has good skills in low emissions technologies, strong institutions and strong trading relationships with key consumers of energy. These advantages leave it well placed to benefit from a domestic and global transition to low emissions energy. Capturing these benefits will require decisions on where to focus effort and long-term commitment to the required actions.
- 2. Australia's existing strengths and needs can guide both local technology RDD&D and Australia's role in global efforts.** Australian research, development, demonstration and deployment (RDD&D) of low emissions technologies can be guided by comparative advantage, existing strengths and where there are local problems to solve. While relying on other countries for many technologies, Australia can also play an important role in global uptake of low emissions technologies, by contributing to technology development, helping regional neighbours deploy technologies, demonstrating possibilities to other countries and exporting low emissions commodities and products.

II. Ambitious improvements in energy productivity, enabled by largely mature technologies, can unlock billions of dollars of cost savings

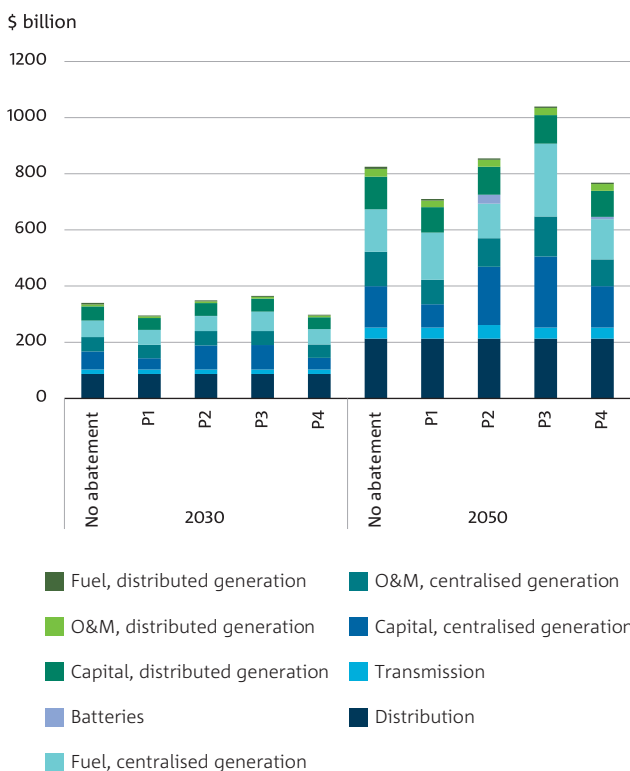
- 3. There are largely mature technologies available within the buildings, industry and transport sectors that could enable significant improvements in energy productivity.** While energy productivity is a key focus for industry leaders, opportunities still remain for many companies. For buildings, considerable energy productivity gains could be realised through more extensive adoption of mature technologies such as efficient lighting, heat pumps, improved building envelopes and higher efficiency appliances and equipment. In the industrial sector, gains can be made via higher efficiency equipment (e.g. boilers, trucks, grinders, motors), electrification, fuel switching, improved use of waste heat as well as use of renewable heat (e.g. from biomass or solar thermal). Improvements within transport can be made through incremental improvements in mature technologies, such as higher efficiency internal combustion engines and improved vehicle aerodynamics. Fuel substitution (e.g. advanced biofuels, hydrogen vehicles and particularly electric vehicles) will increasingly deliver abatement, and energy productivity in transport can be further improved through demand reduction (e.g. mode shifting, telecommuting and improved routing in freight).

4. Ambitious improvements in energy productivity can help minimise energy spend. Pathways with faster improvements in energy productivity have significantly lower average household electricity, gas and transport costs by 2030 than pathways with slower improvements. In the electricity sector, improving energy productivity reduces the amount of electricity required and consequently the price, given that less new build generation is required. In transport, improved energy productivity primarily lowers cost through lower operating costs for electric vehicles (EVs), compared with internal combustion engine vehicles (after the mid-2020s), and reduced demand for travel (measured in vehicle-km). Potential savings from increased energy productivity represent a \$20 billion opportunity to 2030 in buildings (Australian Sustainable Built Environment Council, 2016) and \$14 billion of cumulative benefit to 2040 in road transport (Department of Infrastructure and Regional Development, 2016).

III. A range of technologies exist to allow deep decarbonisation of the electricity sector while maintaining security and reliability of supply, as well as providing significant opportunities for Australian industry

5. A secure and reliable electricity system based on low emissions wind and solar PV could be possible and cost effective, but technical challenges must be addressed. Maintaining reliability in a system with high wind and solar PV share requires technologies that provide flexibility in matching supply and demand, such as energy storage (e.g. batteries and pumped hydro) and demand response (enabled by smart grid technologies), as well as other approaches such as building excess VRE generation capacity and geographic and technology diversity. Modelling carried out for this roadmap finds that with a mix of battery storage, excess VRE capacity and gas generation, a reliable electricity system delivering 95% abatement in 2050 compared with 2005 levels and VRE share of ~90% is possible at moderate cost (as compared to the no abatement scenario in the figure below).

ELECTRICITY SUPPLY CHAIN SPEND IS LEAST IN PATHWAYS 1 AND 4, WHICH HAVE AMBITIOUS IMPROVEMENTS IN ENERGY PRODUCTIVITY



In addition to maintaining reliability, it will be critical to ensure system security, via additional enabling technologies such as synthetic inertia from batteries, wind farms and synchronous condensers. These technologies are expected to be low cost compared with total system spend. For instance, for the mainland network operating with high non-synchronous penetration, an initial conservative estimate suggests \$7 billion worth of synchronous condensers could provide sufficient inertia and fault current; this is less than 1% of cumulative total system spend to 2050. However, as a priority, these technologies need to be appropriately trialled, tested and demonstrated at scale under a range of operating scenarios. This requires a considered, whole of industry approach.

6. An alternate scenario for electricity generation sees a transition to low emissions dispatchable generation, with less need for grid transformation.

Deep decarbonisation of the electricity sector could be achieved using a suite of low emissions electricity generation technologies like CST with storage, post carbon capture (PCC) retrofit and/or HELE with CCS, nuclear, and geothermal. These technologies are dispatchable and synchronous³ and therefore avoid the challenges involved in reaching a high share of wind and solar PV (e.g. intermittency, lack of inertia). These technologies should be considered individually, with the benefits of dispatchability and inertia balanced with the unique cost and risk profiles (technology, commercial, social licence) of each of these technology options and their anticipated development paths.

7. Gas could contribute to decarbonisation of electricity generation, with energy productivity potentially helping to address supply constraints.

While decarbonisation is supported by a shift away from gas in buildings and parts of industry, gas could play a role as a transition fuel in electricity generation. From an emissions point of view, the duration of this role could be extended if ambitious improvements in energy productivity are realised or if gas generation is combined with CCS. Improved energy efficiency

and electrification could reduce gas demand from buildings and industry, helping ease supply constraints for electricity generation. Increased reliance on gas however would further expose the electricity sector to the risk of price increases.

8. While the existing coal power industries may decline, the transition to low emissions electricity presents significant opportunities for Australian industry. The move away from existing thermal generation will impact the local economy, particularly in communities reliant on power stations for employment.

However, replacing Australia's existing generation fleet with low emissions technologies will create significant opportunities in the electricity sector in construction, installation, operations and maintenance (O&M) which provide a source of employment that could continue for decades.

Large-scale low carbon electricity also presents opportunities for manufacture of specialised components such as heliostats for the domestic market and for export. Further, the transition to decentralised low carbon electricity presents opportunities for innovative Australian companies to develop new products and services such as home energy management systems. Australia's leading position in this transformation means Australian companies are well placed to export such products and services. Export opportunities also exist in energy engineering and consulting services such as renewable energy policy, standards and project development. This could also allow Australia to help regional neighbours achieve low carbon growth.

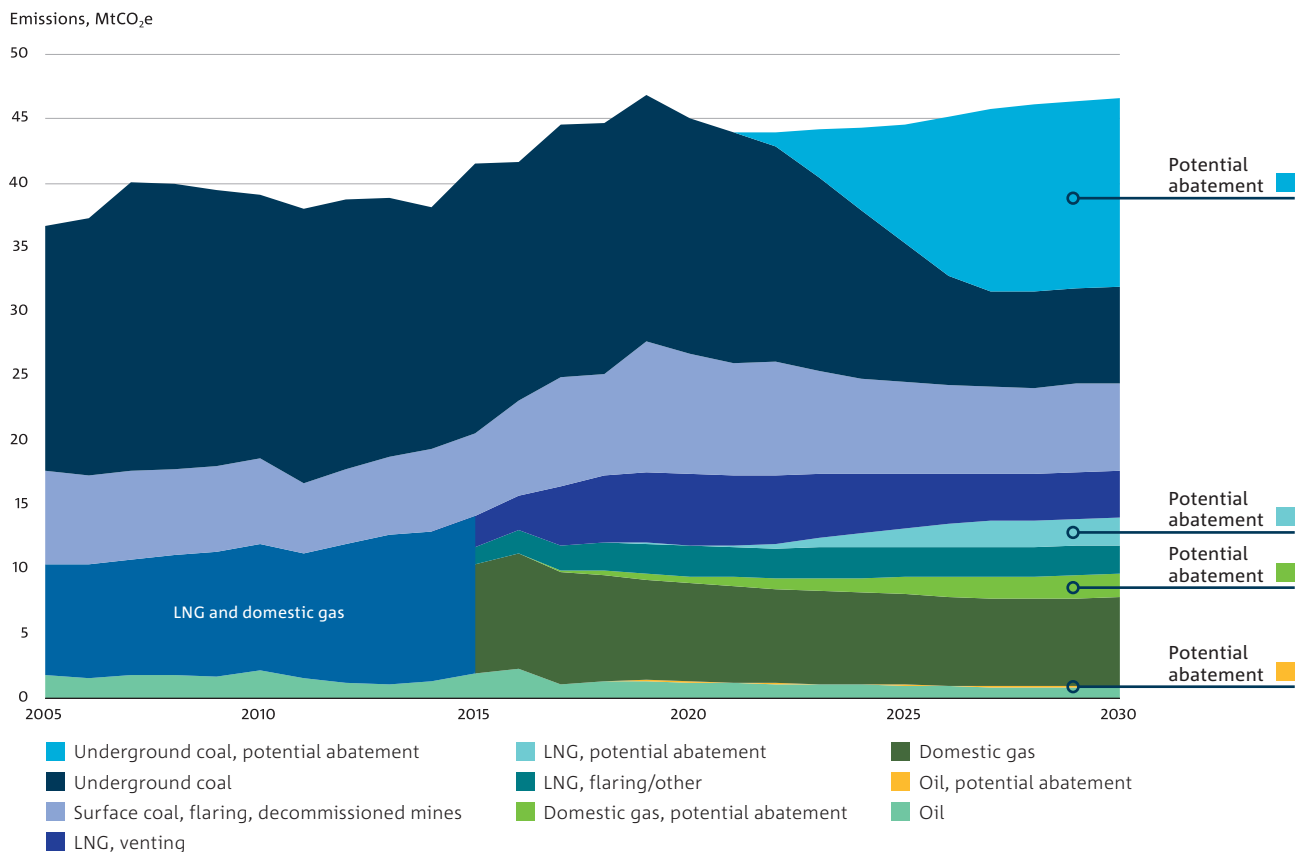
The magnitude of the impact of a move away from coal could also be reduced though the deployment of HELE coal-fired power generation and CCS in both Australia and its trading partner nations. Additionally, CCS could enable the local production of low emissions hydrogen via gasification of coal. This has the potential to become a key export opportunity for Australia and to help transition communities impacted by a decline in coal-fired generation.

³ Dispatchable generation is electricity generation that can be turned on and off when required. Synchronous generation is electricity generation that uses large rotating masses synchronised with the frequency of the alternating current (AC) grid. The rotating masses have high inertia, which helps stabilise the frequency of AC grids.

IV. Fugitive emissions from coal mining, and oil and gas production could be reduced by 40% compared to BAU in 2030

9. Innovative technologies could allow fugitive emissions from coal mining, and oil and gas production to be reduced by up to 40% compared to BAU in 2030, as well as providing export opportunities. Technologies currently in development in Australia for the abatement of ventilation air methane (VAM) in underground coal mining could potentially be deployed at scale by 2030, achieving approximately 80% abatement of emissions from this source. These technologies also represent an export opportunity for Australia, especially to China. Fugitive emissions from liquefied natural gas (LNG) production could be reduced by deployment of CCS where economically feasible. Further, abatement of fugitive emissions in oil and gas production and in domestic gas transmission and distribution could be achieved through improved operational practices. Combined, these technologies could decrease fugitive emissions by 19 MtCO₂e in 2030 compared with BAU and contribute 8% of energy sector abatement.

TECHNOLOGIES FOR THE ABATEMENT OF FUGITIVE EMISSIONS COULD ACHIEVE 19 MtCO₂e OF ABATEMENT BY 2030⁴

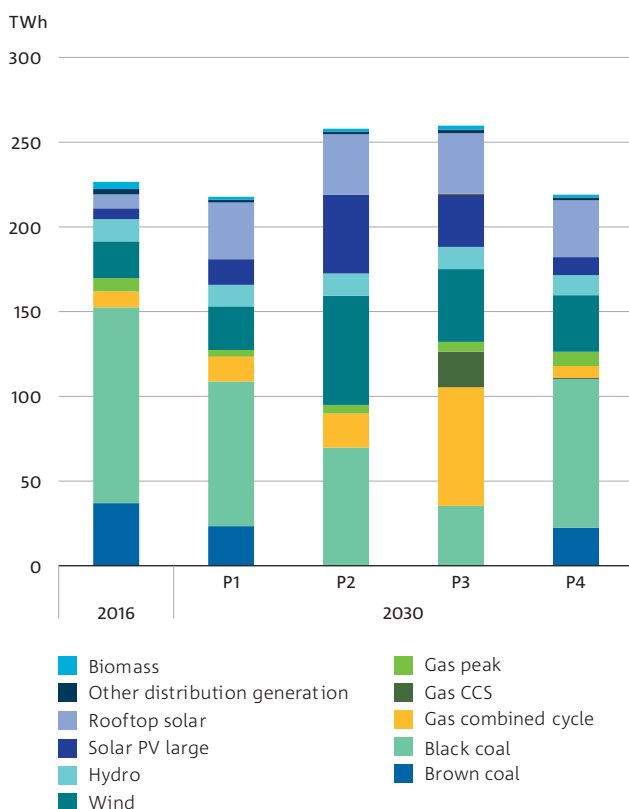


⁴ Current and BAU projected emissions are from (Department of Environment and Energy, 2016). Potential abatement is from CSIRO modelling. Assumes BAU gas consumption; domestic gas consumption, and hence fugitive emissions, increases or decreases depending on the pathway.

V. The energy sector can achieve a proportional share of the 2030 target and achieve deeper abatement post-2030

10. New electricity generation to 2030 is likely to comprise mainly wind and solar PV. In each pathway, onshore wind and large-scale and rooftop solar PV are expected to make up the majority of new generation to 2030. This is due to the low cost, low emissions and commercial maturity of these technologies. An exception is Pathway 3, where gas combined cycle could also form a large part of the mix, combined with CCS towards the end of this period. Less new generation is required to be built in Pathways 1 and 4. These pathways also show slower decreases in coal-fired generation.

NEW GENERATION TO 2030 IS MOSTLY ONSHORE WIND AND SOLAR PV ACROSS ALL PATHWAYS



11. In addition to unlocking billions of dollars of savings, ongoing improvements in energy productivity can prevent increases in emissions in transport and direct combustion to 2030.

As mentioned in Key Finding 4, improving energy productivity can lead to energy cost savings and further decarbonisation.

Even BAU (as opposed to ambitious) energy productivity improvements allow for significant increases in emissions to be avoided. For example, for pathways 2 and 3, despite increasing demand, 2030 transport and direct combustion emissions remain flat as compared with 2015 levels.

For the transport sector, in 2015, road vehicles were responsible for 85% of total transport emissions. Most of the potential abatement in road vehicle emissions to 2030 is likely to stem from improvements in vehicle efficiency, which can offset expected growth in transport demand.

Abatement of direct combustion emissions in buildings and industry can be achieved through energy efficiency improvements, electrification and fuel switching (including direct use of renewables such as CST and bioenergy). An important point to note is that achieving ambitious improvements in energy productivity now, particularly in relation to the deployment of new demand side assets, will help to avoid locking in higher emissions assets that would make subsequent decarbonisation more difficult.



New electricity generation to 2030 is likely to comprise mainly wind and solar PV.

12. Ambitious improvements in energy productivity can allow more time to transition the electricity sector to low emissions generation.

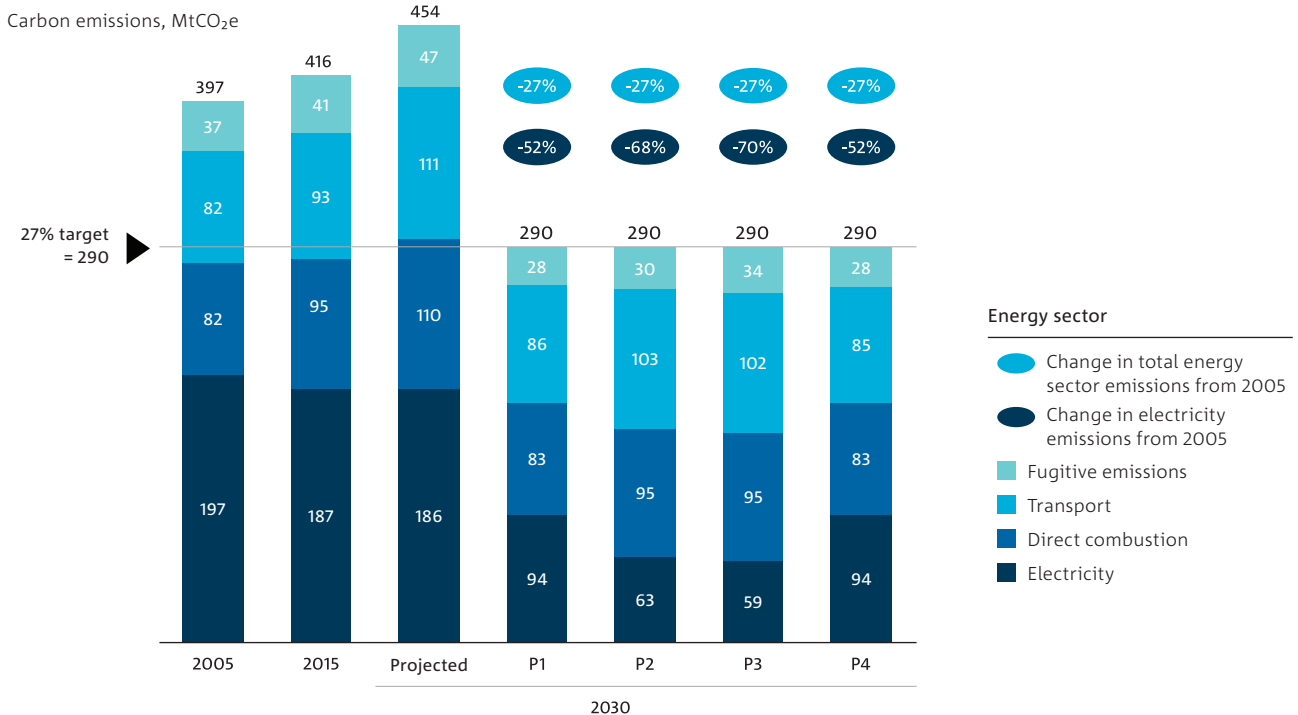
Ambitious increases in energy productivity can allow more time for Australia to transition the electricity sector to low emissions generation and still meet 2030 targets.

There are two reasons for this. Firstly, increasing the rate of energy productivity improvements from BAU to the more ambitious rates (shown in Pathways 1 and 4) would result in up to 35 MtCO₂e of additional abatement (including the effect of reduced gas use on fugitive emissions). Secondly, ambitious energy productivity rates can offset BAU demand growth and increased demand from electrification (as shown in Pathway 1 and 4). These two effects mean that electricity sector emissions can be higher in Pathways 1 and 4 than in Pathways 2 and 3 with the energy sector as a whole still achieving 26-28% abatement compared with 2005 levels by 2030. In Pathways 1 and 4, electricity sector emissions in 2030 could be up to 94 MtCO₂e, while in Pathways 2 and 3 they could be up to 59-63 MtCO₂e, corresponding to reductions in electricity sector emissions of 52-70% compared with 2005 levels. Less electricity sector abatement could be targeted if faster improvements in energy productivity than assumed in this report prove feasible, or if greater abatement is achieved outside the energy sector.



Ambitious increases in energy productivity can allow more time for Australia to transition the electricity sector to low emissions generation and still meet 2030 targets.

ALL PATHWAYS CAN ACHIEVE THE 2030 TARGET, WITH SLOWER TRANSITION OF THE ELECTRICITY SECTOR POSSIBLE IN PATHWAYS WITH AMBITIOUS IMPROVEMENTS IN ENERGY PRODUCTIVITY (P1 AND P4)



13. Continued uptake of likely low emissions technologies could allow the energy sector to reduce emissions by 55-69% by 2050. Deep cuts in energy sector emissions by 2050 will be challenging but possible through a combination of deep decarbonisation of electricity generation and sustained, ambitious improvements in energy productivity in buildings, industry and transport. This could allow abatement of almost 70% compared with 2005 levels with the technologies considered in this report, at rates of uptake likely to be feasible. There may be further opportunities to reduce energy sector 2050 emissions if faster deployment proves possible, as well as through deployment of additional, more prospective technologies. Achieving net zero emissions across the economy in the second half of the century however will likely depend on negative emissions (i.e. net removal of GHG from the atmosphere) in land use, land use change and forestry (LULUCF) and/or carbon credits from other countries which is outside the scope of this report.


14. Progressing multiple pathways would allow Australia to reduce the risks in addressing the energy trilemma. Each pathway faces a different set of risks, including technology risk, commercial risk, market risk, social licence risk and stakeholder coordination risk. By simultaneously progressing multiple pathways, the overall risk in transitioning to a low carbon energy sector, while maintaining energy security and affordability, can be minimised. Progressing pathways will require enabling actions as described below.

15. Low emission energy technologies are higher cost and have a number of associated risks that need to be addressed in order to encourage investment from the private sector. With the exception of regulated networks, Australia's energy sector is designed to be competitive such that new technologies are supplied and purchased by private investors at their own risk. For the most part, investment in new low emission energy technologies comes at a higher cost than continued use of currently deployed higher emissions technologies. Additionally, abatement opportunities, regardless of cost, may face a range of non-financial barriers to investment (including technical, social and stakeholder barriers). Without the right regulatory/policy environment, these risks manifest as barriers to investment and therefore serve as a barrier to adoption of new technologies.

Examples of present policies and institutions designed to overcome these barriers to investment include the Clean Energy Finance Corporation (CEFC), Australian Renewable Energy Agency (ARENA) and State and Federal Renewable Energy Targets. Existing policies do not yet address all available energy sector abatement opportunities or target each of the types of risks faced. Additional policies will therefore likely be required to ensure a broader range of low emissions technologies are deployed and that investment returns are strong enough (relative to risk) for deployment to proceed at the rate required.

“ Deep cuts in energy sector emissions by 2050 will be challenging but possible through a combination of deep decarbonisation of electricity generation and sustained, ambitious improvements in energy productivity in buildings, industry and transport. ”

EACH PATHWAY FACES RISKS; PROGRESSING MULTIPLE PATHWAYS WILL ALLOW OVERALL RISK TO BE MINIMISED

	 Description	Pathways			
		1 Pathway 1: Energy productivity plus	2 Pathway 2: Variable renewable energy (VRE)	3 Pathway 3: Dispatchable power	4 Pathway 4: Unconstrained
Technology, commercial and market risk	<p>Technology risk: Technology needs development to overcome technical challenges or to bring down costs</p> <p>Commercial risk: Technology not commercially mature in Aus. hence costs not well understood</p> <p>Market risk: Revenue generated over the lifetime of the asset is uncertain</p>		Technological challenge to transform the electricity grid to support VRE at high share with acceptable security and reliability, with uncertain cost of transformation	Market risk with large, long lead time projects given uncertain demand Technology and commercial risk with HELE, CCS, CST, geothermal and nuclear	As per P2
Social licence risk	Technology may face opposition from local community, broader community or specific groups e.g. environmental groups	High reliance on expansion of domestic gas for electricity generation	Social licence risk with wind power	Social licence risk with new build coal, CCS, nuclear and with expansion of domestic gas for electricity generation	Social licence risk with gas and CCS
Stakeholder coordination risk	Deploying the technology depends on coordination or behaviour change of a large number of individuals or groups	Relies on behaviour change by millions of energy users	Transformation of the grid to support high share of VRE requires overcoming regulatory and cultural challenges	Investor coordination typically required for large capital projects	As per P1 and P2

Timeframe in which risk becomes significant

■ Before 2020
 ■ 2020–2030
 ■ After 2030

Next steps

Key strategic decisions

The Australian Government will review its climate change policies in 2017 to ensure they are effective in achieving the 2030 target and Paris Agreement commitments. The Low Emissions Technology Roadmap, along with findings from the Finkel Review into the Security and Reliability of the National Electricity Market, will be inputs into that review.

Policy makers face a range of strategic decisions that need to be made now in order to inform policy design, as well as to inform priorities for RDD&D and community engagement. These decisions include:

- Whether policy should be national vs jurisdiction-specific?
- Whether policy to drive uptake of low emissions technologies should be economy-wide vs sector-specific?
- Whether policy should be technology neutral vs technology specific?
- How much should governments rely on private sector co-funding for RDD&D support for specific technologies?
- Whether Australia should develop technology locally vs acting as a ‘technology taker’?

There are also specific key questions for policy makers to decide on regarding the future of nuclear power and domestic gas supply.

While action would be required in the short term to maintain optionality regarding low emissions dispatchable electricity generation technologies, there is a further set of strategic decisions that can be made post-2020 on whether to decrease or increase support for each of these technologies.

Section 4.1 of the report discusses the key points that could be considered in making each of these strategic decisions.

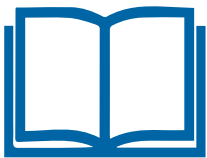


Policy makers face a range of strategic decisions that need to be made now in order to inform policy design, as well as to inform priorities for RDD&D and community engagement.

Key enabling actions

Policy is the most critical enabler for addressing the key barrier to low emissions technologies, namely the risk to investors of deploying them in favour of their higher emission alternatives. Stakeholder engagement, skills and business models and RDD&D funding are also important.

The key enabling actions are listed below, with additional enablers and further detail provided in the body of the report. The relevant actors in each case vary, with government responsible for policy, but with a combination of government and industry responsible for other actions.



POLICY

Action 1.1 Review targeted rate of improvement in energy productivity ('Ambitious' or 'BAU') and revise policy as needed to support this rate, for instance to overcome market failures such as split incentives, competing priorities and lack of information.

Action 1.2 Implement stable, long term policy to drive uptake of low emissions electricity generation technology consistent with required electricity sector decarbonisation.

Action 1.3 Implement policy to drive deployment of enabling technologies for VRE.

Action 1.4 Implement policy to incentivise full deployment of cost-effective technologies to reduce fugitive emissions from coal mining, and oil and gas production.



STAKEHOLDER ENGAGEMENT

Action 2.1 Provide supporting data, information as well as training and education to assist in driving uptake of technologies that improve energy productivity in buildings and industry.

Action 2.2 Continue stakeholder engagement for electricity sector transformation, including creating a technical roadmap to transition the grid to support higher shares of distributed generation and large-scale variable renewable generation with continued security and reliability.

Action 2.3 Communicate findings from the demonstration and deployment of key technologies such as utility-scale battery storage, CCS and microgrids with a high share of renewables, to increase stakeholder confidence in these technologies and enable further deployment.

Action 2.4 Accelerate deployment of consumer technologies such as rooftop solar PV, behind the meter batteries and EVs through increased consumer engagement, including by retailers and other consumer-facing technology providers.

Action 2.5 Continue engagement with the community on all technologies with potential social licence barriers e.g. wind, gas, nuclear and CCS.



SKILLS AND BUSINESS MODELS

Action 3.1 Upskill industries to support rollout of new low emissions technologies, particularly in the electricity sector and in industries where new supply chains will require development.

Action 3.2 Develop business models that increase the rollout of low emissions technologies, e.g. by offering mobility as a service using low emissions vehicles, by offering smart systems to increase energy productivity, and by aggregating behind the meter batteries to provide ancillary services.



RESEARCH, DEVELOPMENT, DEMONSTRATION AND DEPLOYMENT

Action 4.1 Review RDD&D program, ensuring efforts are aligned with comparative advantage, existing strengths, local needs, market opportunities and international collaborations.

Action 4.2 Support demonstration and deployment projects aimed at improving energy productivity in buildings, industry and transport, including through energy efficiency, fuel switching, electrification and direct use of renewable energy for heat.

Action 4.3 Continue RDD&D in low emissions energy generation technologies, such as Solar PV, CST and CCS, aimed at bringing down costs and establishing supply chains.

Action 4.4 Undertake a cross-disciplinary program to understand how to transition electricity grids (including remote area power systems and microgrids) to support higher shares of distributed energy resources and variable renewable energy at least cost, while maintaining security and reliability, including detailed system modelling at sub-5 second timescales, grid-scale demonstration projects (e.g. in South Australia) and development of cyber-security architectures and protocols.

Action 4.5 Increase RDD&D in bioenergy and low emissions hydrogen, including bioenergy conversion pathways, development of bioenergy feedstocks and supply chains and development of hydrogen for export.

Action 4.6 Conduct R&D in next generation VAM abatement technologies and carry out commercial scale demonstration projects for VAM abatement technologies.

Due to the uncertainties inherent in technological development, it will be important to review the findings of this roadmap at regular intervals and to adjust enablers accordingly. In terms of policy, these reviews should generally only be minor course corrections. Stable policy is crucial to creating the investment certainty required to drive investment in low emissions technologies.

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