



# DECARBONISATION FUTURES

TECHNICAL REPORT

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# DECARBONISATION FUTURES

## Solutions, actions and benchmarks for a net zero emissions Australia

Technical Report

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01

# INTRODUCTION

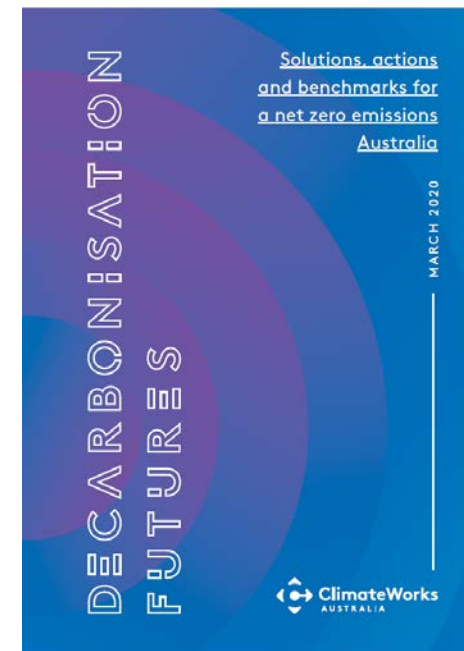
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# ***Decarbonisation Futures* provides a guide for Australian government and business decisionmakers on priority technologies, deployment pathways and benchmarks for achieving net zero emissions.**

This technical report is a companion document to the main report of the same title.

This document is split into three sections:

- + The **model description** section details the tool, it's configuration and overarching parameters as applied to the analysis.
- + In the **scenario development** section, the process for creating the scenarios explored in this work is detailed. Detail of the scenarios themselves resulting from this process are also provided.
- + The report then details the **sectoral modelling approach and assumptions**, for each sector analysed: electricity, buildings, transport, industry, and agriculture and land.





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02

# MODEL DESCRIPTION

# ***Decarbonisation Futures* showcases the new capabilities of the Aus-TIMES model**

- + The TIMES (The Integrated MARKAL-EFOM System) energy system modelling framework is developed and maintained by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA) and has been used extensively in 20 countries. TIMES is a successor to the MARKAL energy system model. The model satisfies energy services demand at the minimum total system cost, subject to physical, technological, and policy constraints. Accordingly, the model makes simultaneous decisions regarding technology investment, primary energy supply and energy trade<sup>1</sup>.
- + CSIRO and ClimateWorks Australia have co-developed Aus-TIMES – an Australian version of the TIMES model.

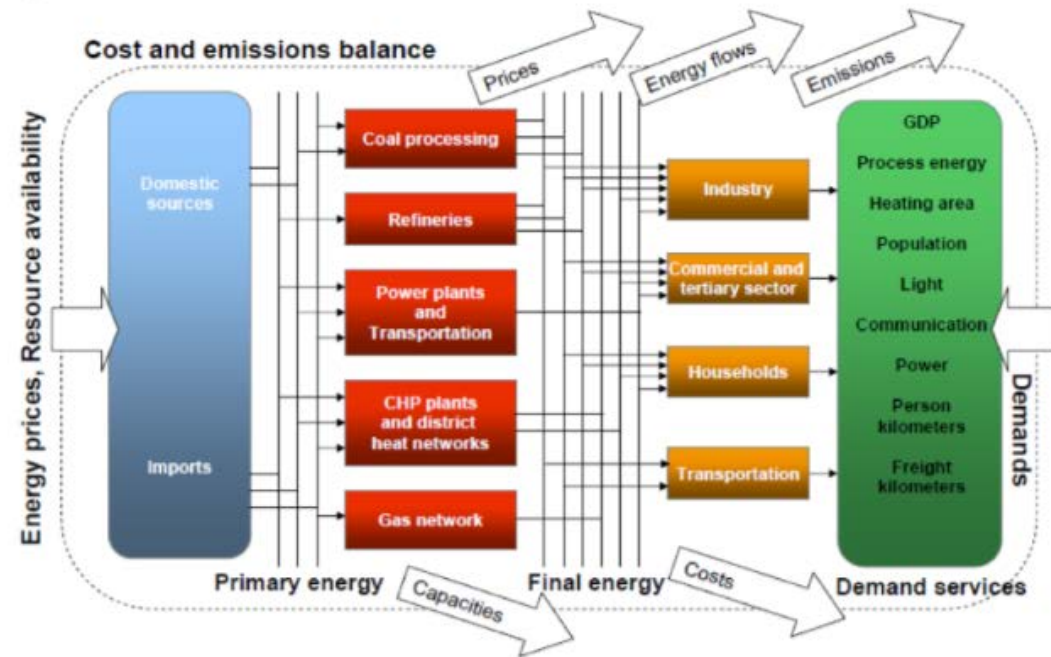


Figure 2: Schematic of TIMES inputs and outputs; source: (Remme et al., 2001)

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# The TIMES framework also allows us to model a wide variety of decarbonisation methods

- + Aus-TIMES optimises the mix of technologies to achieve minimum overall system cost, according to imposed conditions.
- + The representation of sectors, technologies and commodities in the model is tailored specifically to Australia's energy system
- + The types of conditions we can impose include:
  - Demand forecasts for particular areas of the economy
  - An explicit price on carbon
  - The introduction of emission-reduction technologies ('abatement solutions')
  - Constraints on system emissions limits (e.g. a carbon budget)



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# Aus-TIMES can model energy and emissions flows with a high level of granularity

- + Flows in the model can be interrogated across the following structural features:
- + **Regions** representing all states and territories (ACT, NSW, NT, QLD, SA, TAS, VIC, WA)
- + **Time intervals** at an annual frequency from 2015-2020, then in five-year steps (2025, 2030, 2035, 2040, 2045, 2050)
- + An **energy conversion (electricity) sector** based on asset-level generation and interconnector data
  - + 16 time slices per year (seasonal, time of day)
  - + NEM (16 zones), SWIS, NWIS, DKIS, MIIS
  - + Renewable resource availability/potential by zone
- + Four **energy demand** sectors with subdivisions:
  - + **Industry** – including 30 subsectors across mining, manufacturing and other industry
  - + **Buildings** – including 11 commercial building types and 3 residential building types
  - + **Transport** – including 10 road vehicle segments and 3 non-road transport types
  - + **Agriculture** – including 8 subsectors
- + Sector specific baseline and activity assumptions are provided in later sections.

# Model divisions in Aus-TIMES have been mapped to ANZSIC (2006) divisions

Aus-TIMES uses a set of model-specific subsectors to represent the Australian economy. These categories have an emphasis on providing detail around emissions-intensive sectors, and have been informed by prior analysis and data availability. The following tables detail the mapping from Aus-TIMES subsectors to Australian and New Zealand Standard Industrial Classification (ANZSIC) codes. This mapping allows for the integration of and with common external data sets, such as from those the Australian Bureau of Statistics, Australian Energy Statistics or National Greenhouse Gas Inventory.

		Aus-TIMES subsector	ANZSIC codes	ANZSIC titles
AGRICULTURE AND LAND	Livestock	Sheep and cattle	0141, 0142, 0143, 0144	Sheep, Beef Cattle and Grain Farming
		Dairy	016	Dairy Cattle Farming
		Other animals	017, 018, 019	Poultry Farming, Deer Farming, Other Livestock Farming
	Other agriculture	Grains	0145, 0146, 0149, 015	Grain-Sheep or Grain-Beef Cattle Farming, Rice Growing, Other Grain Growing, Other Crop Growing (sugar, cotton...)
		Other agriculture	011, 012, 013	Nursery and Floriculture Production, Mushroom and Vegetable Growing, Fruit and Tree Nut Growing
		Agricultural services and fishing	02, 04, 052	Aquaculture, Fishing, Hunting and Trapping, Agriculture and Fishing Support Services
	Forestry	Forestry and logging	03, 051	Forestry and Logging, Forestry Support Services

# Model divisions in Aus-TIMES have been mapped to ANZSIC (2006) divisions

		Aus-TIMES division	ANZSIC codes	ANZSIC titles
BUILDINGS	Residential	Separate house	N/A	Division based on building archetype
		Townhouse	N/A	Division based on building archetype
		Apartment	N/A	Division based on building archetype
	Commercial	Supermarket	33-38	Grocery, Liquor and Tobacco Product Wholesaling, Basic Material Wholesaling, Machinery and Equipment Wholesaling, Motor Vehicle and Motor Vehicle Parts Wholesaling, Other Goods Wholesaling, Commission-Based Wholesaling
		Retail	39-43	Motor Vehicle and Motor Vehicle Parts Retailing, Fuel Retailing, Other Store-Based Retailing, Non-Store Retailing and Retail Commission Based Buying and/or Selling, Food Retailing
		Hotel	44-45	Accommodation, Food and Beverage Services
		Office	54-60, 62-64, 66-67, 69-70, 72-73, 89-92, 94-96	Publishing, Motion Picture & Sound Recording Activities, Broadcasting, Telecommunications Services, Internet Service Providers, Web Search Portals & Data Processing Services, Library & Other Information Services, Finance, Insurance & Superannuation Funds, Auxiliary Finance & Insurance services, Rental & Hiring Services, Property Operators & Real Estate Services, Professional, Scientific & Technical Services, Computer System Design & Related Services, Administrative Services, Building Cleaning, Pest Control & Other Support Services, Arts & Recreation Services, Other Services, Pharmaceutical & Medicinal Product Manufacturing
		Public building	75 (part) -77	Public Administration, Defence, Public Order, Safety and Regulatory Services
		School	80	Preschool and School Education
		Law court	75	Public Administration
		Tertiary	81-82	Tertiary Education, Adult, Community and Other Education
		Hospital	84-85, 184 (part)	Hospitals, Medical and Other Health Care Services, Pharmaceutical and Medicinal Product Manufacturing
		Aged care	86-87, 184 (part)	Residential Care Services, Social Assistance Services, Pharmaceutical and Medicinal Product Manufacturing
		Data centre	N/A	Division not currently represented in ANZSIC

# Model divisions in Aus-TIMES have been mapped to ANZSIC (2006) divisions

		Aus-TIMES division	ANZSIC codes	ANZSIC titles
ELECTRICITY	Generation	Black coal	2611 (part)	Fossil Fuel Electricity Generation
		Brown coal	2611 (part)	Fossil Fuel Electricity Generation
		Gas	2611 (part)	Fossil Fuel Electricity Generation
		Oil products	2611 (part)	Fossil Fuel Electricity Generation
		Nuclear	2619 (part)	Other Electricity Generation
		Hydro	2612	Hydro-Electricity Generation
		Solar	2619 (part)	Other Electricity Generation
		Wind	2619 (part)	Other Electricity Generation
TRANSPORT	Road transport	Bus	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
		Passenger vehicle	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
		Motorcycle	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
		Articulated vehicle	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
		Light commercial vehicle	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
		Rigid trucks	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
	Non-road	Rail transport	461 (part), 462 (part)	Road Freight Transport, Road Passenger Transport
		Water transport	48	Water Freight Transport, Water Passenger Transport
		Air transport	49 (part)	Air and Space Transport

# Model divisions in Aus-TIMES have been mapped to ANZSIC (2006) divisions

		Aus-TIMES division	ANZSIC codes	ANZSIC titles
INDUSTRY	Metals	Alumina	2131	Alumina Production
		Aluminium	2132	Aluminium Smelting
		Iron and steel – BF	211 (part)	Basic Ferrous Metal Manufacturing (Iron Smelting and Steel Manufacturing) - Black Furnace (BF)
		Iron and steel – EAF	211 (part)	Basic Ferrous Metal Manufacturing (Iron Smelting and Steel Manufacturing) - Electric Arc Furnace (EAF)
	Mining	Coal mining	06	Coal Mining
		Oil extraction	07 (part)	Oil and Gas Extraction
		Gas extraction	07 (part)	Oil and Gas Extraction
		Iron ore mining	0801	Iron Ore Mining
		Bauxite mining	0802	Bauxite mining
		Other non-ferrous metal ores mining	0803-0809	Mining of Copper ore, Gold ore, Mineral Sand, Nickel ore, Silver-Lead-Zinc ore, Other metal ore
		Other mining	09	Non-Metallic Mineral Mining and Quarrying
	Chemicals and minerals	Cement	203	Cement, Lime, Plaster and Concrete Product Manufacturing
		Non-metallic construction materials (not cement)	201-202, 209	Glass and Glass Product Manufacturing, Ceramic Product Manufacturing, Other Non-Metallic Mineral Product Manufacturing
		Petroleum refinery	17	Petroleum and Coal Product Manufacturing
		Other chemicals	181-183, 185, 189	Basic Chemical Manufacturing, Basic Polymer Manufacturing, Fertiliser and Pesticide Manufacturing, Cleaning Compound and Toiletary Preparation Manufacturing, Other Basic Chemical Product Manufacturing

# Model divisions in Aus-TIMES have been mapped to ANZSIC (2006) divisions

		Aus-TIMES division	ANZSIC codes	ANZSIC titles
INDUSTRY	Other manufacturing	Construction services	30-32	Building Construction, Heavy and Civil Engineering Construction, Construction Services
		Meat products	111	Meat and Meat Product Manufacturing
		Motor vehicles and parts	231	Motor Vehicle and Motor Vehicle Part Manufacturing
		Other food and drink products	112-119	Seafood Processing, Dairy Product Manufacturing, Fruit and Vegetable Processing, Oil and Fat Manufacturing, Grain Mill and Cereal Product Manufacturing, Bakery Product Manufacturing, Sugar and Confectionery Manufacturing, Other Food Product Manufacturing, Beverage and Tobacco Product Manufacturing
		Other manufacturing products	239, 24-25	Other Transport Equipment Manufacturing, Machinery and Equipment Manufacturing, Furniture and Other Manufacturing
		Other metal products	212, 214, 22	Basic Ferrous Metal Product Manufacturing, Basic Non-Ferrous Metal Product Manufacturing, Fabricated Metal Product Manufacturing
		Other non-ferrous metals	2133, 2139	Copper, Silver, Lead and Zinc Smelting and Refining, Other Basic Non-Ferrous Metal Manufacturing
		Paper products	15	Pulp, Paper and Converted Paper Product Manufacturing
		Printing and publishing	16	Printing (including the Reproduction of Recorded Media)
		Rubber and plastic products	19	Polymer Product and Rubber Product Manufacturing
		Textiles, clothing and footwear	13	Textile, Leather, Clothing and Footwear Manufacturing
		Wood products	14	Wood Product Manufacturing
	Gas, water supply & waste	Gas supply	27	Gas Supply
		Water supply	28	Water Supply, Sewerage and Drainage Services
		Waste	29	Waste Collection, Treatment and Disposal Services



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03

# SCENARIO DEVELOPMENT

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# ***Decarbonisation Futures* utilises exploratory scenarios**

The scenarios were developing using an interactive exploratory thinking process and are made up of a cascade of assumptions, from a broad global context to the impact of specific abatement solutions.

## **Global and local context**

- + What are the underlying global assumptions, including demographic, economic and development trends?
- + What is the climate outcome and emissions trajectory of the scenario?
- + What are the socio-political conditions and key drivers of change?

## **Abatement solutions**

- + Based on the scenario narrative and drivers

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## Global and local context:

### **Consistent assumptions about a global context underpin all scenarios**

- + Each scenario in decarbonisation futures shares consistent assumptions regarding population growth and economic growth and development. These assumptions are broadly aligned with *Pathways to Deep Decarbonisation in 2050*<sup>1</sup>.

### **It was assumed that Australia and the rest of the world are aligned with regards to the temperature target of the scenario**

- + This means that the world has the same climate ambition (temperature goal) and emissions reduction trajectory as Australia in a given scenario. For example, as Australia transitions away from fossil fuels in line with achieving a well-below 2-degree world, it is assumed that all other countries also transition, reducing global demand for those goods.

<sup>1</sup>ClimateWorks Australia (2015)

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## Global and local context:

*Decarbonisation Futures* identifies three key ‘drivers’ that help develop and deploy solutions when and where they are required:

### TECHNOLOGY

Technological research, development and innovation can help overcome inherent challenges, accelerate uptake of solutions and provide new ways of working, potentially benefiting multiple sectors. But this entails support, with all three modelled scenarios requiring action by government, businesses and individuals.

### POLICY

Policy made by governments can drive emissions reductions through legislation, regulation or incentives (for example, renewable energy targets, vehicle greenhouse gas emissions standards, direct procurement and investment in climate solutions). Governments can provide essential infrastructure to support the rollout of solutions (such as investments in electricity transmission, rail transport, and electric vehicle charging infrastructure), and reduce non-price barriers to their adoption (for example, by providing consumer information and requiring companies to disclose climate strategies and actions).

### BUSINESSES AND INDIVIDUALS

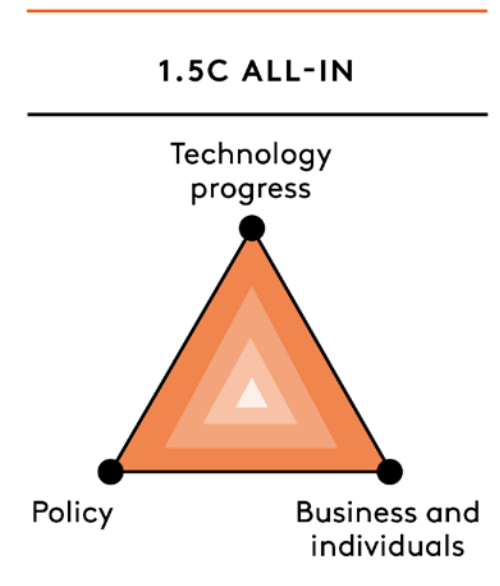
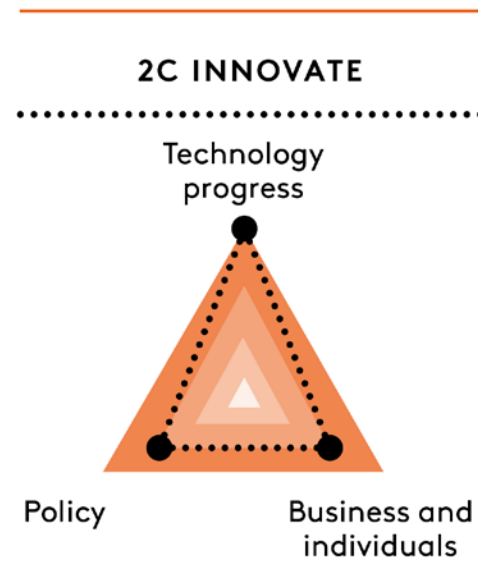
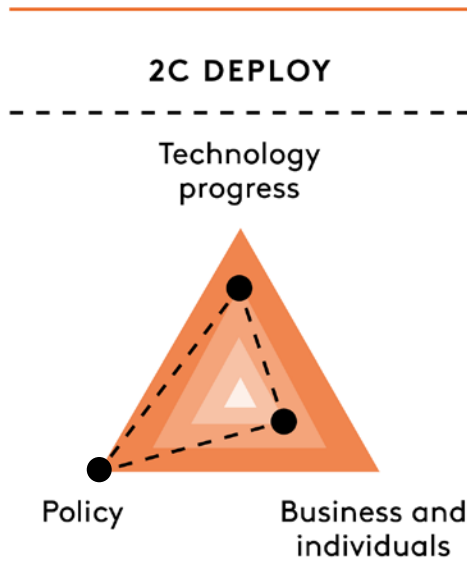
Businesses and individuals can significantly impact emissions reductions through their consumption, investment and advocacy. Businesses can move their operations away from high-emissions processes or inputs to zero-emissions alternatives, and transition their workforces to be developing low-emissions products and services. Individuals can demand carbon neutral products in almost every sector as well as investments (for example, ethical superannuation and banking products) thus providing a strong signal to peers, businesses and governments.

## Global and local context:

The scenarios developed explore a range of possible low-emissions futures for Australia, each using a different set of drivers

These triangles represent the level of progress/action taken towards net zero emissions for each driver, by scenario.

Settings closer to the inside of the triangle indicate less action, while outer settings indicate more/strong action.



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## Global and local context:

Three scenarios are described in *Decarbonisation Futures*

- + The first scenario (**'2C Deploy'**) models emissions reductions compatible with a 2-degree-Celsius global temperature limit, achieved primarily through direct government intervention focused on accelerating and regulating the deployment of demonstration – and mature – stage technologies
- + The second scenario (**'2C Innovate'**) shows how technology at the upper bounds of current expectations can facilitate the same temperature outcome as the previous scenario. In this scenario, emerging technologies create widespread change in emissions-intensive sectors, driven by supportive government and business action
- + The third scenario (**'1.5C All-in'**) models an emissions outcome compatible with limiting the global temperature rise to 1.5 degrees Celsius. It combines elements from the two earlier scenarios, and assumes that governments will drive policies to limit emissions and facilitate technological innovations, with collaboration between policy-makers, businesses and individuals across all sectors.



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## Abatement solutions:

The impact of the identified abatement solutions was set for each scenario based on the drivers in the scenario

The specific setting of abatement solutions in a given scenario is informed by the aforementioned scenario narratives and drivers of change. A visual depiction of the settings of the abatement solutions are shown overleaf.

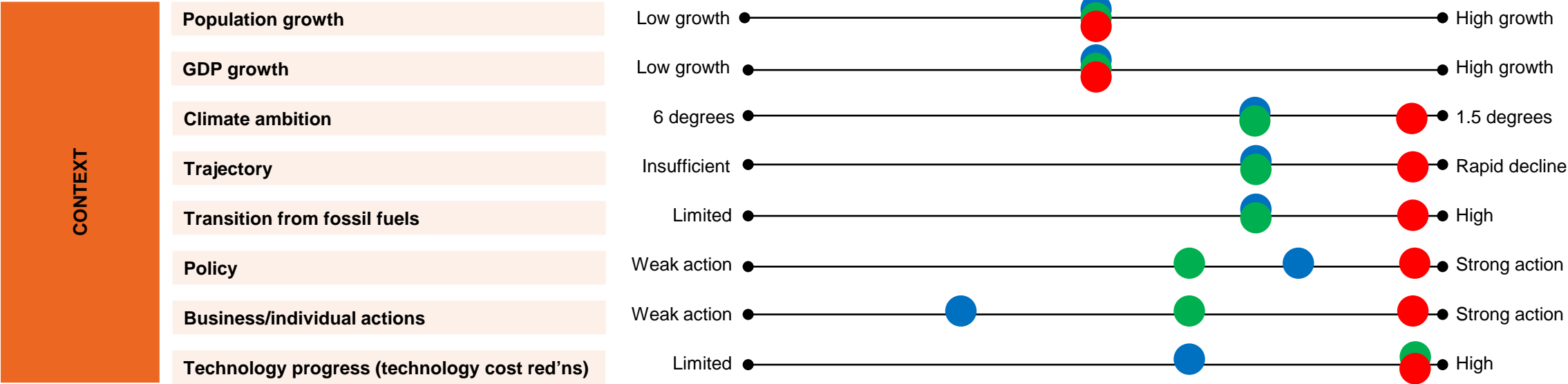
A wide range of abatement solutions were made available to the model. Some solutions are specific to a sector, while other are more general and apply proportionally to many sectors. Some are endogenous (where the impact/outcome is

calculated by the model) while other are exogenous (externally calculated and respected by the model). The abatement solutions can reduce emission through any one of the following mechanisms: adjusting emission intensity, energy intensity or activity levels.

Further detail of the solutions are provided in the sectoral chapter to which the solution relates.

# Global and local context

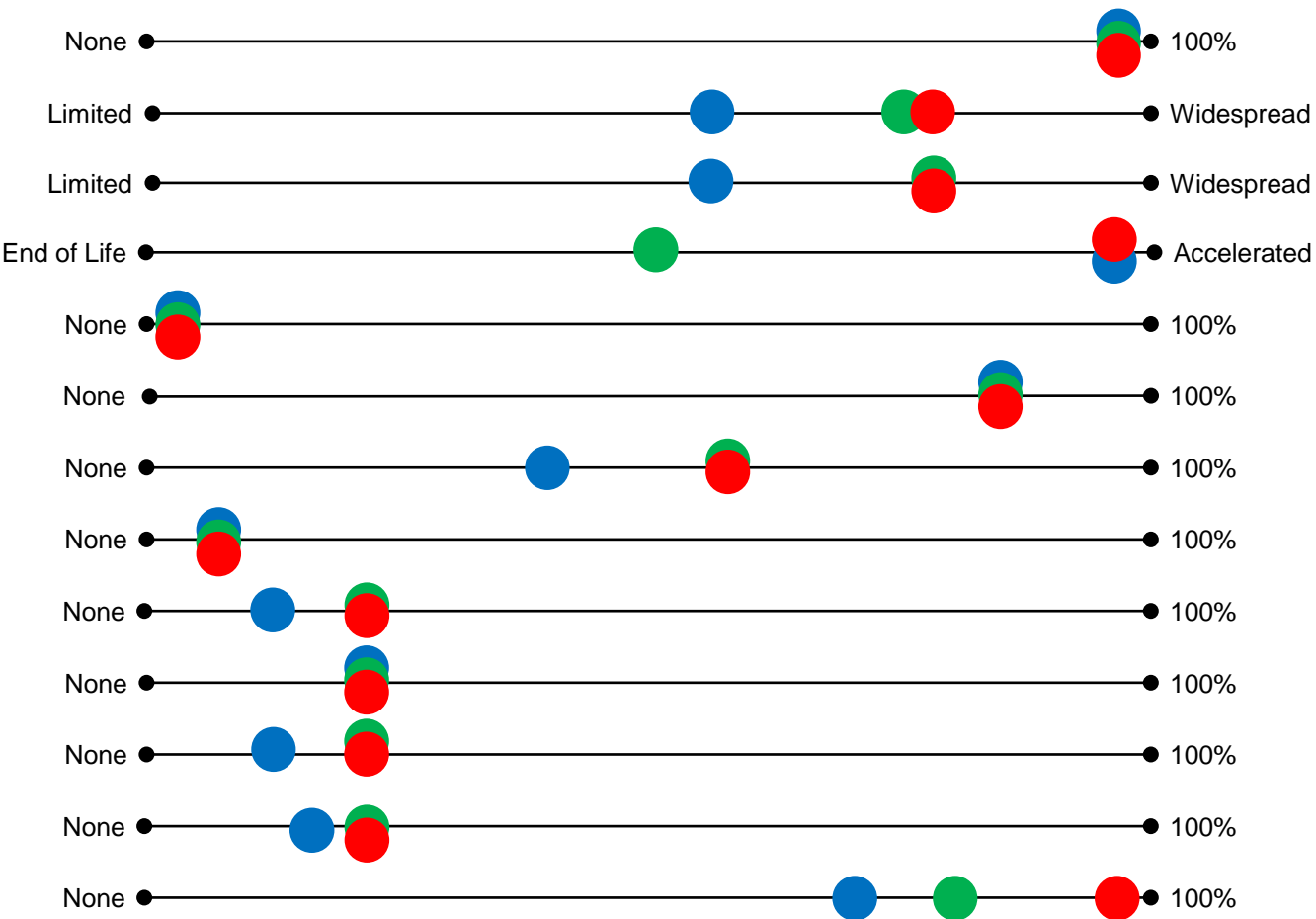
Legend      ● 2C Deploy      ● 2C Innovate      ● 1.5C All-in



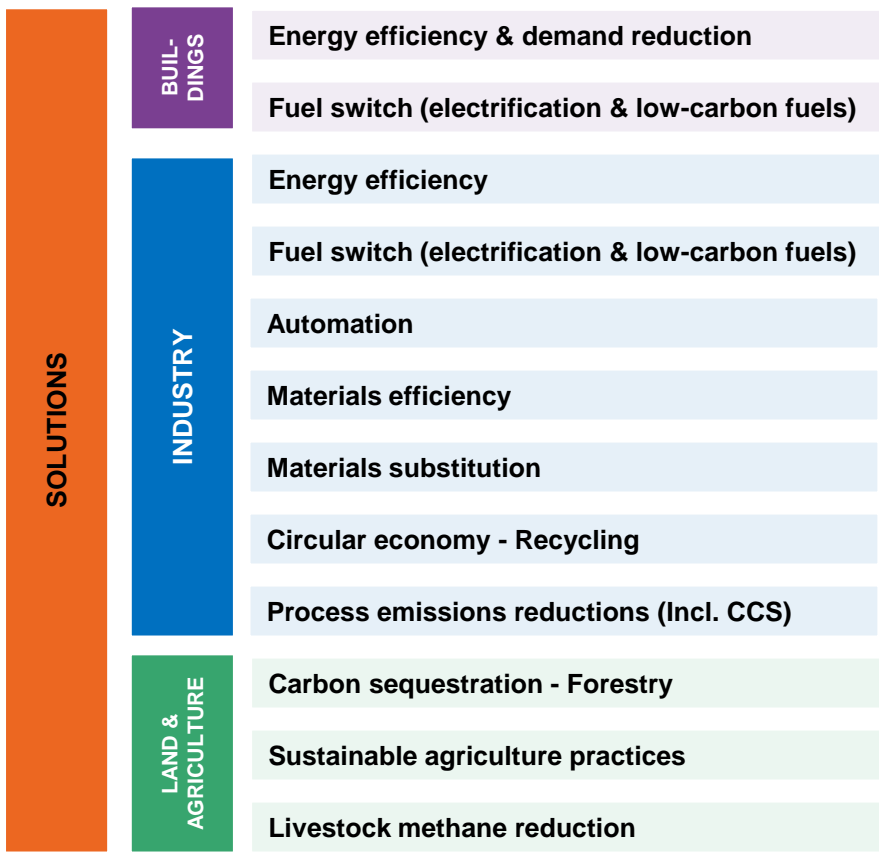
# Abatement solutions (1/2)

Legend      ● 2C Deploy    ● 2C Innovate    ● 1.5C All-in

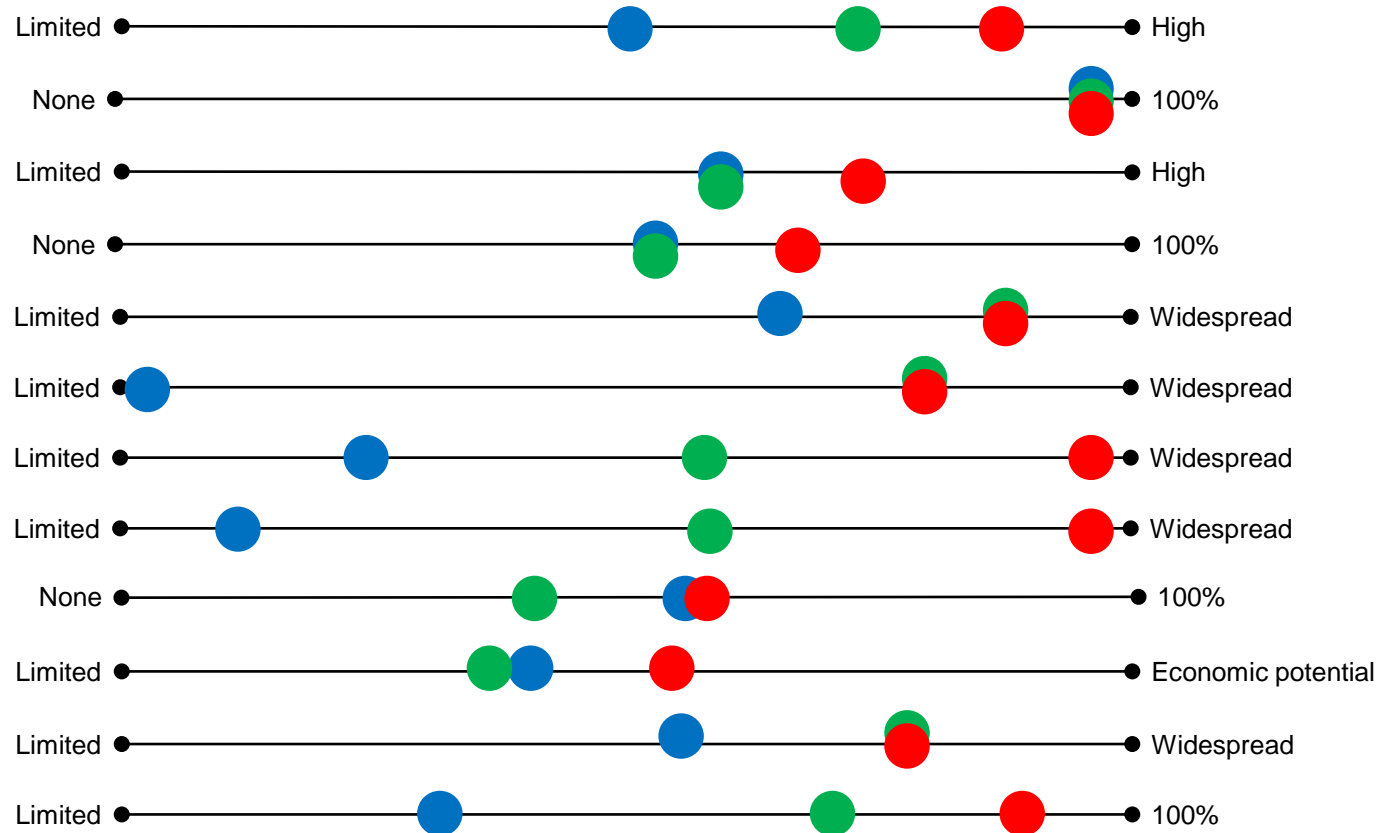
SOLUTIONS	ELECTRICITY	Renewable generation share 2050
		Grid-scale batteries
		Behind the meter generation and storage
		Coal closure
		Nuclear, CCS / BECCS generation share 2050
	TRANSPORT	EV share of light vehicles 2050
		EV share of heavy vehicles 2050
		Fuel cell share of light vehicles 2050
		Fuel cell share of heavy vehicles 2050
		Autonomous vehicles: private travel 2050
		Autonomous vehicles: ride share 2050
		E-commerce share of sales
		Non-road: shift to low carbon fuels



# Abatement solutions (2/2)



Legend 2C Deploy 2C Innovate 1.5C All-in



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# 04

CROSS-CUTTING

ELECTRICITY

BUILDINGS

TRANSPORT

INDUSTRY

AGRICULTURE AND LAND

## SECTOR MODELLING APPROACH AND ASSUMPTIONS

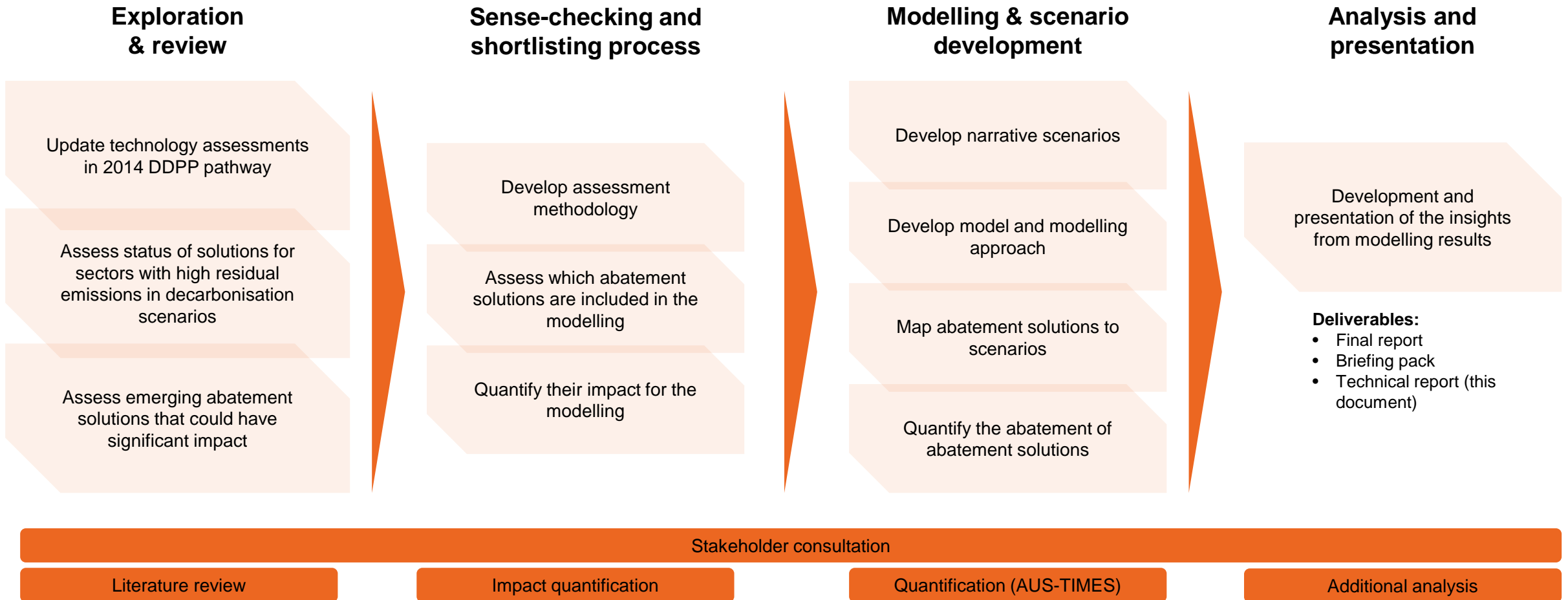
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# Cross-cutting

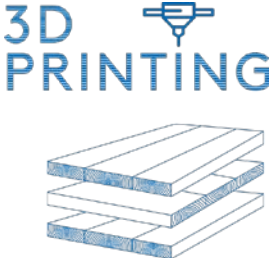
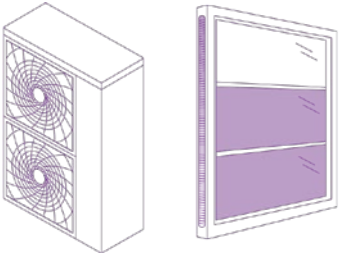





# We've taken a methodological approach to comprehensively identify and assess potential abatement solutions



# The process has led to a focus on a range of topics across the sectors that could dramatically impact on decarbonisation

INDUSTRY	BUILDINGS	ELECTRICITY	TRANSPORT	LAND
<ul style="list-style-type: none"> <li>+ Timber buildings</li> <li>+ Geopolymer cement</li> <li>+ Bio-coke</li> <li>+ Better building design</li> <li>+ 3D printing</li> <li>+ Circular economy</li> <li>+ Automation, AI, ML</li> <li>+ Hydrogen</li> </ul> 	<ul style="list-style-type: none"> <li>+ Cooling mitigation</li> <li>+ HVAC design &amp; control</li> <li>+ Lighting controls</li> <li>+ Passive heating &amp; cooling</li> </ul> 	<ul style="list-style-type: none"> <li>+ Updated generation technology cost assumptions</li> <li>+ Updated renewable integration cost assumptions ( e.g. batteries, smart grid, inertia, pumped hydro)</li> </ul>	<ul style="list-style-type: none"> <li>+ Autonomous vehicles (shared fleets &amp; privately owned)</li> <li>+ Electric Vehicles (EVs) / Plug-in Hybrid (PHEVs)</li> <li>+ Hydrogen Fuel cells Vehicles (FCEV)</li> <li>+ Non-road efficiency improvements (Maritime, Aviation, Rail)</li> <li>+ Mode shift (walking, cycling, UPT)</li> <li>+ e-Commerce</li> </ul>	<ul style="list-style-type: none"> <li>+ Enteric methane emissions reduction methods</li> <li>+ Precision agriculture</li> </ul> 

# The TIMES model framework allows us to analyse the impacts of both cost-driven and externally-calculated abatement solutions on the energy system

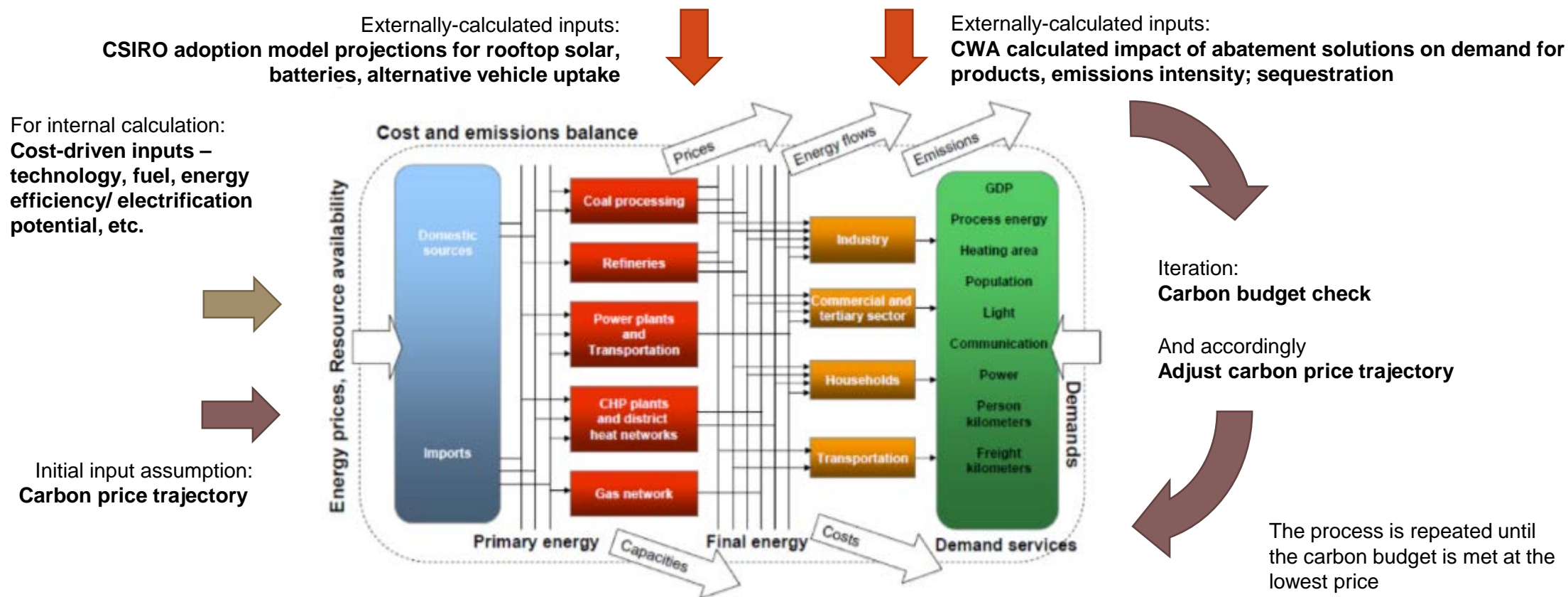


Figure 2: Schematic of TIMES inputs and outputs; source: (Remme et al., 2001)

# ***Decarbonisation Futures* utilises a carbon budget approach to assess the compatibility of the scenarios analysed against the temperature outcomes. (1/2)**

All modelled scenarios are compatible with the intended temperature outcome.

Carbon budgets for Australia were calculated from global carbon budgets for 2 degrees (67% chance of limiting temperature rise to 2 degree), and 1.5 degrees using the sources and methodology explained overleaf.

The budgets used to assess the scenarios are:

- + 2 degrees (67%): 14.0 GtCO<sub>2</sub>eq 2015-2050
- + 1.5 degrees:
  - + 50%: 7.0 GtCO<sub>2</sub>eq 2015-2050.
  - + 67%: 5.1 GtCO<sub>2</sub>eq 2015-2050.

Years are financial years (i.e. 2015=2014/15).

The '1.5C All-in' scenario emissions always stay within the 50% chance of limiting temperature rise to 1.5 degree budget.

However, after reaching net zero emissions ~2035, carbon forestry sequestration continues and leads to Australia being net-negative emissions from 2035-2050. The scenario then reduces cumulative emissions below the 67% chance budget before 2050.

While there is uncertainty around the overshoot-and-return mechanism, net-negative emissions only increases the chance of limiting warming to 1.5 degrees Celsius.

# ***Decarbonisation Futures* utilises a carbon budget approach to assess the compatibility of the scenarios analysed against the temperature outcomes. (2/2)**

In addition to staying within the carbon budget, the 2 degree scenarios met an imposed emissions trajectory of reaching net zero in 2050.

This reflects:

- + that 2 degree scenarios for 'advanced economies' (of which Australia is one) have a clearly distinguishably different trajectory for emissions reductions compared to 'developing economies'<sup>1</sup>,
- + the considerable uncertainty in the carbon budgets. Reducing emissions faster increases chances of a favorable temperature outcome, and
- + that this level of abatement has been shown to not be detrimental to Australia's economy and can in fact lead to significant opportunities if tapped.

A carbon price is assumed in each scenario to drive the uptake of cost-driven abatement options in the modelling to stay within the carbon budget.

- + The carbon price was used as the modelling mechanism through which to drive abatement in the model. As Aus-TIMES is an energy services demand model that seeks minimum total system cost, the carbon price is a minimally intrusive mechanism through which to inform the lowest cost abatement, particularly compared to forced hard limits/constraints.
- + The carbon price represents a range of actions, not necessarily an explicit price on carbon emissions. These actions may well include policy, regulations and incentives, as well as business and individuals behaviours and purchasing decisions.
- + Scenario drivers (technological progress, policy, business & individuals) and consumer uptake models were utilised in this analysis to augment the modelled carbon price trajectory, in order to better reflect the real-world non-price barriers and enablers of certain abatement options (e.g. electric vehicle uptake).
- + The carbon price increased over time and varies between scenarios, consistent with the scenario narrative. The carbon prices rises from \$20 in 2020 to \$200, \$233 and \$300 in 2050 for the 2C Innovate, 2C Deploy and 1.5C All-in respectively.

<sup>1</sup> Based on CO<sub>2</sub> emissions trajectories in the SDS Scenario in International Energy Agency, *World Energy Outlook 2018*,

# Carbon budget - assumptions & sources

- + Global carbon budgets from “IPCC SR15 Chapter 2, ‘Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development’; Table 2.2”
- + ‘Earth System Feedbacks’ are included. Adjustments for ‘pre-industrial’ warming & differences in starting years are applied.
- + Australia’s ‘fair share’ is 0.97%. This is a similar approach to that taken by the Garnaut Review and the Climate Change Authority. Noting that this is a higher share than alternative approaches (e.g. by share of population)
- + Non-CO2 gasses are incorporated according to "Deriving a global 2013-2050 emission budget to stay below 1.5°C based on the IPCC Special Report on 1.5°C" A/Prof. Malte Meinshausen, The University of Melbourne, Draft, 12 February 2019

Additional Warming since 2006–2015 [°C] <sup>(1)</sup>	Approximate Warming since 1850–1900 [°C] <sup>(1)</sup>	Remaining Carbon Budget (Excluding Additional Earth System Feedbacks <sup>(5)</sup> ) [GtCO <sub>2</sub> from 1.1.2018] <sup>(2)</sup>			Key Uncertainties and Variations <sup>(4)</sup>					
		Percentiles of TCRE <sup>(3)</sup>			Earth System Feedbacks <sup>(5)</sup>	Non-CO <sub>2</sub> scenario variation <sup>(6)</sup>	Non-CO <sub>2</sub> forcing and response uncertainty	TCRE distribution uncertainty <sup>(7)</sup>	Historical temperature uncertainty <sup>(1)</sup>	Recent emissions uncertainty <sup>(8)</sup>
		33rd	50th	67th	[GtCO <sub>2</sub> ]	[GtCO <sub>2</sub> ]	[GtCO <sub>2</sub> ]	[GtCO <sub>2</sub> ]	[GtCO <sub>2</sub> ]	[GtCO <sub>2</sub> ]
0.3		290	160	80	Budgets on the left are reduced by about –100 on centennial time scales	±250	–400 to +200	+100 to +200	±250	±20
0.4		530	350	230						
0.5		770	530	380						
0.53	~1.5°C	840	580	420						
0.6		1010	710	530						
0.63		1080	770	570						
0.7		1240	900	680						
0.78		1440	1040	800						
0.8		1480	1080	830						
0.9		1720	1260	980						
1		1960	1450	1130						
1.03	~2°C	2030	1500	1170						
1.1		2200	1630	1280						
1.13		2270	1690	1320						
1.2		2440	1820	1430						



# Bioenergy feedstocks and volume

- + Bioenergy is a low emissions alternative fuel available to all sectors. It is utilised significantly for transport where electrification is not practical (such as aircraft, shipping and some remote long distance freight) and also in various industry sectors.
- + This modelling should not, then, be interpreted as predicting one zero-emissions energy source over another. Rather, modelled bioenergy can be thought of as analogous to any future mix of zero-emissions fuels, with the magnitude of fuel use indicative of the research, development and deployment task required.
- + In the modelled scenarios, total bioenergy use in 2050 ranges from 647 PJ to 783 PJ (see slide 132 below and Figure 3.18 of main report)
- + Given current land use trade-offs associated with production of first-generation sources, bioenergy is more likely to be produced using second- and third-generation feedstocks.
- + Supplying the amount of bioenergy suggested by the Decarbonisation Futures modelling would be subject to numerous practical considerations. One consideration is having sufficient availability of bio feedstock.
- + A detailed assessment of bioenergy availability was not part of the scope of this work given the existence of prior studies. The levels of bioenergy consumption in this modelling are estimated to be compatible with recent biomass availability studies<sup>1</sup>.

<sup>1</sup>Crawford, D, O'Connor, M, Jovanovic, T, Herr, A, Raison, RJ, O'Connell, D & Baynes, T 2015, 'A spatial assessment of potential biomass for bioenergy in Australia in 2010, and possible expansion by 2030 and 2050', *GCB Bioenergy*, Vol. 8, issue 4, pp. 707-722.

<sup>2</sup>Department of the Environment and Energy 2019, 'National Greenhouse Accounts Factors: Australian National Greenhouse Accounts August 2019', Commonwealth of Australia

# Electricity

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## Regional coverage

- + Includes: NEM (16 'NTNDP' transmission zones, as specified by AEMO), NWIS, SWIS, DKIS
- + For each zone: existing generation capacity, maximum renewable resources and renewable generation profile, access to CCS sites (where available)
- + Unit-level data for existing thermal and hydro generation fleet
- + Supply aggregated to meet a pool of demand for each state
- + NEM trade through 6 existing interconnectors links between: NSW & QLD; NSW & VIC; VIC & SA; VIC & TAS
- + Interconnectors can be augmented in the model
- + A 'dummy' interconnector also allows electricity to flow between NSW and ACT.
- + 16 time slices per year: seasonal, time of day

# Cost assumptions

For electricity generation the model requires cost inputs in regard to:

- + Overnight capital costs of construction
- + Operating and maintenance costs (fixed and variable)
- + Fuel costs

Other assumptions which also impact how these costs are captured are the fuel efficiency, plant construction time and technical life. Data for these assumptions were sourced from these references:

- + Graham, P.W., Hayward, J, Foster, J., Story, O. and Havas, L. 2018, GenCost 2018. CSIRO, Australia.
- + GHD 2018, AEMO costs and technical parameter review: Report final Rev 4 9110715, AEMO, Australia.

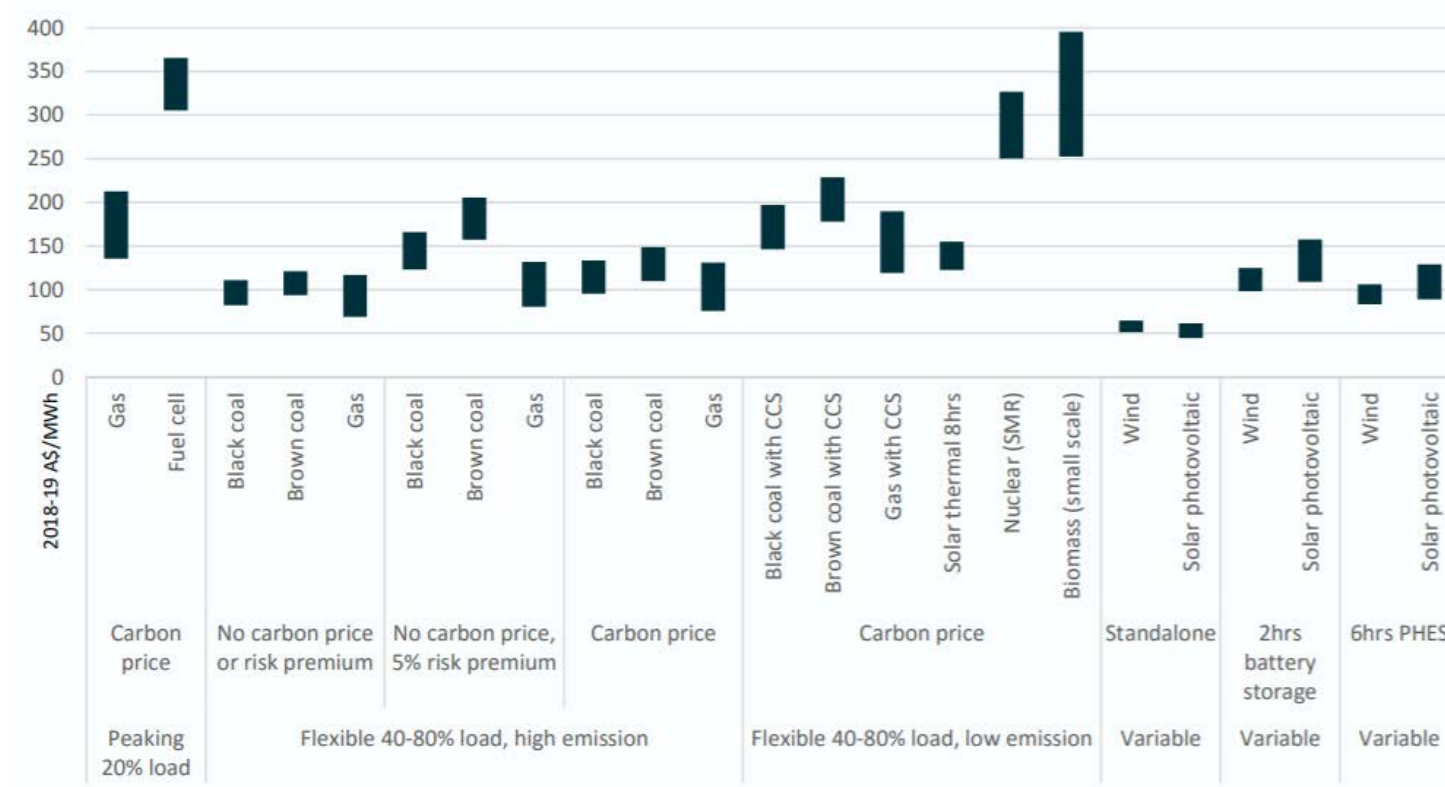
The GenCost project is an annual process for updating

Australia's current and future electricity generation and storage costs and parameters through an open stakeholder process. The process is a partnership of CSIRO and Australian Energy Market Operator and also included commissioned research by GHD.

Future fuel prices are not included in the GenCost project outputs and so these were sourced from input assumptions to the 2018 AEMO ESOO.

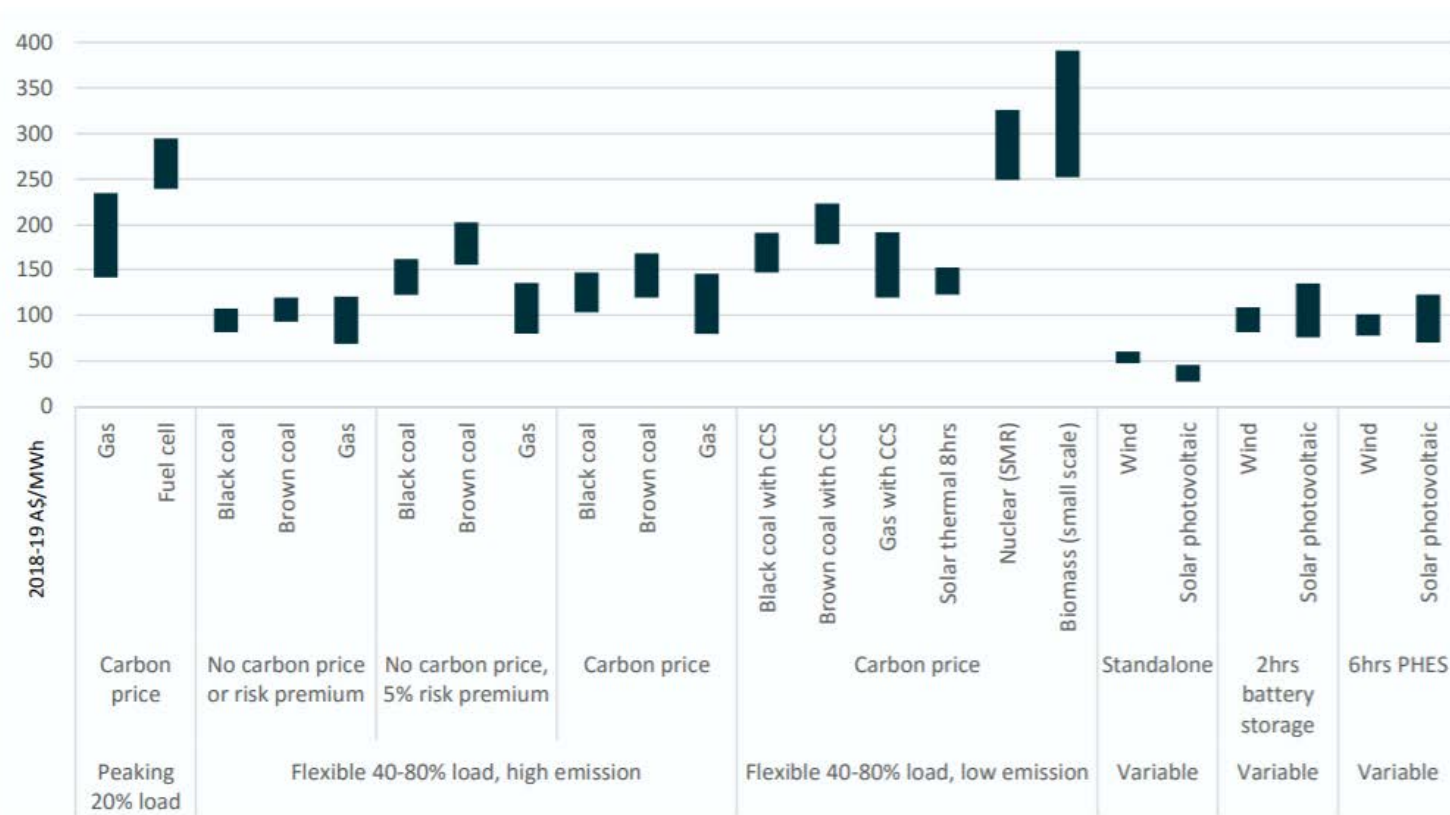
- + AEMO. 2018. 2018 NEM Electricity Statement of Opportunities. [ONLINE] Available at: <https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo/2018-nem-electricity-statement-of-opportunities>. [Accessed 1 February 2019].

# Electricity generation & storage costs (GenCost) for 2020



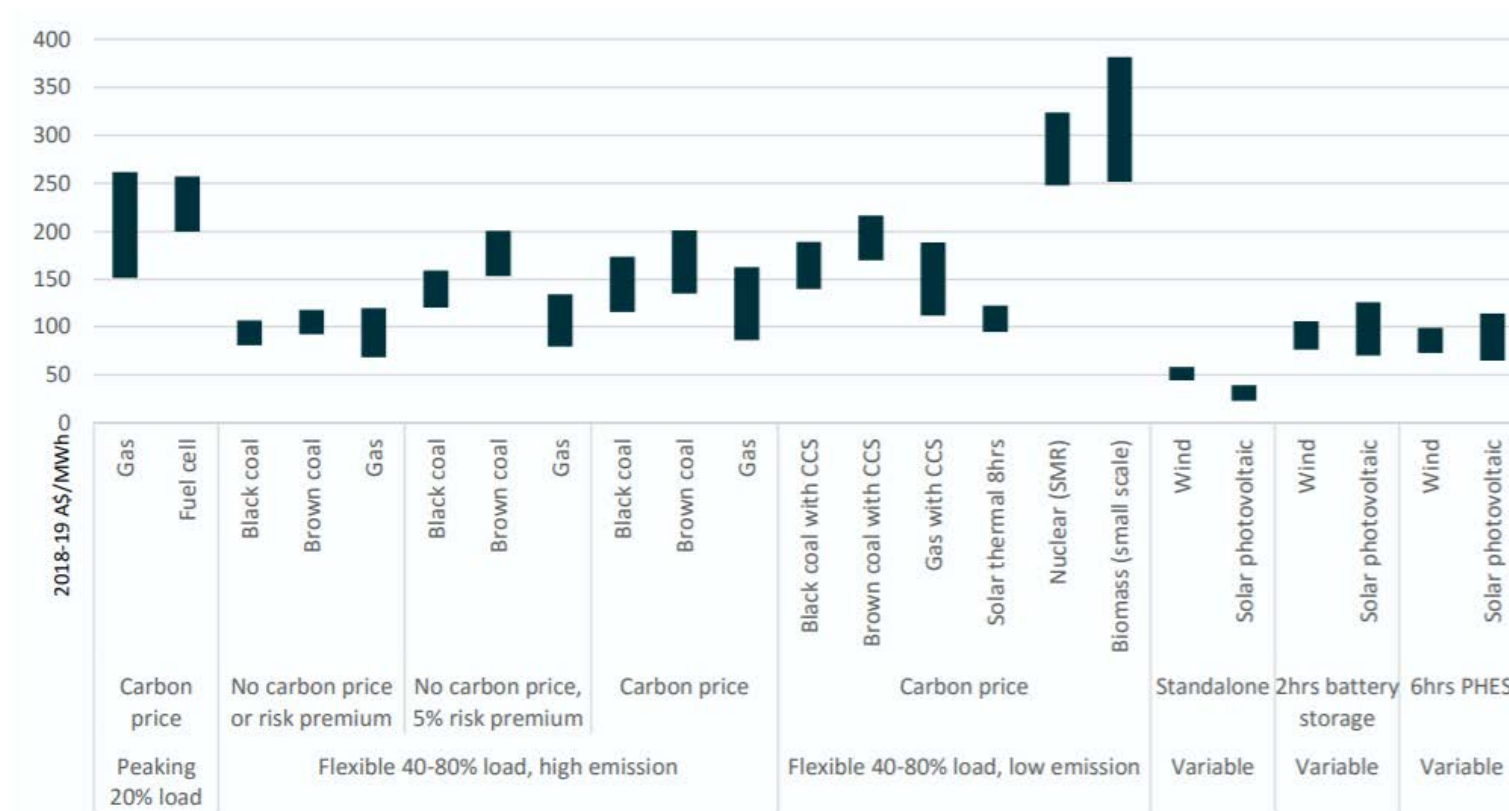
Source: Graham, P.W., Hayward, J, Foster, J., Story, O. & Havas, L. 2018 *GenCost 2018*. CSIRO, Australia.

# Electricity generation & storage costs (GenCost) for 2030



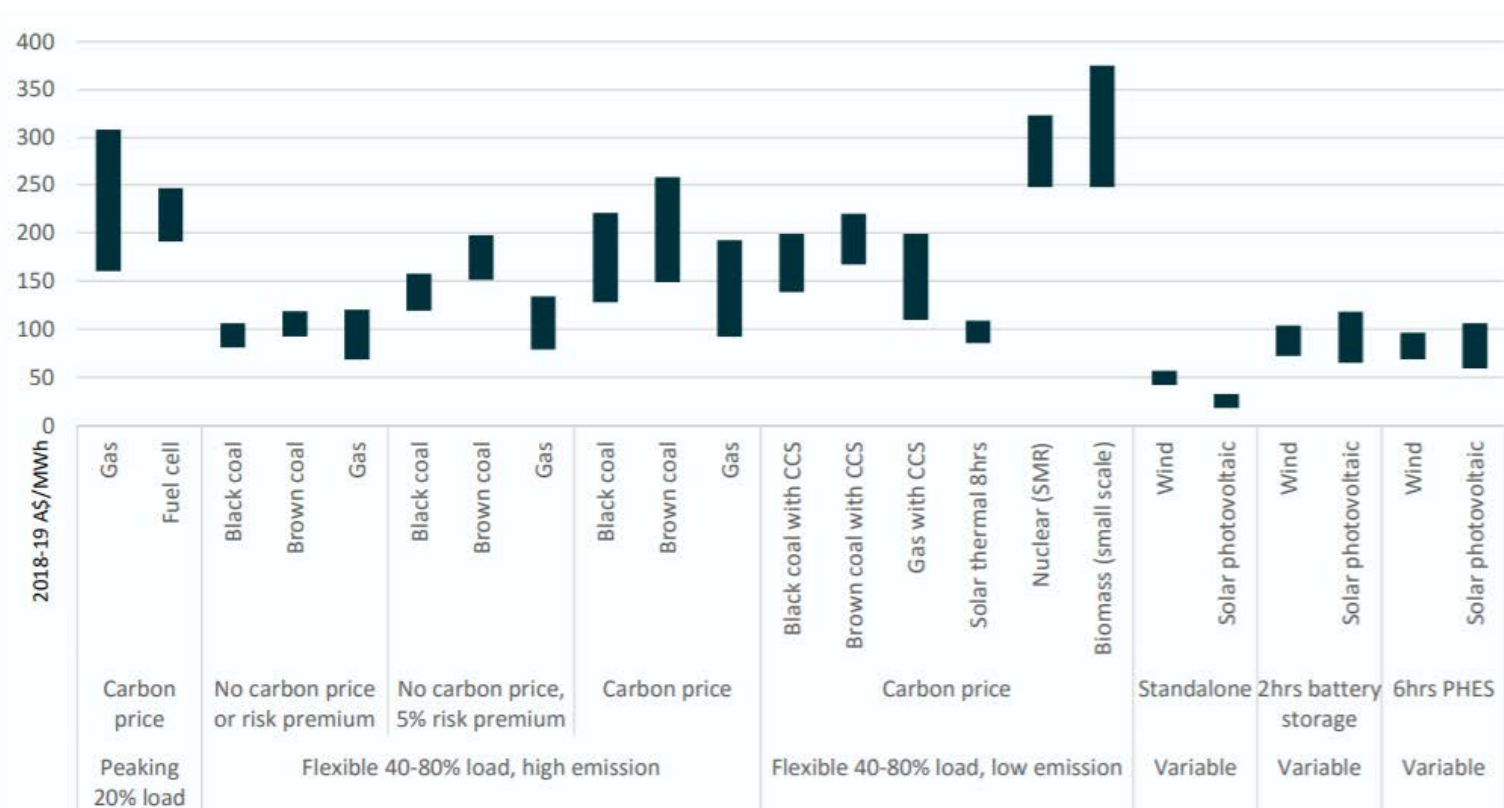
Source: Graham, P.W., Hayward, J, Foster, J., Story, O. & Havas, L. 2018 *GenCost 2018*. CSIRO, Australia.

# Electricity generation & storage costs (GenCost) for 2040



Source: Graham, P.W., Hayward, J, Foster, J., Story, O. & Havas, L. 2018 *GenCost 2018*. CSIRO, Australia.

# Electricity generation & storage costs (GenCost) for 2050



Source: Graham, P.W., Hayward, J, Foster, J., Story, O. & Havas, L. 2018 *GenCost 2018*. CSIRO, Australia.



# Balancing variable renewables in the electricity model

## Weather variability & balancing:

- + In the modelling, wind, solar PV and solar thermal generation profiles are weather dependent.
- + This weather induced variability means that other technologies must be available to support renewables when their production is low.
- + At the beginning of the projection period, existing capacity of flexible coal and gas generation provides this role.
- + As the share of renewables increases and remaining coal generation retires investment in new supporting technologies are required.

## New supporting technologies available:

- + The model has various options for storage whose costs are sourced from the GenCost project.
- + New flexible thermal generation can also play a role balancing the system but faces competitive pressures if any emission constraints are included in the scenario.
- + Biomass is a low emissions flexible plant but both plant and fuel are relatively high cost.
- + The model tends to favour use of batteries and solar thermal storage.
- + However, pumped hydro could also play a role and would be most useful for longer duration storage (particularly if the solar thermal industry fails to develop at the required pace).
- + Batteries and solar thermal are technologies whose costs may still experience significant changes. However, pumped hydro technology is relatively mature. The uncertainty in pumped hydro costs is more related to site conditions.

# Balancing variable renewables in the electricity model

It was not the focus of this analysis to check whether 100% renewables is achievable. We derived comfort from many recent analyses that have found that Australia's electricity system can be supported by 100%+ renewables.

The Energy Transition Hub recently published a comprehensive analysis of possible futures for Australia's electricity system. They used 4 numerical energy-economic models from 5 partner institutes. They modelled 6 scenarios. They did an analysis of each hour of the Australian power system in 2050 for 2 scenarios. They found that:

- + Costs in a renewable-based system are similar or lower than today.
- + Multiple options secure reliable supply from 100 percent renewables.
- + Going beyond 200 percent renewables by producing more hydrogen further decreases the average system cost element

Recent work:

- + Energy Transition Hub , Australia's power advantage - Energy transition and hydrogen export scenarios' [https://www.energy-transition-hub.org/files/resource/attachment/australia\\_power\\_advantage\\_0.pdf](https://www.energy-transition-hub.org/files/resource/attachment/australia_power_advantage_0.pdf)
- + Pumped hydro storage and 100% renewable electricity. Andrew Blakers, Bin Lu, Matt Stocks Australian National University [https://arena.gov.au/assets/2017/08/AndrewBlakers\\_Presentation.pdf](https://arena.gov.au/assets/2017/08/AndrewBlakers_Presentation.pdf)
- + Electricity Network Transformation Roadmap, CSIRO and ENA <https://www.energynetworks.com.au/projects/electricity-network-transformation-roadmap/>

## Distributed energy – rooftop solar and batteries

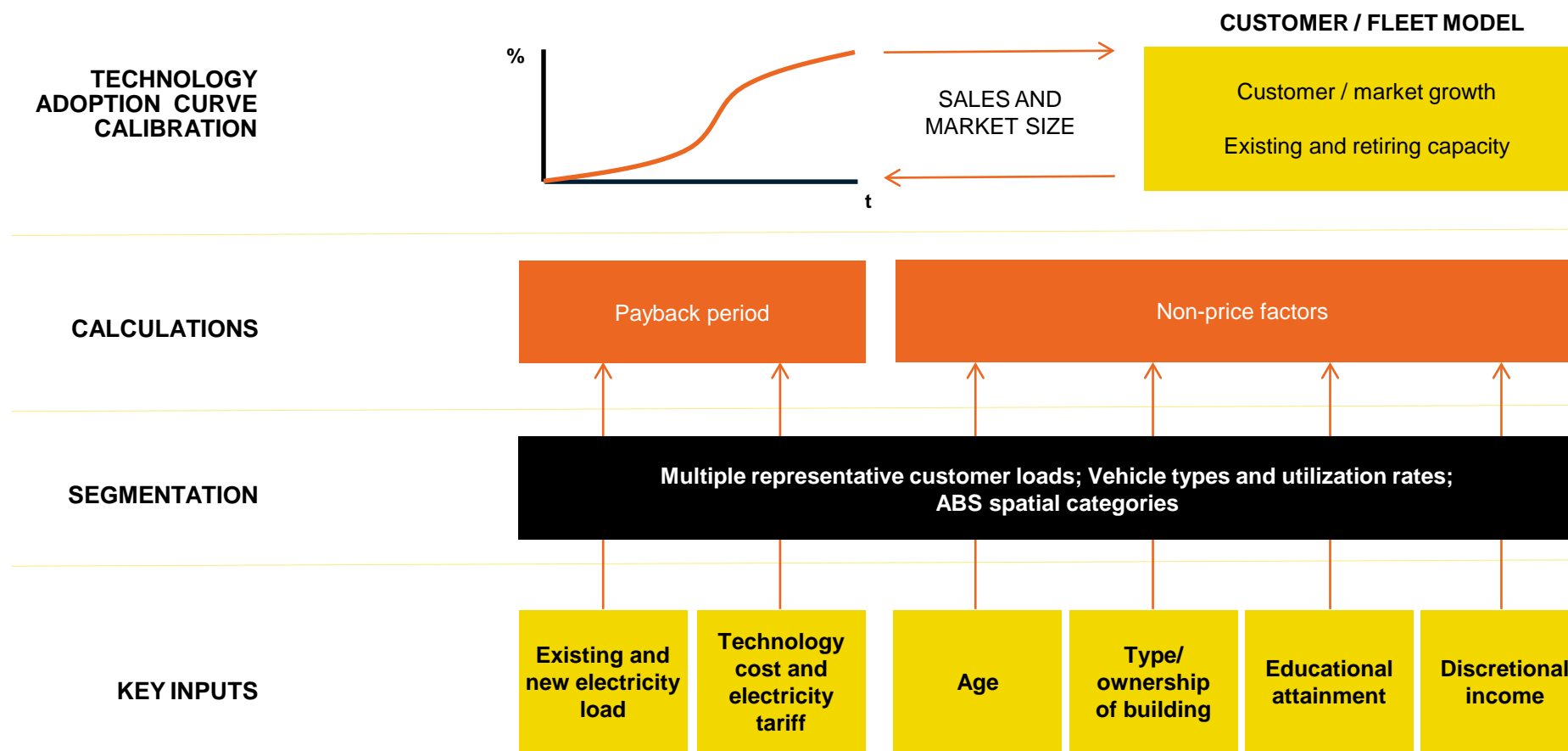
The level of rooftop solar and home battery installations is an external scenario assumption rather than an output of the modelling process. The methodology for CSIRO's projection of rooftop solar and battery projections is detailed in:

- + Graham, P.W., Havas L., Brinsmead, T. and Reedman, L. 2019, Projections for small scale embedded energy technologies, Report to AEMO, CSIRO, Australia.

In brief, the distributed energy projection methodology uses a consumer technology adoption curve which allows for the adoption rate to be expressed as a function of changes in the payback period for technology ownership and a market saturation rate as defined by various social, business model and infrastructure constraints.

In infrastructure constraints relate to issues such as access to roof space which can be more challenging in apartments, for example. New business models can potential overcome social or infrastructure constraints and expand the market. For example, the ability to easily share the outputs of solar amongst an apartment building might make it more likely that rooftop solar is installed. High adoption rates are associated with lower technology costs and the largest possible addressable market.

# Distributed energy and low emissions vehicle adoption model representation



## Build rate of renewables

In 2018 the renewable generation build rate inclusive of solar systems was 5 GW. This is similar to maximum build rate assumptions in the electricity modelling. However, these assumptions are generally not binding in the model.

That is, in the 30 years to 2050, to replace existing capacity and grow our electricity generation, 5 GW per year is more than sufficient.

As a simplified example, replacing 200TWh of generation capacity with renewables (assuming an average capacity factor across solar and renewables of 0.35) would require 65GW of renewables. At 5 GW per year that would take 13 years.

# Electricity sector policy assumptions

The modelling included three specific policy assumptions (2 states and 1 national):

- + Victoria and Queensland would implement policy that would achieve their stated goals of 50% renewables by 2030.
- + The national renewable energy target continued to 2030, including both its support for large scale renewables and rooftop solar (although after 2020 this does not drive major new investment.)

# Electricity sector transition drivers

The main driver for change after 2020 is the improved cost of renewables which, under the GenCost assumptions, leads to renewables being the preferred new investment, even without any specific carbon price signal. However, when a carbon price is included as a proxy for any potential future emissions constraint, this accelerates the retirement of coal capacity.

The model reflects that, under normal circumstances, coal capacity will reach the end of its technical life or choose to close down due to competitive pressures. In the absence of a strong policy driver accelerating retirement, the average lifespan of coal-fired generation in the modelling is 42 years, in line with the NEM average since 2012<sup>1</sup>.

<sup>1</sup> Jotzo, F., Mazouz, S. & Wiseman, J. 2018. *Coal transition in Australia: an overview of issues*. Australian National University: Canberra.

# Buildings

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# Buildings baseline data

- + The building types within Aus-TIMES have been grouped into archetypes which share common traits, such as building structure, hours of operation and heating/cooling loads.
- + Baseline energy data for these building types is derived from several sources:
  - + Commercial Buildings Baseline Study<sup>1</sup>
  - + Australian Energy Statistics<sup>2</sup>

Building archetype	Building type 1	Building type 2	Building type 3
Office	Law Court	Office	Public Building
Health care	Hospital	Aged care	
Retail	Retail	Supermarket	
Education	School	Tertiary	
House	Separate house	Townhouse	
Data centre	Data centre		
Apartment	Apartment		
Hotel	Hotel		

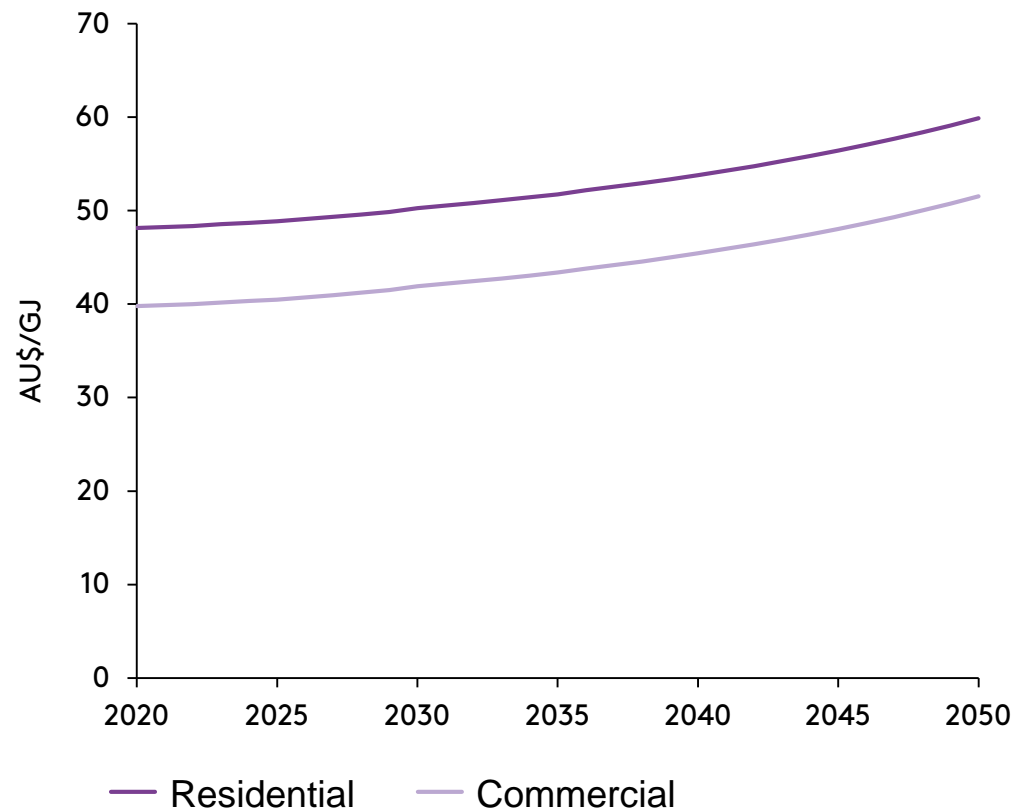
<sup>1</sup>Pitt & Sherry 2012. *Baseline Energy Consumption and Greenhouse Gas Emissions In Commercial Buildings in Australia*.

<http://www.industry.gov.au/ENERGY/ENERGYEFFICIENCY/NONRESIDENTIALBUILDINGS/Pages/CommercialBuildingsBaselineStudy.aspx>

<sup>2</sup>Department of the Environment and Energy 2018, *Australian Energy Statistics – Table F*.

# Buildings fuel cost data

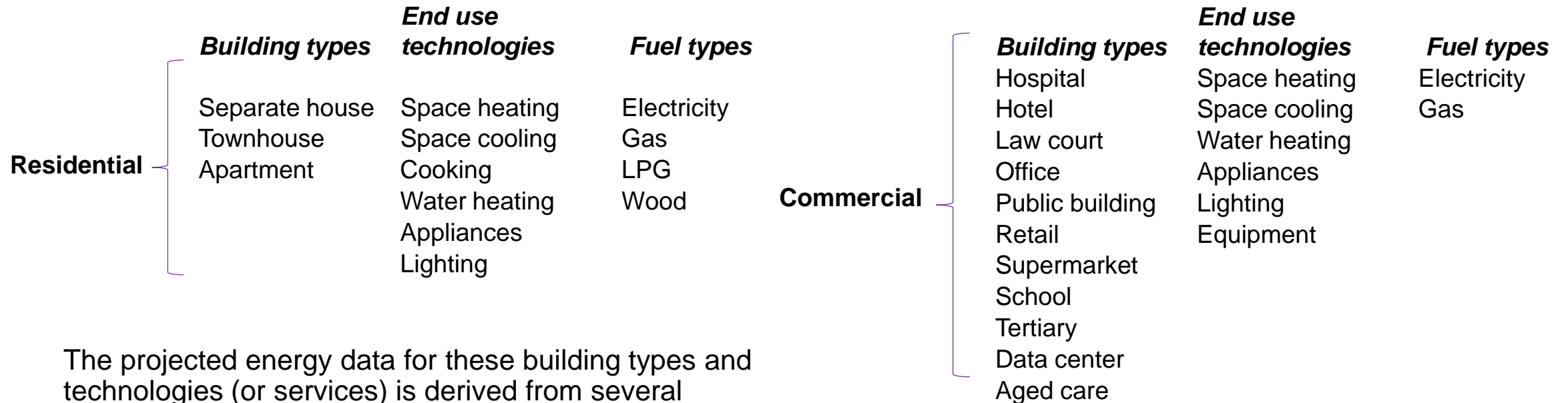
Average base gas price in buildings<sup>1</sup>



Alternative zero emissions fuels assumptions:

- + **Bioenergy** - Campey, T., Bruce, S., Yankos, T., Hayward, J.A., Graham, P.W., Reedman, L.J., Brinsmead, T.S., and Deverell, J. 2017, *Low Emissions Technology Roadmap*, Report No. EP167885, June, <https://www.csiro.au/en/Do-business/Futures/Reports/Low-Emissions-Technology-Roadmap>

# Demand in buildings is modelled by building type and technology



The projected energy data for these building types and technologies (or services) is derived from several sources:

- + Census data<sup>1</sup>
- + Population and dwellings projections<sup>2,3</sup>

<sup>1</sup>Australian Bureau of Statistics (ABS) 2016. *Census*.

<sup>2</sup>Australian Bureau of Statistics (ABS) 2010. *Projected number of households, Household type—2006 to 2031*,

*"Series II"*.

<sup>3</sup>Australian Bureau of Statistics (ABS) 2013. *3222.0 Population Projections Australia Series B*.

# An autonomous energy efficiency improvement rate applies to buildings

All buildings experience a business as usual efficiency improvement at no cost which is the autonomous energy efficiency improvement.

Autonomous energy efficiency improvement rate (% per annum)				
			Now - 2030	2031 - 2050
Residential	Existing Buildings	Lighting	1.76	0.43
		Hot water, appliances and HVAC - electricity	0.64	0.57
		Hot water and appliances - gas	0.82	0.66
		HVAC - gas	0.82	0.20
	New Builds	HVAC – electricity and gas	0.26	0.29
Commercial	Existing Buildings	Lighting	1.33	0.79
		Hot water, appliances and HVAC - electricity	0.20	0.10
		Hot water, appliances and HVAC – gas	0.13	0.10
	New Builds	Heating, cooling and lighting - electricity	0.58	0.24
		Heating, cooling and lighting - gas	0.76	0.24

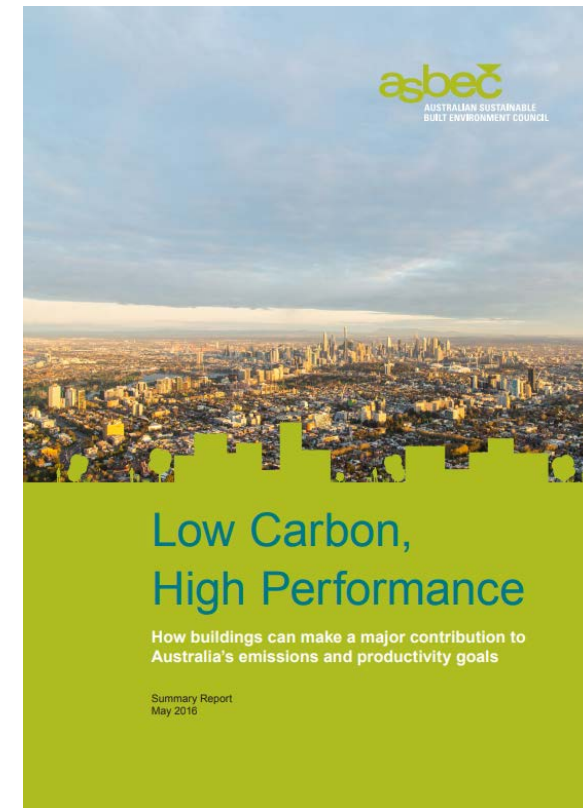
# Endogenous and exogenous abatement options for Buildings are available in the model

Additional 'best practice' energy efficiency and electrification options (**endogenous** abatement options) are available, at an additional incremental cost. The model will take up any available option that reduces overall system costs.

- + This is a calculation that involves the investment cost and period, as well as energy costs and carbon price costs with or without the investment in the abatement option
- + All assumptions on costs and savings are derived from the Low Carbon High Performance report

Scenario-specific disruptions are imposed as an **exogenous** decarbonisation option.

- + A methodological approach was taken to comprehensively identify and assess potential disruptions, following a comprehensive review of available options across all sectors
- + The disruptions, assumed impact and sources are detailed in this document



## Endogenous abatement options are available for residential building types and services (1/2)

Residential	Lighting	Hot water	Appliances	HVAC
Existing buildings	All lights replaced with LED or efficient fluorescent	Replacement of electric resistance hot water with heat pump. Replacement of gas with efficient instantaneous. Electrification of gas and LPG hot water system.	Upgrade to high efficiency appliances, assumed best on market technology today is standard in 2030 and best available technology is standard to 2050	Sealing areas of air leakage, weather stripping doors and windows, insulating attic and wall cavities. Replacement of air conditioners Electrification of space heaters and improved maintenance
New Builds	All new residential buildings are built to a 7.2 star standard from 2019 to 2030 based on assessment of cost effective mitigation. Assumes that energy efficiency improves with trends to 2050. Includes installing high efficiency windows and doors; increasing outer wall, roof, and basement ceiling insulation; mechanical ventilation with heat recovery, basic passive solar principles.			

# Endogenous abatement options are available for commercial building types and services (1/2)

Commercial	Lighting	Hot water	Appliances	HVAC
Existing Buildings	Lighting upgrades to most efficient LED and fluorescent technology equivalent to 5W/m <sup>2</sup> to 2030. Assumes a linear rate of improvement in performance of LED from 2030.	Replace standard gas water heaters with condensing gas or solar water heater; replace electric water heater with heat pump or solar water heater	Replacement by high-efficiency (best identified technology (Identified through E3 Equipment Energy Efficiency, 2016)	Replace HVAC with highest efficiency system, improve building insulation, improve HVAC control systems. Improved operation of HVAC through building management systems.
New Builds	All new commercial buildings are built to a NABERS 6 star equivalent on average from 2019 (where no rating exists, equivalent savings above BAU). New buildings assumed to be 20% more efficient on average for electricity and 28% more efficient.			

# Exogenous abatement options are available for buildings

## Innovation and accelerated uptake of best practice

- + A significant discrepancy exists between the energy efficiency of market leading buildings and the worst performing buildings. Significant emissions abatement potential exists in the development and implementation of innovative technology, as well as the improvement of efficiency of more poorly performing buildings. Due to this, the **exogenous** abatement options being considered include:
  - Innovative technologies with minimal market penetration
  - Well established technologies with significant penetration in market leading buildings
- + In the latter category, the technologies themselves are not disruptive, however the accelerated uptake of the technologies in parallel has the potential to change energy and emissions profiles in a way that could cause significant disruption
- + Both of these categories of technologies will need to be considered in order to accurately model the potential pathways to net zero emissions buildings



# Exogenous abatement options are available for buildings

## Technology uptake methodology

### Definitions

- + New builds: buildings constructed or rebuilt after the year in which a given technology becomes available
- + Rebuild rate: the percentage of buildings assumed to be knocked down and rebuilt in any given year (1%)
- + Retrofits: buildings which experience replacement of technology at end of life
- + Technology lifespan: number of years a technology will generally last (useful life)
- + Turnover rate: the inverse of the technology lifespan
- + Penetration rate: the sum of uptake rates of a technology of new buildings and retrofits for the given year.

### Penetration

- + Penetration rates for a given technology in a given year are calculated by building type by state
- + The year a technology becomes available can be changed, depending on its economic and technological readiness for a given scenario
- + For modelling purposes we have set three levels of implementation– so that we can model scenarios that include these technologies to various extents. More information on this is on the next slide.

# Key assumptions underpin the uptake of abatement options in buildings

## Technology uptake methodology

### New builds

- + On the “high” setting, uptake of the given technology will occur in 100% of new buildings and 100% of rebuilds
- + On the “medium” setting, uptake of the given technology will occur in 66.7% of new buildings and 66.7% of rebuilds
- + On the “low” setting, uptake of the given technology will occur in 33.3% of new buildings and 33.3% of rebuilds

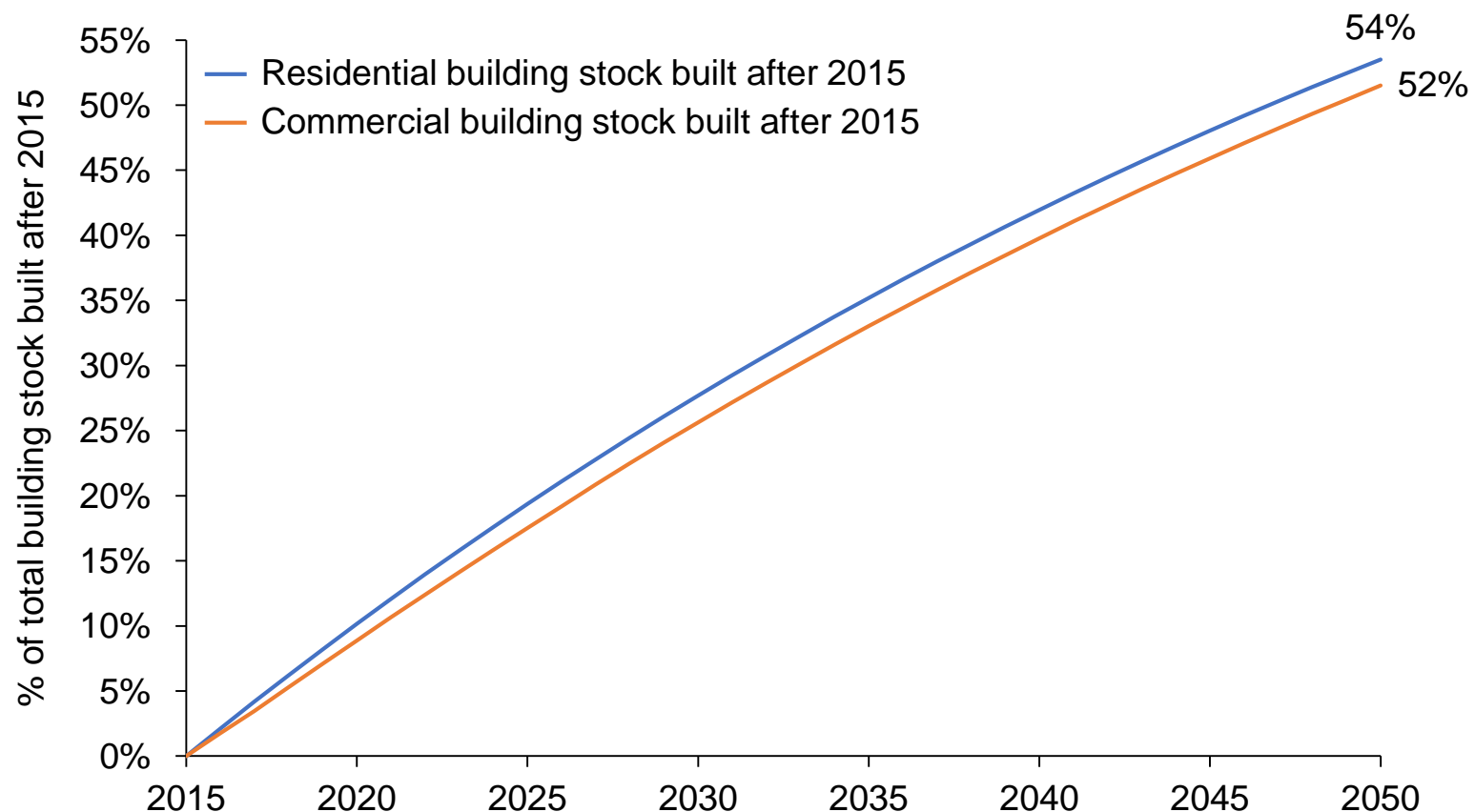
### Retrofits

- + On the “high” setting, uptake of the given technology will occur in 100% of buildings which require a change of the given technology that year (based on the turnover rate)
- + On the “medium” setting, uptake of the given technology will occur in 66.7% of buildings which require a change of the given technology that year (based on the turnover rate)
- + On the “low” setting, uptake of the given technology will occur in 33.3% of buildings which require a change of the given technology that year (based on the turnover rate)

# Key assumptions underpin the availability of abatement options in buildings

## New builds

- + New buildings are calculated by building type by state
- + Technologies which are part of building design are only available for new buildings
- + All other technologies are available for new buildings and retrofits



# Key assumptions underpin the availability of abatement options in buildings

## Retrofits

- + Retrofit technologies can be applied to both new buildings and retrofits
- + Retrofit technologies in existing buildings are assumed to be taken up when existing technology needs to be replaced
- + Technology turnover rates are different for commercial and residential buildings, as shown in the tables to the right
- + When a retrofit technology becomes available after a 'new building' is built, it can be installed after the building is equal to the age of the equipment lifetime
- + If the technology is unavailable in that year, or in the "off" setting, 0% of buildings will receive the technology

Commercial	Equipment lifetime	Turnover rate p.a.
Lighting	10	10.0%
HVAC	32	3.1%
Drinking hot water	15	6.7%
Appliances	10	10.0%

Residential	Equipment lifetime	Turnover rate p.a.
Lighting	10	10.0%
HVAC	15	6.7%
Drinking hot water	15	6.7%
Appliances	10	10.0%

# Buildings abatement options

Scenario-specific abatement solutions are imposed as exogenous abatement options

- + **Passive heating & cooling**

- + Stack ventilation
- + Trombe wall
- + Phase change material
- + Cool roof

- + **HVAC design**

- + Ground source heat pump
- + Variable air volume (VAV) system
- + Indirect evaporative cooling
- + Thermal energy storage (TES) systems

- + **Lighting controls**

- + Occupancy detection & zoning
- + Daylight dimming

- + **HVAC controls**

- + Proportional band economizer control
- + Water-side free cooling
- + HVAC equipment optimisation

- + **Precinct level technologies**

- + Cool Biz (behaviour change)

# Passive heating & cooling

## Stack ventilation

- + **Solution description:** A vertical ventilation column which can either induce natural or forced (fan assisted) ventilation, allowing cool outside air to replace the warm air inside which rises through the stack.
- + **Solution abatement impact and rationale:** This technology reduces the need for forced ventilation, reducing the electricity consumption and associated emissions while increasing productivity in buildings due to increased natural ventilation. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** This is a well understood design principle, more economically attractive in cooling dominated climates when considered early in the

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	3% reduction in cooling energy demand by 2050	5% reduction in cooling energy demand by 2050

design phase of new buildings. Mainstreaming of this technology in building design could occur as a result of developer or customer preference, regulatory requirements or inclusion in building rating systems such as Green Star. Passive cooling design elements make other HVAC efficiency measures less financially attractive as the demand for cooling is reduced.

### Key assumptions<sup>1</sup>:

- + 5% reduction in cooling energy demand for all **new buildings** of the following archetypes:
  - + Apartment
  - + Hotel
  - + Office
  - + Education

<sup>1</sup>Kolokotroni, M. & Aronis, A., 1999, 'Cooling-energy reduction in air-conditioned offices by using night ventilation', *Applied Energy*, Vol. 63, issue 4, pp 241-253.

# Passive heating & cooling

## Trombe wall

- + **Solution description:** Walls that are able to absorb and store solar radiation, to be used for space heating.
- + **Solution abatement impact and rationale:** This solution reduces heating demand for new apartments and houses. When applied in parallel with other heating energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** The inclusion of Trombe walls in building design is purely from an energy efficiency perspective, given this it is likely that their use could be driven by consumer demand for efficient housing.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	13% reduction in heating requirements by 2050	20% reduction in heating requirements by 2050

The technology is cost effective when taking into account the average lifetime of a residential home. This technology is more economically attractive in heating dominated climates.

### Key assumptions<sup>1</sup>:

- + 20% reduction in heating requirements for all **new buildings** of the following archetypes:
  - + Apartment
  - + House

<sup>1</sup>Torcellini, P. & Pless, S., 2004, 'Trombe Walls in Low-Energy Buildings: Practical Experiences', to be presented at the *World Renewable Energy Congress VIII and Expo*, 29 August – 3 September, United States, <https://www.nrel.gov/docs/fy04osti/36277.pdf>

# Passive heating & cooling

## Phase change material (PCM)

- + **Solution description:** Materials used in building construction that absorb excess heat, and radiate it back when cool.
- + **Solution abatement impact and rationale:** This solution reduces heating demand for new apartments and houses. When applied in parallel with other HVAC energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** They have been extensively researched for applications in passive housing design, however the implementation of this technology has been slow. PCM is likely to be mainstreamed by a consumer demand for efficient housing.

<sup>1</sup>Khudhair, A. M. & Farid, M. M., 2004, 'A review on energy conservation in building applications with thermal storage by latent heat using phase change materials', *Energy Conversion and Management*, Vol. 45, pp 263-275.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	10% reduction in heating requirements by 2050	15% reduction in heating requirements by 2050

## Key assumptions<sup>1</sup>:

- + 15% reduction in heating requirements for all **new buildings** of the following archetypes:
  - + Apartment
  - + House



# Passive heating & cooling

## Cool roof

- + **Solution description:** Roofs designed to reflect more sunlight and absorb less heat.
- + **Solution abatement impact and rationale:** This solution reduces cooling demand for new and existing houses, hospitals, hotels and schools. When applied in parallel with other cooling energy efficiency cooling measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** The relatively cheap cost makes it an attractive option for building owners who are looking for a low cost energy efficiency option, particularly in cooling dominated climates. If rooftop solar PV becomes widely prevalent cool roofs could be rendered obsolete.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	3-17% reduction in cooling energy use by 2050	5-25% reduction in cooling energy use by 2050

## Key assumptions<sup>1</sup>:

- + 25% reduction in cooling energy use for all **new buildings and retrofits** of the following archetypes:
  - + Houses
- + 5% reduction in cooling energy use for all **new buildings and retrofits** of the following archetypes:
  - + Health care
  - + Hotel
  - + Education

<sup>1</sup>The University of Melbourne, 2011, *Cool Roofs: City of Melbourne Research Report*, <https://www.melbourne.vic.gov.au/SiteCollectionDocuments/cool-roofs-report.pdf>

# Passive heating & cooling

## Motorised shading design

- + **Solution description:** Motorized shading design adds control functions to shading technologies such as blinds and curtains. This allows for directional control depending on the position of the sun, meaning that during summer heat gain can be mitigated and in winter it can be encouraged.
- + **Solution abatement impact and rationale:** Reduction in the amount of cooling required, reducing electricity demand and associated emissions. When applied in parallel with other cooling energy efficiency cooling measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** This is a low cost measure which is easy to implement in a new build or retrofit. It is more economically attractive in cooling dominated

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	2% reduction in cooling demand by 2050	3% reduction in cooling demand by 2050

climates. Uptake could likely be driven by demand from designers and owners alike for more energy efficient and convenient technology. This measure may inhibit the effectiveness of daylighting energy savings potential and the efficacy of daylight dimming, potentially rendering it obsolete.

## Key assumptions<sup>1</sup>:

- + 3% reduction in cooling demand for all **new buildings and retrofits** of the following archetypes:
  - + Hotel
  - + Office
  - + Education
  - + Health care
  - + Retail

<sup>1</sup>Tzempelikos, A. & Athienitis, A. K., 2007, 'The impact of shading design and control on building cooling and lighting demand', *Solar Energy*, Vol. 81, issue 3, pp 369-382.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	50% reduction in heating and cooling energy use by 2050	75% reduction in heating and cooling energy use by 2050

# Heating, ventilation & air conditioning (HVAC) design

## Ground source heat pump

- + **Solution description:** Heat pump design that relies on the ground as a heat sink/source.
- + **Solution abatement impact and rationale:** This solution reduces heating and cooling demand for new houses. When applied in parallel with other HVAC energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** They are likely to become standard due to consumer demand for energy efficient housing, particularly in heating dominated climates such as North America and Europe. Uptake in Australia may be slow due to the more temperate climate in most of the country.

### Key assumptions<sup>1</sup>:

- + 75% reduction in heating and cooling energy use for all **new buildings** of the following archetypes:
  - + House

<sup>1</sup>Omer, A. M., 2008, 'Ground-source heat pumps systems and applications', *Renewable and Sustainable Energy Reviews*, Vol. 12, issue 2, pp 344-371.

# Heating, ventilation & air conditioning (HVAC) design

## Variable air volume (VAV) system

- + **Solution description:** HVAC systems that vary air flow volume, enabling more precise temperature control and greater efficiency.
- + **Solution abatement impact and rationale:** This solution reduces heating and cooling demand for new hospitals, hotels, offices, shops and schools. They deliver significant energy savings compared to their constant air volume predecessors. When applied in parallel with other HVAC energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** There is significant opportunity to retrofit buildings with VAV systems, particularly in parallel with improved HVAC controls which can take advantage of the flexibility of the system, maximising

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	16% reduction in heating and cooling energy use by 2050	24% reduction in heating and cooling energy use by 2050

the energy efficiency potential. The shift to VAV systems is primarily driven by the attractive cost savings and short payback periods of the technology.

### Key assumptions<sup>1</sup>:

- + 24% reduction in heating and cooling energy use for all **new buildings** of the following archetypes:
  - + Health care
  - + Hotel
  - + Office
  - + Retail
  - + Education

<sup>1</sup>Yao, Y., Lian, Z., Liu, W., Hou, Z. & Wu, M., 2007, 'Evaluation program for the energy-saving of variable-air-volume systems', *Energy and Buildings*, Vol. 39, issue 5, pp 558-568.

# Heating, ventilation & air conditioning (HVAC) design

## Chilled beams

- + **Solution description:** Chilled water is pumped through a beam (heat exchanger) which generally sit near the ceiling, cooling the air in the space and promoting air circulation due to the placement of the beams.
- + **Solution abatement impact and rationale:** This technology is more efficient than pumping cool air for cooling, meaning energy is saved on fans and chillers, leading to a reduction in electricity consumption and the associated emissions. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** This technology is more economically attractive in cooling dominated climates.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	5% reduction in cooling energy use by 2050	8% reduction in cooling energy use by 2050

Uptake could likely be driven by demand from public and commercial tenants for highly energy efficiency buildings. A barrier could be the cost associated with ongoing tuning, which can be required to ensure that cooling does not reduce the air temperature to the dew point and cause condensation.

## Key assumptions<sup>1</sup>:

- + 8% reduction in cooling energy use for all **new buildings** of the following archetypes:
  - + Health care
  - + Hotel
  - + Office
  - + Retail
  - + Education

<sup>1</sup>Stetiu, C., 1999, 'Energy and peak power savings potential of radiant cooling systems in US commercial buildings', *Energy and Buildings*, Vol. 30, issue 2, pp 127-138.

# Heating, ventilation & air conditioning (HVAC) design

## Indirect evaporative cooling (IEC)

- + **Solution description:** High-efficiency evaporative cooling systems.
- + **Solution abatement impact and rationale:** This solution reduces cooling demand for new hospitals, hotels, offices, shops and schools. They are a cost effective option for building designers to reduce reliance on chillers, improving the resilience of the plant while reducing upfront and operational costs. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** IECs are likely to be adopted due to a preference for cheaper mechanical equipment during the design phase. IECs require adequate roof

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	5% reduction in cooling energy use by 2050	8% reduction in cooling energy use by 2050

space so they may not be suitable for all buildings and may inhibit the uptake of other technologies, such as rooftop PV and cool roofs.

### Key assumptions<sup>1</sup>:

- + 8% reduction in cooling energy use for all **new buildings** of the following archetypes:
  - + Health care
  - + Hotel
  - + Office
  - + Retail
  - + Education

<sup>1</sup>Maheshwari, G. P., Al-Ragom, F. & Suri, R. K., 2001, 'Energy-saving potential of an indirect evaporative coolers', *Applied Energy*, Vol. 69, issue 1, pp 69-76.

# Heating, ventilation & air conditioning (HVAC) design

## Thermal energy storage system

- + **Solution description:** Systems that store excess heat (or cool), for later use in building heating/cooling.
- + **Solution abatement impact and rationale:** This solution reduces heating and cooling demand for new hospitals, hotels, offices and schools. When applied in parallel with other HVAC energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** Energy conscious building designers are likely to implement this technology, driven by pressure for more efficient buildings as electricity and peak demand costs continue to rise.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	13% reduction in cooling energy use by 2050	19% reduction in cooling energy use by 2050

Currently the technology requires an incentive to be within the financial payback cut offs of most building owners, however rising energy prices may change this in the near future.

### Key assumptions<sup>1</sup>:

- + 19% reduction in cooling energy use for all **new buildings** of the following archetypes:
  - + Health care
  - + Hotel
  - + Office
  - + Education

<sup>1</sup>Dincer, I., 2002, On thermal energy storage systems and applications in buildings', *Energy and Buildings*, Vol. 34, issue 4, pp 377-388.

# Lighting controls

## Occupancy control and zoning

- + **Solution description:** Sensor-based systems to switch off lighting when areas of a building are unoccupied.
- + **Solution abatement impact and rationale:** This solution reduces lighting demand for new and existing hotels, hospitals, offices and schools. Reduced demand for lighting will reduce the internal heat gain, reducing the demand for cooling in summer but increasing the demand for heating in summer. When applied in parallel with other lighting energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** They are significantly cheaper if installed in a new build, however can also be installed

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	7% reduction in lighting energy use by 2050	13% reduction in lighting energy use by 2050

cost effectively as part of lighting retrofit packages. The uptake is likely to be driven by energy conscious building owners.

### Key assumptions<sup>1</sup>:

- + 13% reduction in lighting energy use for all **new buildings and retrofits** of the following archetypes:
  - + Hotel
  - + Health care
  - + Office
  - + Education

<sup>1</sup>Von Neida, B., Maniccia, D. & Tweed, A., 2001, 'An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems', *Journal of the Illuminating Engineering Society*, Vol. 30, issue 2, pp 111-125.



Exogenous scenario setting

# Lighting controls

2C Deploy	2C Innovate	1.5C All-in
N/A	13% reduction in lighting energy use in all offices by 2050	20% reduction in lighting energy use in all offices by 2050

## Daylight dimming

- + **Solution description:** Sensor-based systems to dim lights to an appropriate level in the daytime.
- + **Solution abatement impact and rationale:** This solution is an inexpensive and effective strategy for reducing lighting demand while maintaining occupant comfort in new and existing offices. When applied in parallel with other lighting energy efficiency measures, the combined impact is less than the sum of the total. Reduced demand for lighting will reduce the internal heat gain, reducing the demand for cooling in summer but increasing the demand for heating in summer.
- + **Barriers/enablers:** This strategy is suitable for implementation in a new build or during a lighting upgrade and could likely be driven by building managers or BMS operators. If motorized shading design is implemented it would reduce the efficacy of this energy efficiency measure, potentially rendering it obsolete.

**Key assumptions<sup>1</sup>:**

- + 20% reduction in lighting energy use for all **new buildings and retrofits** of the following archetypes:
  - Office

<sup>1</sup> Doulos, L., Toplis, F. V. & Tsangrassoulis, A., 2008, 'Quantifying energy savings in daylight responsive systems: The role of dimming electronic ballasts', *Energy and Buildings*, Vol. 40, issue 1, pp 36-50.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	3% reduction in cooling energy use by 2050	4% reduction in cooling energy use by 2050

# Heating, ventilation & air conditioning (HVAC) controls

## Proportional band economizer control

- + **Solution description:** Energy input optimisation controls for HVAC systems through the installation of a controller to enable digital control, rather than analog, on the economiser vent.
- + **Solution abatement impact and rationale:** This technology can be applied to the HVAC controls system of any modern buildings such as new and existing hotels, hospitals, offices, shops, schools and data centres to reduce cooling energy use. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** The uptake is likely to be driven by BMS controls engineers.

### Key assumptions<sup>1</sup>:

- + 4% reduction in cooling energy use for all **new buildings and retrofits** of the following archetypes:
  - Hotel
  - Health care
  - Office
  - Retail
  - Education
  - Data centre

<sup>1</sup>Huang, W. Z., Zaheeruddin, M. & Cho, S. H., 2006, 'Dynamic simulation of energy management control functions for HVAC systems in buildings', *Energy Conversion and Management*, Vol. 47, pp 926-943.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	13% reduction in cooling energy use in all data centres by 2050	20% reduction in cooling energy use in all data centres by 2050

# Heating, ventilation & air conditioning (HVAC) controls

## Water side chiller-free cooling

- + **Solution description:** Cooling systems supplemented by air-chilled water. It is a climate dependent strategy which is effective in buildings with a consistent cooling load, particularly at night when the outside air is cooler, making it ideal for data centres which generally have a constant internal heat gain from equipment as the major cooling requirement.
- + **Solution abatement impact and rationale:** This solution reduces cooling energy use for new and existing data centres. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.

- + **Barriers/enablers:** This control method is likely to be adopted by cost conscious operators of data centres.

### Key assumptions<sup>1</sup>:

- + 20% reduction in cooling energy use for all **new buildings and retrofits** of the following archetype:
  - Data centre

<sup>1</sup>Greenberg, S., Mills, E., Tschudi, B. & Rumsey, P., 2006, 'Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers', *Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings*.

# Heating, ventilation & air conditioning (HVAC) controls

## HVAC optimisation

- + **Solution description:** General improvements to HVAC use regimes including better thermostats, timing controls, etc.
- + **Solution abatement impact and rationale:** This reduces cooling energy use for new and existing hospitals, hotels, offices, shops, schools and data centres. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.
- + **Barriers/enablers:** Although HVAC optimisation has been studied for some time, it is only starting to be mainstreamed recently due to rising energy prices. Optimisation is generally considered in retrofits as a

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	21% reduction in cooling energy use by 2050	32% reduction in cooling energy use by 2050

cost effective energy savings measure, either by the buildings managers or clients.

### Key assumptions<sup>1</sup>:

- + 32% reduction in cooling energy use for all **new buildings and retrofits** of the following archetypes:
  - Health care
  - Hotel
  - Office
  - Retail
  - Education
  - Data centre

<sup>1</sup>West, S., Ward, J. & Wall, J., 2014, 'Trial results from a model predictive control and optimisation system for commercial building HVAC', *Energy and Buildings*, Vol. 72, pp 271-279.

# Precinct level technologies

Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	15% reduction in cooling energy use in all offices by 2050	23% reduction in cooling energy use in all offices by 2050

## Cool Biz (behaviour change)

- + **Solution description:** Cool Biz is a Japanese campaign which encourages employees to limit unnecessary air conditioning use to reduce electricity consumption. It is done by increasing the temperature of office buildings in summer.
- + **Solution abatement impact and rationale:** This reduces cooling demand for new and existing offices. This change does not require the installation of new technology, so it can be implemented in all new and existing buildings immediately. When applied in parallel with other cooling energy efficiency measures, the combined impact is less than the sum of the total.

- + **Barriers/enablers:** This social change requires behavior change which would likely result from an advertising campaign.

### Key assumptions<sup>1</sup>:

- + 23% reduction in cooling energy use for all **buildings** of the following archetypes:
  - Office

<sup>1</sup>Manning, M. M., Swinton, M. C., Szadkowski, F., Gusdorf, J. & Ruest, K., 2007, 'The effects of thermostat set-back and setup on seasonal energy consumption, surface temperatures and recovery times at the CCHT Twin House Facility', *ASHRAE Transactions*, Vol. 113, pp 1-12.

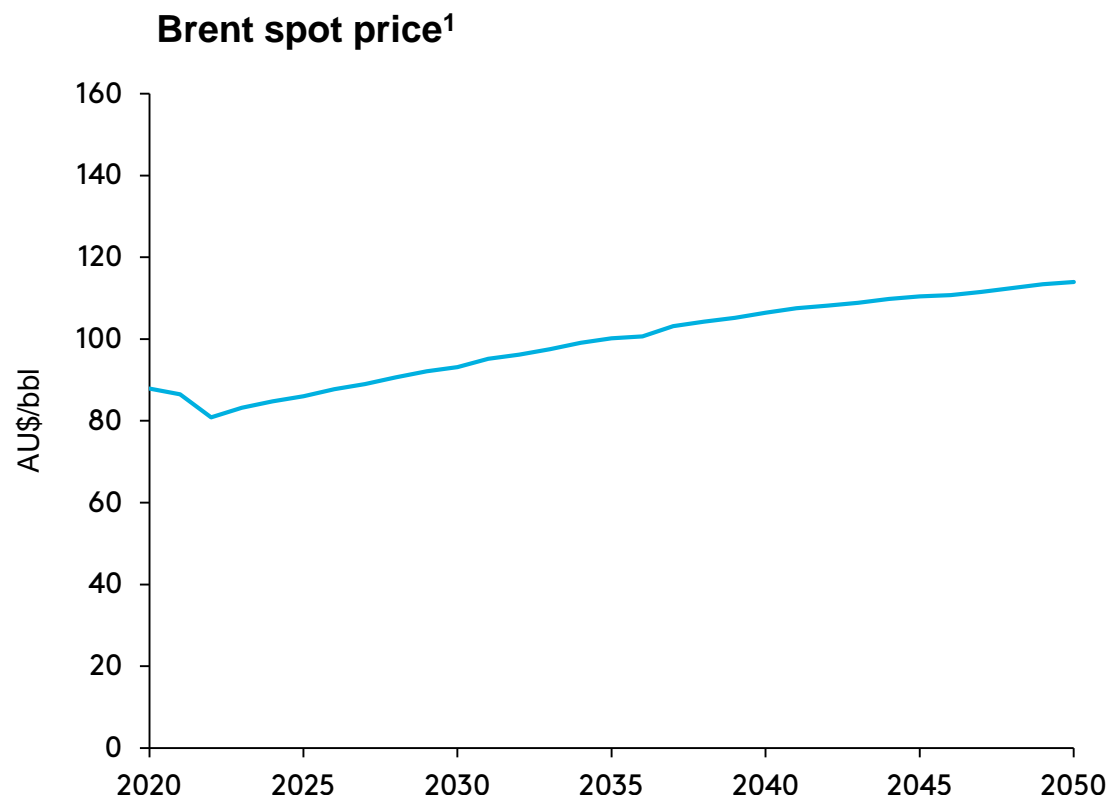
# Transport

# Transport baseline data

Baseline activity and energy use data was derived from multiple sources

- + Vehicle stock, scrapping rate: *ABS Catalogue No. 9309.0 - Motor Vehicle Census, Australia, 31 Jan 2016* (ABS, 2016)
- + Average vehicle kilometres travelled: *ABS Catalogue No. 9208.0 - Survey of Motor Vehicle Use, Australia, 12 months ended 30 June 2016* (ABS, 2017)
- + Vehicle costs (capital, maintenance): Graham, P., Havas, L., Brinsmead, T., Reedman, L. *Projections for small scale embedded energy technologies*. Report for the Australian Energy Market Operator (2019)
- + Registration, insurance costs: State/territory government websites
- + Vehicle fuel efficiency: ABS, BITRE, NTC *Carbon dioxide emissions intensity of new light vehicles 2016*, National Transport Commission (and updates)
- + Retail fuel price components: Australian Institute of Petroleum
- + Oil price projection: International Energy Agency *World Energy Outlook*
- + Fuel excise rates: Australian Taxation Office
- + Biofuel mandates: NSW - *Biofuel (Ethanol Content) Act 2007*, historical take-up of ethanol and biodiesel is from the *Office of Fair Trading*. QLD - *The Liquid Fuel Supply (Ethanol and Other Biofuels Mandate) Amendment Act 2015*

# Transport fuel costs data



Alternative zero emissions fuels assumptions:

- + **Hydrogen** – Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D. and Hartley, P. 2018, *National Hydrogen Roadmap*. CSIRO, Australia
- + **Bioenergy** - Campey, T., Bruce, S., Yankos, T., Hayward, J.A., Graham, P.W., Reedman, L.J., Brinsmead, T.S., and Deverell, J. 2017, *Low Emissions Technology Roadmap*, Report No. EP167885, June, <https://www.csiro.au/en/Do-business/Futures/Reports/Low-Emissions-Technology-Roadmap>

<sup>1</sup> Based on International Energy Agency's *World Energy Outlook 2018* (converted to AUD)



# Transport activity assumptions

Growth in transport activity was estimated drawing on historical trends and scenario drivers

Historically, transport activity is strongly linked to either GDP or population growth for freight and passenger demand respectively. GDP and population assumptions do not vary between scenarios. This tends to lead to common transport activity projections across scenarios.

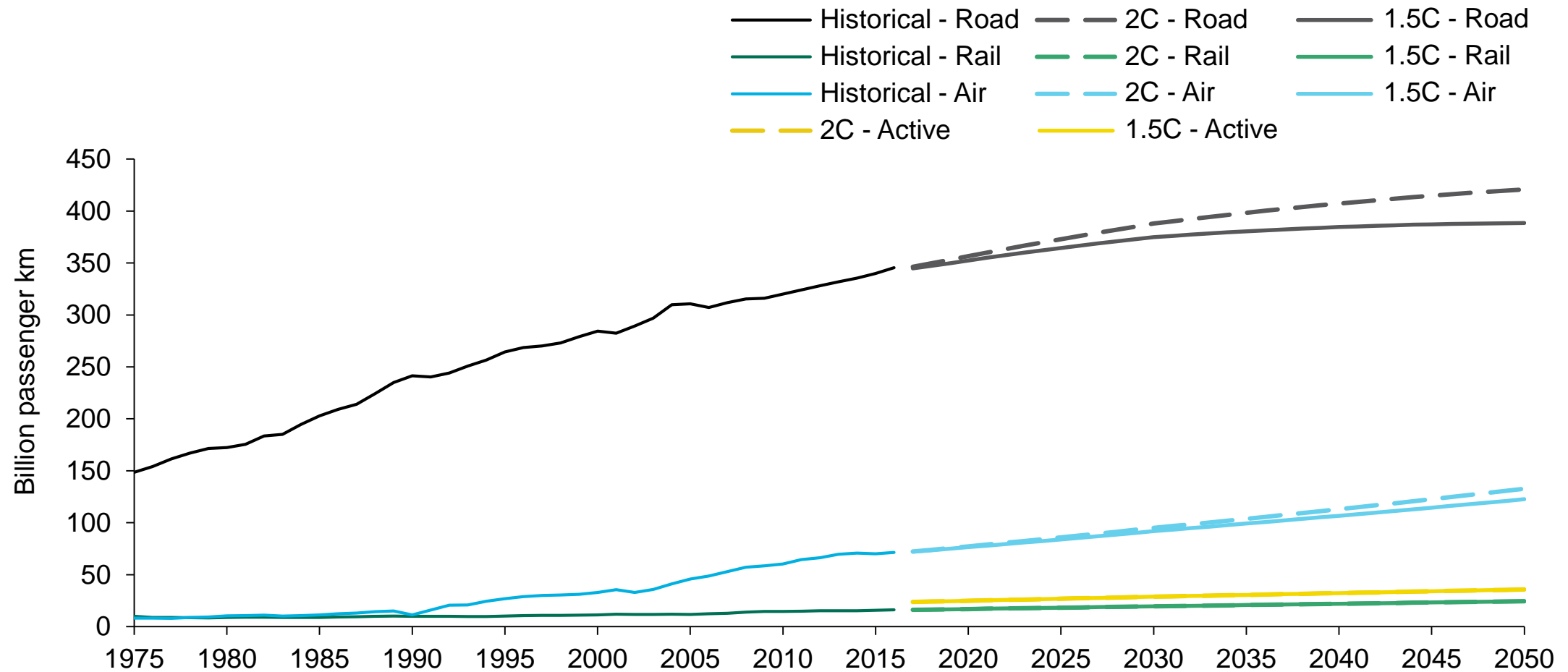
## Freight

- + Assumptions made about road, rail, aviation and shipping shares

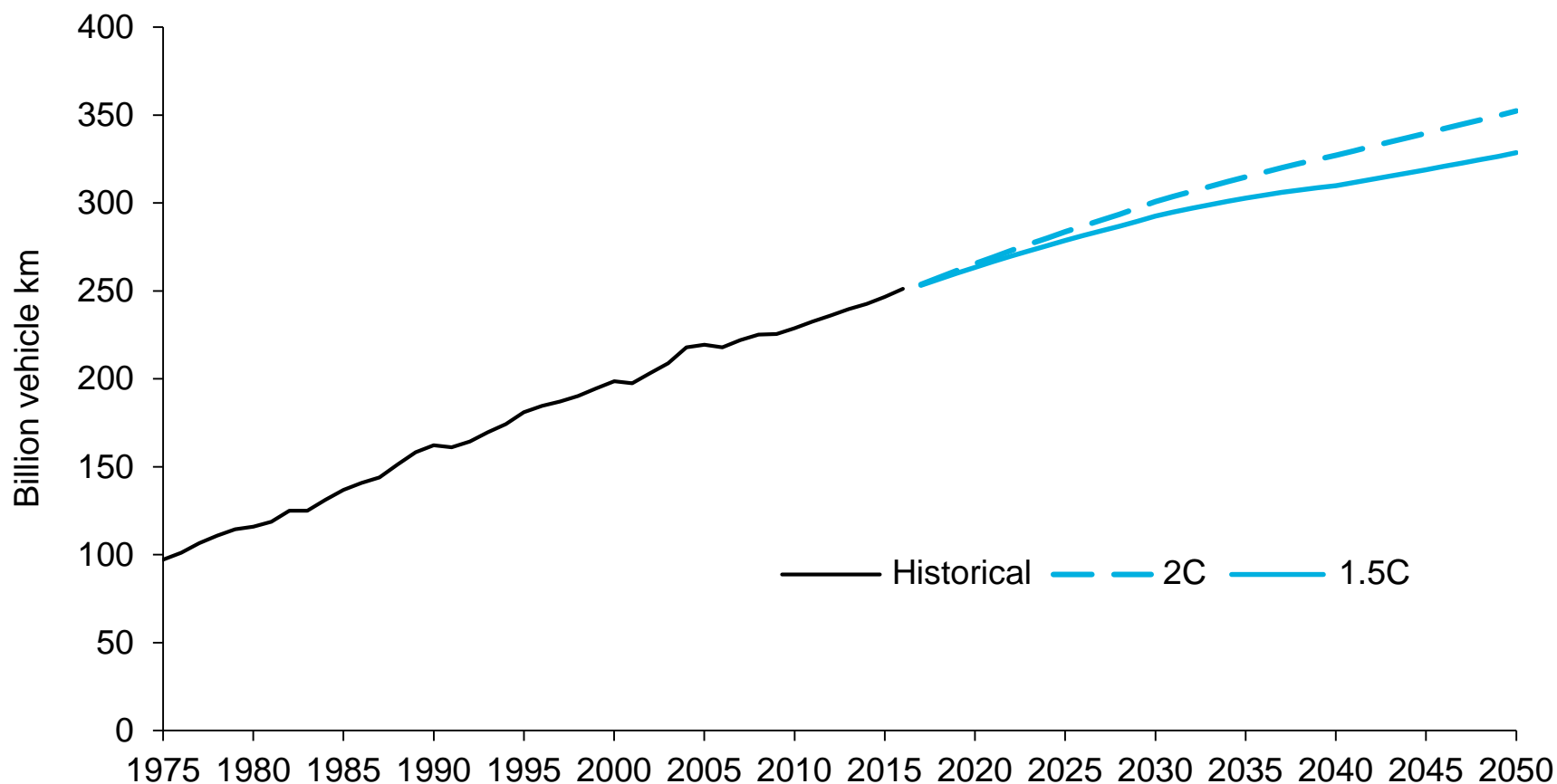
## Passenger

- + Assumptions made about road, aviation, rail and active shares

# Passenger kilometres all transport modes



# Road transport demand (passenger and freight)



# Transport abatement options

A range of abatement options were applied to road and non-road transport modes by scenario

- + **Alternative vehicles**

- + Hybrid and efficient ICEs
- + Battery electric vehicles
- + Fuel cell electric vehicles
- + Autonomous vehicles

- + **Mode shifting**

- + Passenger – Road-Active-Air
- + Freight – Road-Rail-Shipping-Air
- + Telecommute and Ecommerce impact the scale of passenger and freight tasks

- + **Low emission fuels**

- + Biofuels
- + Hydrogen

- + **Efficiency improvements\*:**

- + International aviation
- + Domestic aviation
- + Rail
- + Shipping

\* Note: Road transport emissions are most materially impacted by alternative vehicles, mode shifting and low emissions fuels. Efficiency assumptions are not presented for these modes.

# Alternative vehicles

## Battery electric vehicles

- + **Solution description:** Vehicles that use one or more electric motors for propulsion powered by electricity from self-contained rechargeable batteries. In addition to charging from the grid, they are charged in part by regenerative braking. As the grid decarbonises, they have the potential to be carbon neutral.
- + **Solution abatement impact and rationale:** Abatement from increased adoption of electric vehicles is enabled by decarbonisation of the electricity grid but reduced by any reductions in road share of transport.
- + **Barriers/enablers:** Availability and cost of electric vehicles are important factors for rapid adoption. Policy action can assist the transition, encouraging rapid uptake through investment, incentives, regulation and charging infrastructure.

<sup>1</sup>Lutsey, N & Nicholas, M, 2019, *Update on electric vehicle costs in the United States through 2030*, <https://theicct.org/publications/update-US-2030-electric-vehicle-cost>

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
90% share of light vehicles and 40% share of heavy vehicles by 2050	90% share of light vehicles and 60% share of heavy vehicles by 2050	90% share of light vehicles and 60% share of heavy vehicles by 2050

## Key assumptions<sup>1,2</sup>:

- + Electric vehicle upfront cost parity is widely believed to occur around 2025, even under 'BAU' conditions.
- + However such forecasts are generally for short range electric vehicles and are in the context of markets where internal combustion engine (ICE) vehicle cost are increasing due to fuel efficiency or greenhouse gas emission standards.
- + Australian ICE vehicle costs have been falling since the mid-1990s owing to tariff reform and no equivalent standards.
- + The uptake results in a 90% share of light vehicles and a 60% share of heavy vehicles being battery electric vehicle by 2050.

<sup>2</sup>Australian Bureau of Statistics (ABS) 2019, *6401.0 Consumer Price Index Australia*,

# Alternative vehicles

## Fuel cell electric vehicles

- + **Solution description:** A type of electric vehicle that uses a fuel cell, instead of a battery, to power its on-board electric motor. Fuel cells generate electricity using oxygen from the air and compressed hydrogen. As the hydrogen supply chains decarbonise, they have the potential to be carbon neutral.
- + **Solution abatement impact and rationale:** Abatement from increased adoption of fuel cell vehicles is enabled by hydrogen fuel supply chains supporting abatement elsewhere in the economy but reduced by any reductions in road share of transport.
- + **Barriers/enablers:** The establishment of a renewable-based hydrogen supply chain to decarbonise various parts of the Australia economy, could enable imported fuel cell vehicles to establish a foothold alongside electric vehicles as part of the road fleet.

<sup>1</sup>Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D. & Hartley, P. 2018, *National hydrogen roadmap: pathways to an economically sustainable hydrogen industry in*

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
5% share of light vehicles and 10% share of heavy vehicles by 2050	5% share of light vehicles and 20% share of heavy vehicles by 2050	5% share of light vehicles and 20% share of heavy vehicles by 2050

## Key assumptions<sup>1</sup>:

- + Fuel cell vehicle costs are declining but lag behind batteries.
- + The world is gearing up for investment in hydrogen supply chains owing to low costs renewables emerging as primary energy source.
- + Fuel cell vehicles will still include a cost premium over ICE but compete with long range EVs in the long run.
- + The uptake results in a 5% share of light vehicles and a 20% share of heavy vehicles being fuel cell electric vehicle by 2050.

Australia, CSIRO.

# Alternative vehicles

Cost assumptions:  
2C Deploy and 2C Innovate  
scenarios, \$'000

	2020	2025	2030	2035	2040	2045	2050
<b>Internal combustion engine</b>							
Light/small car - petrol	15	15	15	15	15	15	15
Medium car - petrol	25	25	25	25	25	25	25
Large/heavy car - petrol	41	41	41	41	41	41	41
Rigid truck - diesel	61	61	61	61	61	61	61
Articulated truck - diesel	300	300	300	300	300	300	300
Bus - diesel	180	180	180	180	180	180	180
<b>Electric vehicle short range</b>							
Light/small	27	21	15	15	15	15	15
Medium	47	36	25	25	25	25	25
Large/heavy	65	53	41	41	41	41	41
Rigid truck	104	92	80	77	75	73	72
Bus	269	246	223	215	211	209	206
<b>Electric vehicle long range</b>							
Light/small	39	28	20	20	20	20	20
Medium	59	42	30	30	30	30	30
Large/heavy	80	61	46	46	46	46	46
Rigid truck	143	125	109	104	102	99	96
Articulated truck	N.A.	694	535	511	502	485	472
Bus	310	279	252	243	240	235	231
<b>Plug-in hybrid electric vehicle</b>							
Medium car - petrol	37	35	33	33	33	33	33
Large/heavy car - petrol	58	53	49	49	49	49	49
Rigid truck – diesel	N.A.	464	81	81	81	81	81
Articulated truck - diesel	N.A.	648	396	396	396	396	396
<b>Fuel cell vehicle</b>							
Light/small	46	42	38	34	30	27	25
Medium	57	53	49	45	41	38	36
Large/heavy	93	87	80	73	67	63	59
Rigid truck	135	127	119	108	100	94	88
Articulated truck	665	626	586	532	493	461	434
Bus	399	376	352	319	296	277	260

# Alternative vehicles

Cost assumptions:  
1.5C All-in scenario<sup>1</sup>, \$'000

	2020	2025	2030	2035	2040	2045	2050
<b>Internal combustion engine</b>							
Light/small car - petrol	15	15	15	15	15	15	15
Medium car - petrol	25	25	25	25	25	25	25
Large/heavy car - petrol	41	41	41	41	41	41	41
Rigid truck - diesel	61	61	61	61	61	61	61
Articulated truck - diesel	300	300	300	300	300	300	300
Bus - diesel	180	180	180	180	180	180	180
<b>Electric vehicle short range</b>							
Light/small	27	15	15	15	15	15	15
Medium	40	25	25	25	25	25	25
Large/heavy	61	41	41	41	41	41	41
Rigid truck	99	80	77	75	73	72	71
Bus	260	223	215	211	209	206	204
<b>Electric vehicle long range</b>							
Light/small	36	20	20	20	20	20	20
Medium	49	30	30	30	30	30	30
Large/heavy	70	46	46	46	46	46	46
Rigid truck	133	109	104	102	99	96	94
Articulated truck	N.A.	535	511	502	485	472	462
Bus	300	252	243	240	235	231	228
<b>Plug-in hybrid electric vehicle</b>							
Medium car - petrol	36	33	33	33	33	33	33
Large/heavy car- petrol	56	49	49	49	49	49	49
Rigid truck – diesel	N.A.	81	81	81	81	81	81
Articulated truck - diesel	N.A.	396	396	396	396	396	396
<b>Fuel cell vehicle</b>							
Light/small	45	38	34	30	27	25	23
Medium	56	49	45	41	38	36	34
Large/heavy	91	80	73	67	63	59	56
Rigid truck	135	119	108	100	94	88	83
Articulated truck	665	586	532	493	461	434	408
Bus	399	352	319	296	277	260	245

<sup>1</sup> As CSIRO transport models used 2015 as base year, inputs for 2020 in this scenario vary slightly from the 2C scenarios on previous slide



# Alternative vehicles

## Autonomous vehicles

- + **Solution description:** Vehicles capable of sensing its environment and operating safely without human involvement.
- + **Solution abatement impact and rationale:** Autonomous vehicles are likely to be electric, any usage will have limited emissions impact so long as they are powered by renewable electricity. Where adopted they accelerate the deployment of electric vehicles and change our view of the need for private vehicle ownership. The reduced cost of travel that is attainable through the combination of autonomous electric vehicles and ride sharing induces additional passenger road kilometers. This offsets some of the other efforts to reduce passenger demand.
- + **Barriers/enablers:** Given the attractive financial incentives, the main barrier is whether the technology can deliver a safe,

<sup>1</sup>Boston Consulting Group (BCG), 2015, *Revolution in the driver's seat: The road to autonomous vehicles*, [https://image-src.bcg.com/Images/BCG-Revolution-in-the-Drivers-Seat-Apr-2015\\_tcm9-64351.pdf](https://image-src.bcg.com/Images/BCG-Revolution-in-the-Drivers-Seat-Apr-2015_tcm9-64351.pdf)

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
20% share of heavy and light private vehicles, and 10% share of light ridesharing vehicles by 2050	20% share of heavy and light private vehicles, and light ridesharing vehicles by 2050	20% share of heavy and light private vehicles, and light ridesharing vehicles by 2050

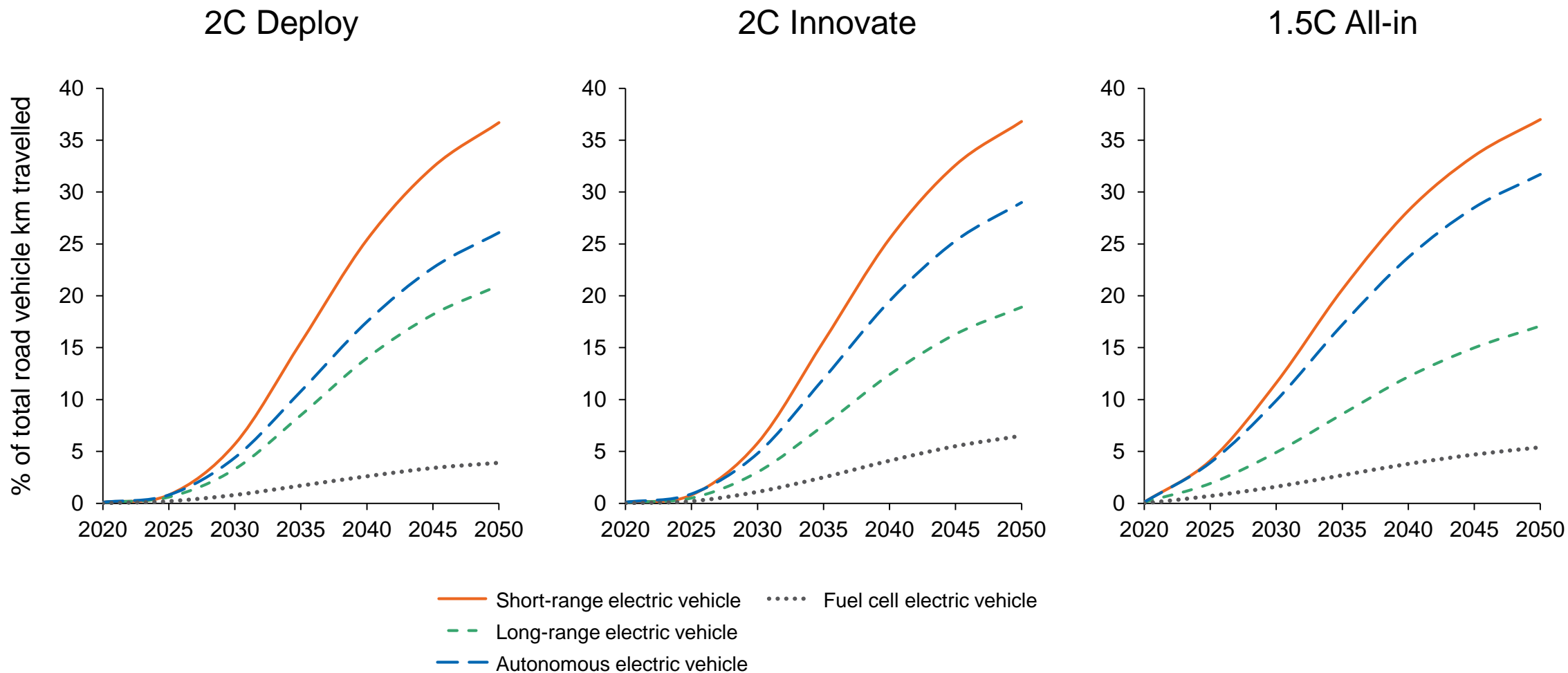
equivalent (or better) level of service.

### Key assumptions<sup>1,2</sup>:

- + Passenger vehicle drivers who value their time at around \$20/hr would be willing to pay a premium of more than \$10,000 to buy a self-driving vehicle.
- + Truck fleet owners could offset the annual cost of wages to pay for self-driving trucks.
- + Ridesharing provides an opportunity to reduce vehicle ownership and spread costs (potentially inducing more travel)
- + The uptake results in a 20% share of heavy and light private vehicles, and light ridesharing vehicles being autonomous by 2050.

<sup>2</sup>KPMG, 2018, *Vehicles advice – financial analysis, Infrastructure Victoria Final Report*, [https://www.infrastructurevictoria.com.au/wp-content/uploads/2019/04/Vehicles\\_Advice\\_-\\_Financial\\_Analysis.pdf](https://www.infrastructurevictoria.com.au/wp-content/uploads/2019/04/Vehicles_Advice_-_Financial_Analysis.pdf)

# Alternative vehicle road share (light and heavy vehicles)



# Mode shifting

## Passenger transport

- + **Solution description:** Passenger shifting transport mode from private road vehicles to passenger rail services and active transport.
- + **Solution abatement impact and rationale:** Abatement from this solution is enabled by reduction of road vehicle demand and the overall kilometres travelled, and the decarbonisation of electricity supplied to power Australia's passenger rail services. The decreased share of road passenger transport is slightly offset by increased demand for road travel from low cost autonomous ridesharing services in some scenarios and growth in aviation passenger demand.
- + **Barriers/enablers:** Continued government commitment to invest in public transport infrastructure can reduce passenger road transport activity.

### Key assumptions<sup>1</sup>:

- + Since around the turn of the century, road transport has been historically losing market share to rail, active and aviation modes. Increased rail and active market share has been supported by city densification and government investment, particularly following the high oil price period of 2006 to 2014.
- + Increased aviation passenger transport share has been supported by reduced cost of air travel relative to income.
- + Road passenger transport shares are assumed to continue to decline to varying degrees across the scenarios.
- + Refer to the chart on Slide 90 for the exogenous scenario setting on passenger kilometres travelled in all transport modes from 1975 to 2050.

<sup>1</sup>Bureau of Infrastructure Transport and Regional Economics (BITRE), 2018, *Yearbook 2018: Australian Infrastructure Statistics, Statistical Report*, BITRE, Canberra ACT.

# Mode shifting

## Telecommuting and e-commerce

- + **Solution description:** Telecommuting is a work arrangement in which employees do not commute or travel to a central place of work, hence reducing transport demand. E-commerce refers to commercial transactions conducted electronically on the Internet.
- + **Solution abatement impact and rationale:** These measures reduce the amount of passenger and freight transport demand in road and aviation which has no impact where transport can be decarbonised but is useful, for example, where electrification is impractical.
- + **Barriers/enablers:** New business models and practices are needed to stimulate uptake. Concerns about social cohesion and productivity remain a barrier.

<sup>1</sup>CSIRO transport demand model

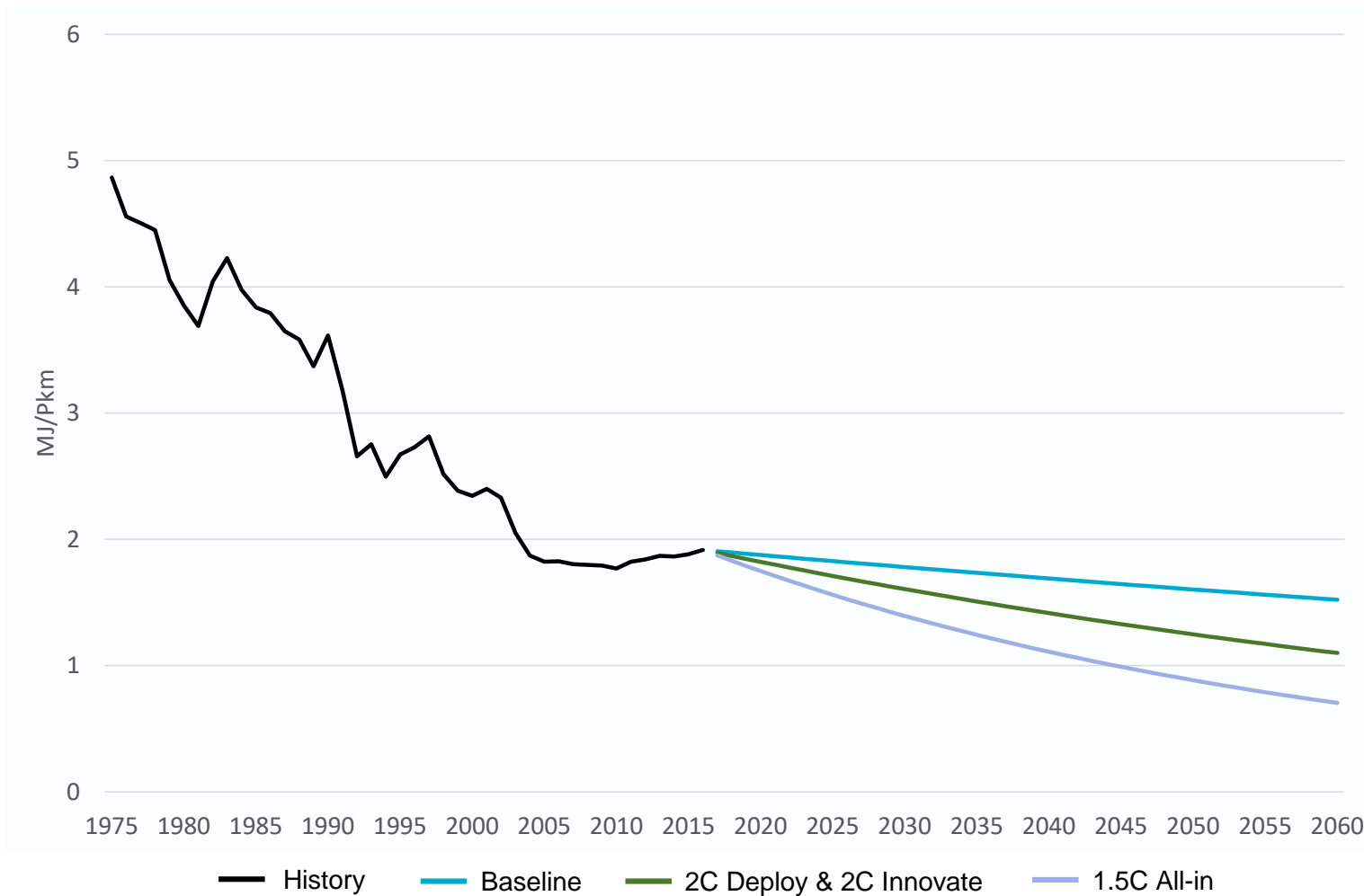
## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
15% reduction in demand for passenger kilometres by 2050 due to telepresence	20% reduction in demand for passenger kilometres by 2050 due to telepresence	20% reduction in demand for passenger kilometres by 2050 due to telepresence
15% share of retail sales being e-commerce by 2050	20% share of retail sales being e-commerce by 2050	20% share of retail sales being e-commerce by 2050

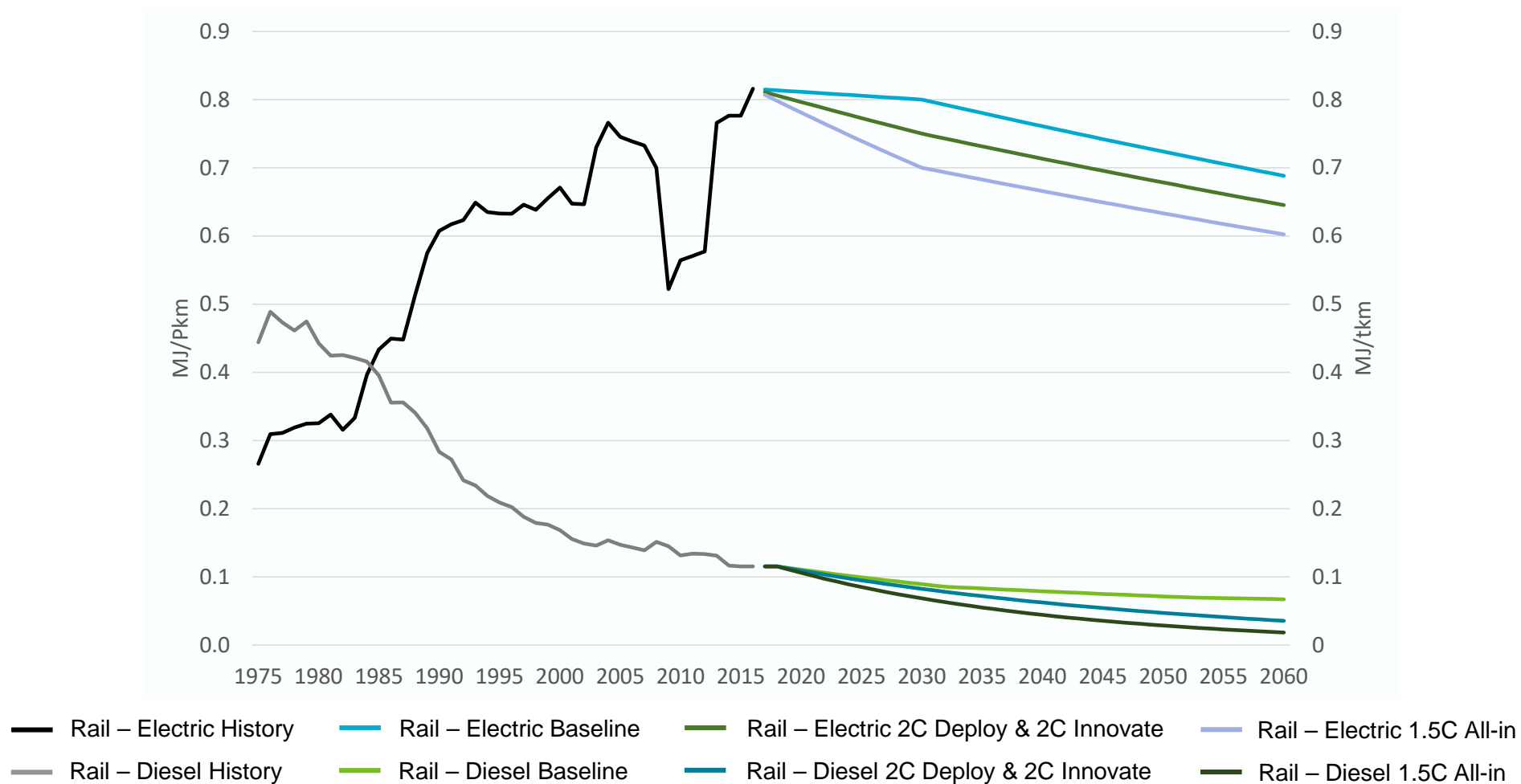
### Key assumptions<sup>1</sup>:

- + There is a large potential for avoided passenger travel through video and audio presence technologies in lieu of in person meetings and work arrangements.
- + E-commerce reduces freight if products can be shipped from warehouse to customer without going through a retail centre. However it could increase road freight kilometers if customers are more dispersed. On balance we assume an overall reduction with some shifting between heavy to lighter road freight vehicles.
- + E-commerce increases its share of retail sales from less than 5% today to between 15-20% depending on the scenario.
- + Increasing adoption of telepresence leads to a 20% reduction of demand for passenger kilometres.

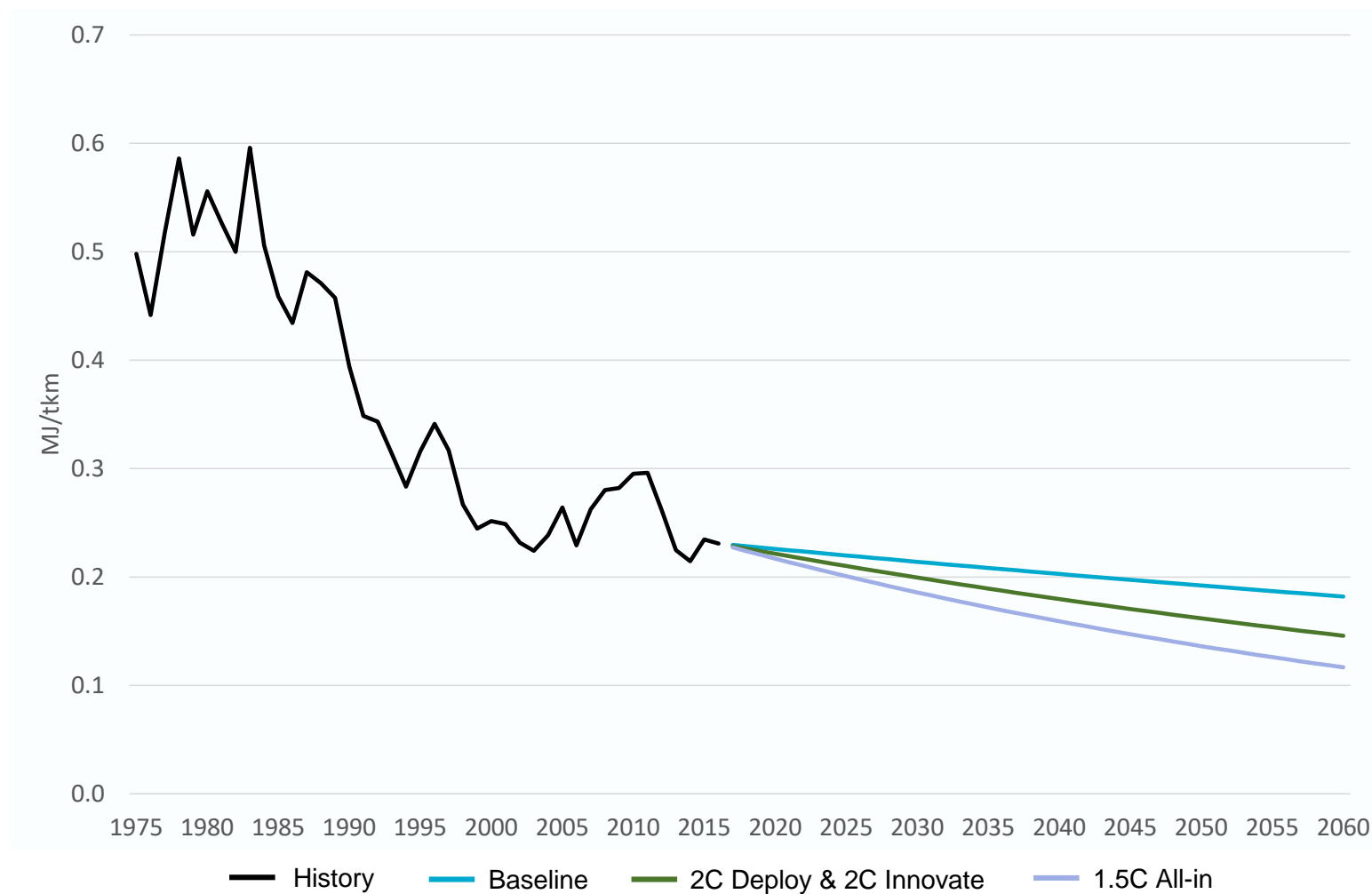
# Domestic aviation fuel efficiency



# Rail fuel efficiency



# Shipping fuel efficiency



# Industry



# Industry baseline data

Baseline energy use for industry was derived from the Australian Energy Statistics and NGGI

- + Baseline industry energy data is taken for the year 2017.
- + The Australian Energy Statistics<sup>1</sup> provides energy data by subsector and fuel type:
  - Oil
  - Gas
  - Bioenergy
  - Brown coal
  - Black coal
  - Electricity
- + Baseline non-energy emissions data is taken from the National Greenhouse Gas Inventory<sup>2</sup> for the year 2017.
  - This contains emissions by subsector, split into standard reporting categories.
- + In the model, non-energy greenhouse gas emissions are aggregated into a single CO2-e value based on National Accounts Factors<sup>3</sup>.

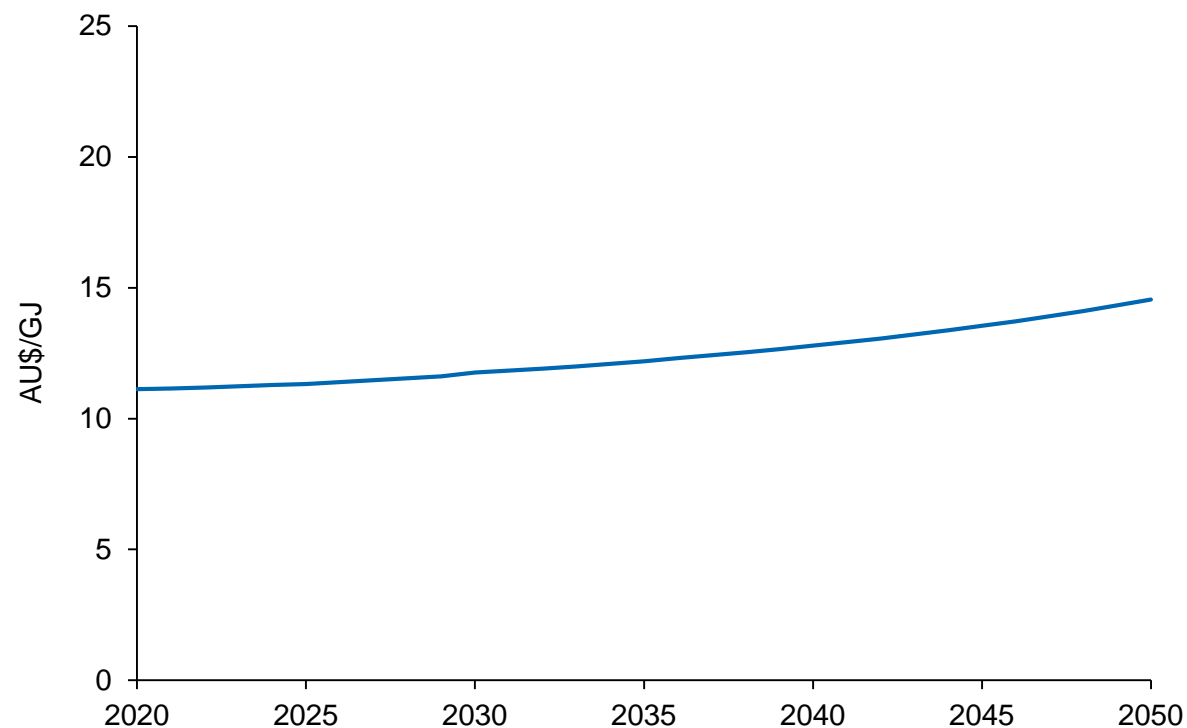
<sup>1</sup>Department of the Environment and Energy 2018, *Australian Energy Statistics – Table F*.

<sup>2</sup>Department of the Environment and Energy 2018, *National Greenhouse Gas Inventory*.

<sup>3</sup>Department of the Environment and Energy 2018, *National Greenhouse Accounts Factors – July 2018*

# Industry fuel costs data

Average base gas price in industry<sup>1</sup>



Alternative zero emissions fuels assumptions:

- + **Bioenergy** - Campey, T., Bruce, S., Yankos, T., Hayward, J.A., Graham, P.W., Reedman, L.J., Brinsmead, T.S., and Deverell, J. 2017, *Low Emissions Technology Roadmap*, Report No. EP167885, June, <https://www.csiro.au/en/Do-business/Futures/Reports/Low-Emissions-Technology-Roadmap>

## Growth in industry subsectors is projected using several data sources

- + Activity growth in industry subsectors is unitless, indexed to base year energy use
- + The growth is projected to 2050 based on assumptions that vary by subsector, including:
  - Forecasts of sectoral activity developed through the Pathway to Deep Decarbonisation Project (CWA, 2015), drawing on results of CGE analysis by the Centre of Policy Studies and Victoria University.
  - Asset-level assumptions for alumina, aluminium, steel and petroleum refining facilities.
- Recent trends of changes in energy use by sector, drawing on historical data from the Office of the Chief Economist (2017)
- Demand for Australian energy exports based on the International Energy Agency's World Energy Outlook (2019)

# Global demand for commodities has a significant impact on domestic production and associated energy and emissions (1/2)

## Assumed coal demand in *Decarbonisation Futures* scenarios

### Coal demand in the 2 degree scenarios:

- + This is well documented in the IEA's sustainable development scenario, which provides demand projections by region. This predicts a steady decline in global coal demand
- + IEA also provide projections for coal demand by region. This is not disaggregated into thermal/metallurgical coal. However, coal production projections are disaggregated into these categories at a global level
- + To project coal export demand, this analysis:
  1. Takes IEA demand by region (China, Japan, India, Asia Pacific, World) and extrapolates to 2050
  2. Uses global production projections of metallurgical and thermal coal to estimate each country's demand from each category
  3. Uses country/region demands to project demand for Australian coal (i.e. if one country's demand decreases by 10%, Australian exports to that country also decrease by 10%)
- + This export demand was then combined with modelled domestic demand to arrive at a 61% decrease in total coal demand in 2050 v 2020, which is the assumed change in domestic coal production for the 2 degree scenarios (linearly interpolated)

### Coal demand in the 1.5 degree scenario:

- + The IPCC Special Report on 1.5 degrees includes some high-level analysis on 1.5 degree-compliant scenarios from their database (85 scenarios included in these figures), but this is not disaggregated by region, or metallurgical vs. thermal coal.
- + To project coal export demand, this analysis:
  1. Assumed the split of metallurgical vs thermal coal remains the same as in IEA's 2-degree projections
  2. Uses IEA 2-degree scenario data to estimate the proportion of global coal demand from Australia's export markets in 2050
  3. Converts this to real demand data for 2050 using 2050 global coal demand from IPCC 1.5 degree scenarios
  4. Assumes that Australia will supply the same percentage of each country's demand as it does today, and multiplies this percentage by each key market's projected 2050 demand.
- + This export demand was then combined with modelled domestic demand to arrive at a 74% decrease in total coal demand in 2050 v 2020, which is the assumed change in domestic coal production for the 2 degree scenarios (linearly interpolated)

# Global demand for commodities has a significant impact on domestic production and associated energy and emissions (2/2)

## Assumed gas demand in *Decarbonisation Futures* scenarios

### Gas demand in the 2 degree scenarios:

- + This is well documented in the IEA's sustainable development scenario, which provides demand projections by region. This predicts a peak in global gas demand at around 2030
- + To project LNG export demand, this analysis:
  1. Takes IEA 2-degree scenario 2050 gas demand projections for Australia's key export markets
  2. Assumes that Australia will supply the same percentage of each country's demand as it does today, and multiplies this percentage by each key market's projected 2050 demand
- + This export demand was then combined with modelled domestic demand to arrive at a 3% decrease in total gas demand in 2050 v 2020, which is the assumed change in domestic gas production for the 2 degree scenarios (linearly interpolated)

### Gas demand in the 1.5 degree scenario:

- + The IPCC Special Report on 1.5 degrees includes some high-level analysis on 1.5 degree-compliant scenarios from their database (85 scenarios included in these figures), but this is not disaggregated by region
- + To project export demand, this analysis:
  1. Uses IEA 2-degree scenario data to estimate the proportion of global LNG demand from Australia's export markets in 2050
  2. Converts this to real demand data for 2050 by multiplying this proportion by 2050 global gas demand from IPCC 1.5 degree scenarios
  3. Assumes that Australia will supply the same percentage of each country's demand as it does today, and multiplies this percentage by each key market's projected 2050 demand
- + This export demand was then combined with modelled domestic demand to arrive at a 55% decrease in total gas demand in 2050 v 2020, which is the assumed change in domestic gas production for the 2 degree scenarios (linearly interpolated)

## Industry energy use is projected as proportional to activity, minus an autonomous efficiency improvement rate

- + Growth indices for each subsector underpin energy demand
- + Beyond raw activity projections, some energy efficiency improvements are expected to occur in industry 'autonomously'; with no intervention.
  - As equipment is naturally retired, technological advances generally result in more efficient replacements at the same price point.
  - Additional efficiency improvement measures also become more widely available over time (e.g. IT infrastructure).
  - These energy efficiency improvements are included in baseline energy use projections
- + An autonomous energy efficiency improvement rate of **0.4% p.a.** is assumed across all subsectors of industry
  - This is consistent with analysis of long-term energy efficiency trends that have occurred in industry (CWA 2015, Pathways to Deep Decarbonisation Project)

# Endogenous and exogenous abatement options for Industry are available in the model

## Endogenous

Aus-TIMES can choose from three categories of **endogenous** decarbonisation options for energy emissions across every subsector:

- + Energy efficiency improvements
- + Electrification
- + Fuel switching

These options are associated with costs, and the model will take up any available option that reduces overall system costs

- + This is a calculation that involves the investment cost and period, as well as energy costs and carbon price costs with or without the investment in the abatement option

## Exogenous

Scenario-specific abatement solutions are imposed as an **exogenous** abatement option

- + A methodological approach was taken to comprehensively identify and assess potential abatement solutions, following a comprehensive review of available options across all sectors
- + The abatement solutions, assumed impact and sources are detailed in this document

# Three categories of endogenous energy efficiency improvements are available in industry

Energy efficiency improvements in industry can occur beyond the autonomous rate, but at cost. Aus-TIMES considers three categories of energy efficiency improvement:

## + **Process improvements**

- Relatively small capital requirement, technology payback of one year. E.g. Process optimisation, system controls, behaviour change and maintenance.

## + **Small equipment upgrades**

- Moderate capital requirement, technology payback period of three years. E.g. equipment optimisation, thermal electricity generation, heating system upgrades and motor improvements<sup>1</sup>.

## + **Large equipment upgrades**

- Larger capital requirement, technology payback period of seven years. E.g. coke dry quenching, high-pressure gas capture in iron and steel or dry cement kilns<sup>2</sup>.

<sup>1</sup>ClimateWorks Australia 2012, *Industrial Energy Efficiency Data Analysis Project*.

<sup>2</sup>Energy Transitions Commission 2018, *Mission Possible: Reaching net-zero carbon emissions from*

*harder-to-abate sectors by mid-century.*



## Three categories of endogenous energy efficiency improvements are available in industry

- + The maximum possible efficiency improvement each year is modelled as a percentage of baseline energy use that can be reduced in each year from each efficiency improvement category.
- + This percentage varies by subsector, and in the case of long payback improvements, increases over time.
- + Maximum efficiency capacities are derived from the Pathways to Deep Decarbonisation Project (CWA, 2015) and informed by the Industrial Energy Efficiency Data Analysis Project (CWA, 2012)

Maximum efficiency improvement (% p.a.)						
Category		Agriculture & forestry	Mining & extraction	Light manufacturing	Heavy manufacturing	Other industry
Short payback		0.2%	0.2%	0.3%	0.2%	0.2%
Medium payback		0.2%	0.2%	0.3%	0.3%	0.2%
Long payback (increases over time)	Present-2030	0.2%	0.2%	0.3%	0.3%	0.2%
	2031-2040	0.4%	0.4%	0.5%	0.5%	0.4%
	2041-2050	0.6%	0.6%	0.7%	0.7%	0.6%

# Direct fuels can be switched to electricity via electrification

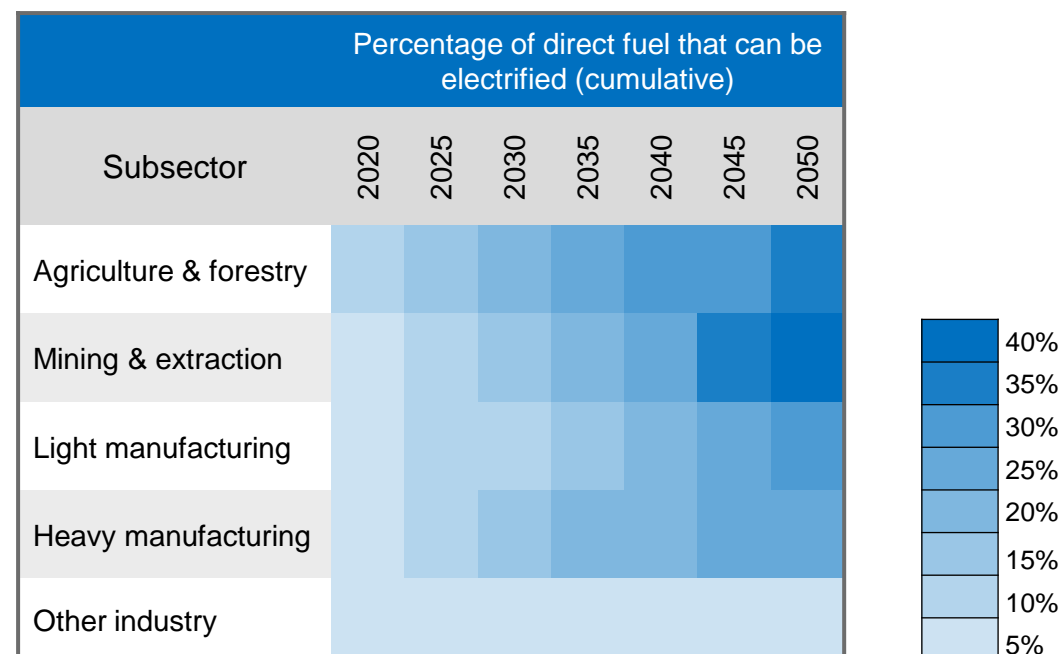
- + Electrification refers to the substitution of industrial processes that rely on direct fuels for energy supply with those that rely on electricity. For example, industrial heat pumps or electric furnaces.
- + Converting to electrical energy allows for decarbonisation by a combination of two factors:
  - If electricity grids transition towards low-carbon generation technologies, emissions associated with the production of energy for industrial processes will also decline.
  - Electrical industrial processes generally have fewer energy losses than direct fuel-reliant processes, decreasing energy intensity.
- + The ratio of direct fuel energy to electrical energy (GJ switched:GJ) is assumed to be:
  - **3.6:1** for mining<sup>1</sup>
  - **2:1** for all other subsectors<sup>2</sup>

<sup>1</sup>ClimateWorks modelling based on average efficiency of electricity-based technologies versus heavy vehicles.

<sup>2</sup>ClimateWorks Australia 2015, *Pathways to Deep Decarbonisation in 2050*

# Direct fuels can be switched to electricity via electrification

- + The maximum technical electrification potential for each subsector is modelled as a cumulative percentage of direct fuel that can be electrified (right)
- + These capacities were developed from ClimateWorks analysis, informed by the Pathways to Deep Decarbonisation Project (CWA 2015)



# Emission-intensive fuels can be switched to low-carbon alternatives

- + Fuel switching describes the switching of fossil fuels in industrial processes with low-carbon alternative energy sources such as biomass, biogas or liquid biofuels. As discussed in slide 33, modelled bioenergy can be interpreted as any possible future mix of zero-emissions fuels
- + Fuel switching is a viable option in cases where electrification is impractical or infeasible – for example, remote locations distant from electricity grid connections.
- + The quantity of fuel switched is determined based on the difference in fuel costs and is limited by the total availability of bio feedstock (in competition with other potential uses across the economy).

# Industry abatement options

Scenario-specific abatement solutions are imposed as exogenous abatement options

Each disruption represents the influence of a new technology on the activity, energy intensity or non-energy emissions intensity on one or more subsectors.

Abatement solutions lead to a cumulative change of a relevant parameter over the time interval 2020-2050.

In some cases, Australian industries are only expected to be impacted from domestic impacts of a disruption. In other cases, international impacts may have an effect on export-exposed subsectors.

## Abatement options

- + **Materials substitution**
  - + Timber buildings
  - + Geopolymer cement
  - + Bio-coke
- + **Materials efficiency**
  - + Better building design
  - + Additive manufacturing (3D printing)
- + **Circular economy**
  - + Plastic recycling
  - + Metal recycling
- + **Automation (Artificial Intelligence)**
- + **Process improvement**
  - + Catalysts
  - + Centralised networks
  - + VAM oxidation
  - + Inert anode
- + **Carbon capture and storage**

# Materials Substitution

## Timber buildings

- + **Solution description:** Using timber (particularly engineered wood products) in the construction of some new buildings.
- + **Solution abatement impact and rationale:** This solution replaces or reduces the demand of cement & steel for buildings. Cement and steel (reinforcement) are common building materials in construction of large buildings. The processes involved in the creating of cement and steel create significant emissions that are challenging to abate.
- + **Barriers/enablers:** Constructing buildings using engineered wood products has been demonstrated, particularly for low-rise buildings. Expanding this to a larger share of buildings could be enabled by demonstrated low cost of production, regulatory support to allow for larger buildings to be made using timber and strong customer demand (perhaps from social licence pressures from an increased appreciation of embedded carbon).

### Key assumptions (Australia)<sup>1</sup>:

- + Up to 20% of new buildings are made from timber by 2030, increasing to 40% in 2050.

<sup>1</sup>Beyond Zero Emissions 2017, *Zero Carbon Industry Plan: Rethinking Cement*

<sup>2</sup>ClimateWorks Australia 2015, *Pathways to Deep Decarbonisation in 2050*

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
13% timber buildings by 2050	40% timber buildings by 2050 in Aus & 27% internationally	40% timber buildings by 2050

- + The use of concrete in new buildings can be reduced by up to 60% in 2030 by using engineered timber
- + Up to 60% of Australia's domestic cement demand comes from new buildings by 2030
- + Up to 65% of Australia's domestic steel demand is from new buildings by 2030

### Key assumptions (International)<sup>2,3,4</sup>:

- + Increased demand for timber building internationally would affect demand of Australian commodities in two key industries:
  - Iron ore mining (97% of products are exported; 50% of steel is used in construction globally).
  - An international reduction of demand results in a proportional reduction in activity in steel and coal produced for exports.

<sup>3</sup>Beyond Zero Emissions 2017, *Zero Carbon Industry Plan: Rethinking Cement*

<sup>4</sup>International Energy Agency 2017, *Coal Information: Overview*

# Materials Substitution

## Geopolymer and high-blend cement

- + **Solution description:** The replacement of traditional Portland cement with alternatives that have a much lower clinker content, hence reducing the emissions that are created as a result of the limestone calcination process (used to produce clinker). Geopolymer cement, and high-blend cement (using fly ash, slag, metakaolin, ground limestone) can replace Portland cement. This reduces the emissions from the cement sector significantly, due to reduced non-energy emissions intensity and also improved energy intensity.
- + **Solution abatement impact and rationale:** Cement is an emissions-intensive industry. Recognising that demand for cement is unlikely to wane completely, any improvements in emissions intensity are valuable. There are many examples of projects today utilising geopolymer or high-blend cements.
- + **Barriers/enablers:** Technological development towards cost reductions could enable the uptake of geopolymer and high-blend cement. Moderate policy support, through supporting regulations and increased deployment would help reduce costs, and make it a more viable option for property developers. It could be further enabled by support from business and individuals in the form of increased consumer demand for lower embodied emissions in their buildings.

<sup>1</sup>Beyond Zero Emissions 2017, *Zero Carbon Industry Plan: Rethinking Cement*

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	100% geopolymer blend by 2040	100% geopolymer blend by 2030

### Key assumptions (Australia)<sup>1</sup>:

- + All Portland cement (75% clinker) can be replaced with 50% geopolymer/50% high-blend cement (15% clinker) by 2030.
- + A 10% reduction in the volume of clinker in a cement mix can reduce emissions by 6%.
- + 100% of direct fuel energy in cement is used in clinker production.
- + 27% of electrical energy in cement is used in clinker production.

# Materials Substitution

## Bio-coke

- + **Solution description:** A biomass-based alternative coke that is used to supplement metallurgical coal (coking coal) in the steelmaking process. Bio-coke is substantially less emissions-intensive than coal, and when derived from wood has the potential to be carbon neutral.
- + **Solution abatement impact and rationale:** CO<sub>2</sub> emissions from the use of coking coal are a significant source of direct emissions in the iron and steel industry, with few abatement options. Bio-coke is technologically viable today, and a valuable option for mitigating these emissions at a process level.
- + **Barriers/enablers:** Moderate technological progress in bio-coke development could lead to increased accessibility of fit-for-purpose products, while moderate policy support could encourage or require industry to switch from coking coal to bio-coke.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
50% bio-coke by 2050	50% bio-coke by 2050	50% bio-coke by 2050

### Key assumptions (Australia)<sup>1</sup>:

- + By 2050, 50% of the coking coal used in iron and steel can be replaced with bio-coke.
- + The use of bio-coke reduces non-energy emissions in iron and steel (blast furnace only).
- + Iron and steel non-energy emissions intensity can be reduced by 50% by 2050 (based on Pathways to Deep Decarbonisation Project analysis recalibrated to current penetration rates).

<sup>1</sup>ClimateWorks Australia, 2014, *Pathways to deep decarbonisation in 2050: how Australia can prosper in a low carbon world*, <https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisation-in-2050-how-australia-can-prosper-in-a-low-carbon-world/>



# Materials Efficiency

## Better building design

- + **Solution description:** Designing large structures to use specially-designed, high-strength concrete, coupled with the efficient use of cement through the use of better design, enabled by computer modelling. Both of these reduce cement and steel demand, and therefore reduce the emissions from the production of these products.
- + **Solution abatement impact and rationale:** Both high strength concrete and computer design are a relatively well established technologies and can be readily applied to new builds, and reduce the reliance on cement and steel for construction - both of which have emissions that are challenging to decarbonise.
- + **Barriers/enablers:** Improvements in technology (reducing compute resource cost and advancing software) could unlock progress in better building design, alongside and increased capacity from construction businesses to deliver better building designs and an increased social demand for more sustainable buildings. Better building design is also closely linked with developments in timber buildings and geopolymers.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	5% reduction in input requirements by 2030 in Aus and by 2050 internationally	7% reduction in input requirements in 2030

### Key assumptions (Australia)<sup>1,2:</sup>

- + The use of high-strength concrete and better building design result in up to a 20% decrease in input requirements for large projects, or a 7% reduction across all projects.
- + 60% of cement use in Australia is in new buildings.
- + 65% of steel use in Australia is in new buildings.
- + 65% of steel consumed in Australia is produced locally.

### Key assumptions (international)<sup>1,3:</sup>

- + 97% of iron ore products are exported.
- + 50% of steel is used in construction globally.
- + An international reduction of demand results in a proportional reduction in activity in steel and coal produced for exports.

<sup>1</sup>Beyond Zero Emissions 2017, *Zero Carbon Industry Plan: Rethinking Cement*

<sup>2</sup>Office of the Chief Economist 2018, *Resources and Energy Quarterly: March 2018*

<sup>3</sup>International Energy Agency 2017, *Coal Information: Overview*

# Materials Efficiency

## Additive manufacturing (3D printing)

- + **Solution description:** Additive manufacturing, is the process of constructing objects by depositing layers of material. The process is computer-controlled, instructed by a digital model, and deposits material only where necessary. This differs from traditional subtractive machining manufacturing processes (such as turning and milling) which start with a block of material, and progressively remove material until the final form is reached. With fewer manufacturing limitations, it possible to create lighter parts and more complex assemblies.
- + **Solution abatement impact and rationale:** Additive manufacturing has the potential to completely change traditional manufacturing. 3D printed parts have the ability to greatly improve the energy efficiency of end-use products – be it reduced fuel burn due to lighter parts in aircraft, or improved heat transfer in injection moulding equipment. Like many technologies, 3D printing is not a ‘new’ – it has been around in commercial applications for many decades. However, equipment costs have been falling rapidly, the availability of smaller and more accessible machines have been spurred on by open access to technology, as well as continued materials development are encouraging signs towards higher penetration.

<sup>1</sup>PwC 2017, *Five ways 3-D printing is changing manufacturing*

<sup>2</sup>ING 2017, *3D printing: a threat to global trade*

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	Up to 50% machinery 3D-printed by 2050 & 33% internationally	Up to 50% machinery 3D-printed by 2050

- + **Barriers/enablers:** Technology-driven cost reductions in components and input materials could enable the uptake of 3D printing. Beyond this, increasing value of customised, on-demand, locally-produced products from business and individuals could increase demand for 3D printed products and lead to further progress.

### Key assumptions (Australia and international)<sup>1,2,3</sup>:

- + Up to 50% of vehicle parts, heavy machinery parts, gas turbines, miscellaneous machinery and medical or surgical appliances are 3D-printed by 2050.

<sup>3</sup>Verhoef et al. 2018, ‘The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach’, *Energy Policy*.

# Circular Economy

## Plastic recycling

- + **Solution description:** The recovery and recycling of plastic products to greatly reduce the amount of energy used and emissions created in the manufacturing process. This directly impacts the energy and emissions intensity in the chemicals sector, but also has up-stream impacts\* for the demand of resources (e.g. oil and/or natural gas).
- + **Solution abatement impact and rationale:** Only 4% of Australia's plastic production comes from locally recycled plastic, leaving a huge margin for improvement. The manufacture of plastics consumes energy and produces direct emissions which are difficult to decarbonise. Increased recycling also minimises the demand for extraction of fossil fuels.
- + **Barriers/enablers:** Technological developments in recycling and waste capture processes, leading to a reduction in costs in recycling could enable uptake. Continued and enhanced participation in metals recovery by business and individuals could be a significant enabler, as would an increased understanding on the embedded emissions in plastic products.

*\*Note: The Decarbonisation Futures analysis focusses only on the potential impacts on plastic manufacturing in Australia, not the upstream impacts.*

<sup>1</sup>Based on share of employment, (DIIS 2017, *Australian Chemicals and Plastics Manufacturing Update*)

<sup>2</sup>ClimateWorks modelling based on the following sources:

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	Up to 39% emissions reduction by 2050	Up to 59% emissions reduction by 2050

### Key assumptions (Australia)<sup>1,2</sup>:

- + Five main types of plastic can be recycled: PE, PET, PVC, PS & PP.
- + Emissions in plastic manufacturing can be reduced by up to 59% in 2050 from recycling.
- + Plastics occupy an 8.8% share of the 'Other chemicals' subsector.

- Deloitte 2015, *Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment*
- Envisage Works & Sustainable Resource Use 2017, *2016-17 Australian Plastics Recycling Survey*
- Material Economics 2018, *The Circular Economy – A Powerful Force for Climate Mitigation*

# Circular Economy

## Metal recycling

- + **Solution description:** The recovery and recycling of metal products to greatly reduce the amount of energy used and emissions created in the manufacturing process. This directly impacts the energy and emissions intensity in the Aluminium and Iron & Steel sectors, but also has up-stream impacts\* for demand in resources and processing sectors: Bauxite, Alumina, Iron ore mining and Coal mining.
- + **Solution abatement impact and rationale:** The manufacture of metals requires large amounts of energy and produces direct emissions which are difficult to decarbonise. Increasing the rate of recovery of metal products and recycling the scrap can reduce the demand for virgin metals. Hence, this minimises the need for primary production and therefore minimises impacts.
- + **Barriers/enablers:** Technological developments in recycling and waste capture processes, leading to a reduction in costs in recycling could enable uptake. Continued and enhanced participation in metals recovery by business and individuals could be a significant enabler, as would an increased understanding on the embedded emissions in metal products.

*\*Note: The vast majority of raw materials for metals such as iron ore and bauxite are exported. Since local manufacturing of steel and aluminium consume a small percentage of these materials, the upstream impacts of recycling are only modelled in the "2C Innovate" scenario. In this scenario, recycling is taken up significantly internationally and as such the effect on iron and steel & aluminium production is of a sufficient scale to affect these export-dominated sectors.*

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	90% scrap capture rate by 2050 in Aus and internationally	100% scrap capture rate by 2050

### Key assumptions by 2050<sup>1-6</sup>:

- + Australian trends in scrap metal availability follow global trends.
- + All scrap exports are recovered for domestic recycling.
- + Scrap capture rates increase from 70% to 100%.
- + The share of recycled aluminium in Australia's aluminium industry grows from 8% to 49%.
- + The energy intensity of aluminium recycling reduces by 95%
- + An increase in steel production leads to a proportional increase in scrap availability.
- + Priority in steel recycling goes to EAF, up to its full potential.

<sup>1</sup>Hatayama et al. 2012, 'Evolution of aluminium recycling initiated by the introduction of next-generation vehicles and scrap sorting technology', *Resources, Conservation and Recycling*

<sup>2</sup>World Aluminium 2017, *Global Aluminium Cycle 2017*

<sup>3</sup>WEF 2015, *Mining & Metals in a Sustainable World 2050*

<sup>4</sup>OCE 2018, *Resources and Energy Quarterly: March 2018*

<sup>5</sup>Golev & Corder 2016, 'Modelling metal flows in the Australian economy', *Journal of Cleaner Production*

<sup>6</sup>Paraschos 2012, *Production of aluminium (emphasis on energy and material requirements)*

# Automation

## Artificial Intelligence

- + **Solution description:** Substantial optimisation of manufacturing processes through improved data collection, monitoring and operation. This includes the use of ‘smart’ (sensor-laden) equipment to provide data to monitoring platforms that can be utilised to adjust the operation of equipment (this may involve artificial intelligence/machine learning). Sometimes referred to as ‘Industry 4.0’, this smart operation improves the energy intensity of all manufacturing sectors, and reduced demand for materials as a result of reduced wastage.
- + **Solution abatement impact and rationale:** The efficiency and productivity improvements afforded by the integration of artificial intelligence into manufacturing are substantial and firms will ultimately be required to incorporate these in order to maintain competitiveness. These approaches are already being utilised to some extent locally and overseas, and will continue to be enabled by the ongoing simultaneous reductions in costs and increasing capability of sensors and compute. Furthermore, the growing intersection of manufacturing with information technology increases the opportunity for abatement solutions.

<sup>1</sup>ACEEE 2013, *Intelligent Efficiency: Opportunities, Barriers, and Solutions*

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
N/A	Up to 30% reduction in energy intensity for manufacturing sectors by 2050 in Aus and 20% internationally	Up to 30% reduction in energy intensity for manufacturing sectors by 2050

- + **Barriers/enablers:** The proliferation of low-cost sensors and informatics provides a strong incentive for manufacturers and business operators to incorporate artificial intelligence into products and practices. The primary enabler behind artificial intelligence is therefore progress in the development of artificial intelligence technologies.

### Key assumptions by 2050<sup>1,2</sup>:

- + Artificial intelligence could lead to up to a 30% reduction in energy intensity for manufacturing sectors.
- + There is a 5% reduction in materials intensity due to less scrap waste.
- + The effects of Artificial Intelligence on global manufacturing industries lead to equivalent effects on related material export industries in Australia.

<sup>2</sup>McKinsey Global Institute 2017, *Artificial Intelligence: The Next Digital Frontier?*

# Process improvement

## Catalysts

- + **Solution description:** Catalysts that are formulated to convert GHG by-products from chemical manufacturing processes (most significantly, N<sub>2</sub>O from ammonia production) into inert gases.
- + **Solution abatement impact and rationale:** GHG emissions such as nitrous oxide (N<sub>2</sub>O) are a significant source of process emissions for the chemical manufacturing industry. Catalysts have the potential to eliminate N<sub>2</sub>O emissions from the ammonia production process.
- + **Barriers/enablers:** Technological progress in the development of emissions-abating catalysts, encouraged by moderate policy support, could increase the potential range of emissions that can be abated and make these catalysts more accessible to chemical manufacturing companies.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
Nearly 100% elimination of N <sub>2</sub> O emissions by 2050	Nearly 100% elimination of N <sub>2</sub> O emissions by 2050	Nearly 100% elimination of N <sub>2</sub> O emissions by 2050

## Key assumptions (Australia)<sup>1,2</sup>:

- + N<sub>2</sub>O emissions account for 31.5% of all emissions in chemical manufacturing.
- + By 2050, nearly all N<sub>2</sub>O emissions from chemical manufacturing can be eliminated using catalysts.

<sup>1</sup>DoEE 2018, *National Greenhouse Gas Inventory*.

<sup>2</sup>ClimateWorks Australia, 2014, *Pathways to deep decarbonisation in 2050: how Australia can*

*propose in a low carbon world*, <https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisation-in-2050-how-australia-can-prosper-in-a-low-carbon-world/>

# Process improvement

## Centralised networks

- + **Solution description:** Smaller, centralised gas distribution networks that can efficiently supply a core (but smaller) set of users while minimising fugitive emissions from pipe leakage.
- + **Solution abatement impact and rationale:** Urban gas transmission in Australia currently occurs via large distribution networks, which often have significant leakage issues leading to fugitive emissions. Smaller, more centralised networks can result in fewer fugitive emissions due to the reduced length of pipes in their network. As buildings and industry electrify, a reduced demand for natural gas is expected, and switching to these smaller, centralised networks can be an important strategy for mitigating emissions.
- + **Barriers/enablers:** A number of technological challenges need to be overcome for centralised networks to be deployed, as they will require a greater proportion of residential and commercial gas users to switch their processes to electrical energy. This process, and the process of deploying centralised gas networks in cities could also be influenced by moderate policy support.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
50% non-energy emissions reduction by 2050	50% non-energy emissions reduction by 2050	50% non-energy emissions reduction by 2050

### Key assumptions (Australia)<sup>1</sup>:

- + Non-energy emissions from gas transmission can be reduced by 50% by 2050.

<sup>1</sup>ClimateWorks Australia, 2014, *Pathways to deep decarbonisation in 2050: how Australia can prosper in a low carbon world*, <https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisationin-2050-how-australia-can-prosper-in-a-low-carbon-world/>



# Process improvement

## VAM oxidation

- + **Solution description:** Systems that extract methane gas from ventilation air in coal mines and convert it into useful energy
- + **Solution abatement impact and rationale:** Coal veins contain embedded methane that is released into the air as coal is mined. Underground mines typically use ventilation systems to expel this air into the atmosphere. However, the methane contained in this ventilation air can be captured before it is emitted into the atmosphere and combusted to produce useful energy.
- + **Barriers/enablers:** Technological progress in expanding the applicability of VAM oxidation technologies (particularly in underground mines with relatively low VAM concentrations) could enable the widespread deployment of VAM oxidation systems. Policy support may also add incentives for mine operators to deploy VAM oxidation systems.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
Around 70% reduction of VAM emissions from gassy mines by 2030	Around 70% reduction of VAM emissions from gassy mines by 2030	Around 70% reduction of VAM emissions from gassy mines by 2030

### Key assumptions (Australia)<sup>1</sup>:

- + VAM oxidation can abate ~70% of VAM emissions from gassy mines by 2030.
- + These emissions represent 60% of all coal fugitive emissions.

<sup>1</sup>ClimateWorks Australia, 2014, *Pathways to deep decarbonisation in 2050: how Australia can prosper in a low carbon world*, <https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisation-in-2050-how-australia-can-prosper-in-a-low-carbon-world/>



# Process improvement

## Inert anode

- + **Solution description:** The use of alternative anodes for aluminium production that do not react with the alumina solution. Currently, the CO<sub>2</sub> emitted in aluminium production is derived from carbon anodes reacting with alumina solution.
- + **Solution abatement impact and rationale:** The current Hall–Héroult process for producing aluminium involves reacting alumina solution with a carbon anode, which directly produces CO<sub>2</sub>. Alternative anodes can be used that do not directly react with the solution, and produce no GHG process emissions. This offers a potential means to completely eliminate process emissions that could otherwise only be abated via capture.
- + **Barriers/enablers:** Technological progress on inert anodes, particularly settling on a standard, widely available anode material, could increase their usage in the aluminium industry. Policy support could also encourage or require the use of inert anode technologies.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
Near 100% elimination of aluminium process emissions by 2050	Near 100% elimination of aluminium process emissions by 2050	Near 100% elimination of aluminium process emissions by 2050

### Key assumptions (Australia)<sup>1</sup>:

- + Aluminium process emissions could nearly be eradicated by 2050 due to use of inert anodes.

<sup>1</sup>ClimateWorks Australia, 2014, *Pathways to deep decarbonisation in 2050: how Australia can prosper in a low carbon world*, <https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisation-in-2050-how-australia-can-prosper-in-a-low-carbon-world/>

# Carbon capture and storage

## CCS for industrial non-energy emissions

- + **Solution description:** Systems that can intercept CO<sub>2</sub> from emission point sources, and transfer it to geological storage such that it is not emitted into the atmosphere.
- + **Solution abatement impact and rationale:** CCS has potential applications to abate non-energy emissions across a wide range of industries, and Australia has a large number of suitable sites for storage. The broad applicability of CCS means it can capture certain emissions where there is alternative means of mitigation are unavailable or nascent, for example, in the cement industry. It is ideally utilised where there is a waste stream of CO<sub>2</sub> extracted from the production process, for example in the LNG liquefaction.
- + **Barriers/enablers:** Strong policy action could encourage or require industries to implement CCS technologies. Industries located in close proximity to suitable storage sites and with favourable process characteristics could be prime candidates for early demonstration, paving the way for further deployment. CCS could benefit from technological developments in the assessment, storage and monitoring of sequestration sites.

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
25-50% penetration of CCS by 2050	8-17% penetration of CCS by 2050	25-50% penetration of CCS by 2050

### Key assumptions (Australia)<sup>1</sup>:

- + The assumed potential for CCS in industry varies by subsector. By 2050, CCS could:
  - + Capture up to 50% of process emission in cement
  - + Capture up to 25% of the process emissions in chemical manufacturing
  - + Reduce emissions in iron and steel to below zero when combined with bio-coke
  - + Reduce fugitive emissions from oil and gas extraction by up to 60-65% when combined with increased flaring

<sup>1</sup>ClimateWorks Australia, 2014, *Pathways to deep decarbonisation in 2050: how Australia can prosper in a low carbon world*, <https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisation-in-2050-how-australia-can-prosper-in-a-low-carbon-world/>

# Agriculture and land

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# Agriculture and land baseline data & activity assumptions

This sector was modelled using the same methodology as for Industry

The sources of baseline data and activity assumptions are common with Industry. Given the large share of non-energy emissions in Agriculture and Land, the key sources are repeated here:

- + Baseline non-energy emissions data was taken from the National Greenhouse Gas Inventory for the year 2017. Source: *Department of the Environment and Energy 2018, National Greenhouse Gas Inventory*.
- + Non-energy greenhouse gas emissions were aggregated into a single CO<sub>2</sub>-e value based on National Accounts Factors. Source: *Department of the Environment and Energy 2018, National Greenhouse Accounts Factors – July 2018*
- + Forecasts of sectoral activity were developed through the Pathway to Deep Decarbonisation Project, drawing on results of CGE analysis by the Centre of Policy Studies and Victoria University. Source: *ClimateWorks Australia, ANU, CSIRO and CoPS 2014, Pathways to Deep Decarbonisation in 2050: How Australia can prosper in a low carbon world: Technical report, ClimateWorks Australia*
  - Detail of CSIRO's Land-Use Trade Offs (LUTO) model used to estimate the volume of carbon forestry is included in the above source, and is not repeated in this documentation for brevity.

# Agriculture and land abatement options

Decarbonisation options are imposed upon select scenarios depending on the narrative

Each abatement solution represents the influence of a new technology or practice on the energy intensity or non-energy emissions intensity of the agriculture land sectors.

Abatement solutions lead to a cumulative change of the relevant parameter over the time interval 2020-2050.

## **Agriculture abatement options**

- + Methane reduction methods package
- + Precision agriculture

## **Land abatement options**

- + Carbon Forestry

# Agricultural emissions

## Methane reduction methods package

- + **Solution description:** Deployment of a suite of abatement options targeting methane emissions from agriculture. Options include the application of nitrification inhibitors to animal waste, composting of manure and feed additives or vaccines to reduce enteric fermentation emissions from cattle, sheep and goats.
- + **Solution abatement impact and rationale:** Fugitive methane emissions make up the majority of greenhouse gas emissions from the agriculture sector, with emissions from enteric fermentation (digestive processes in sheep and cattle) being one of the most significant categories. Australia has a very large agricultural sector, and high demand for animal products which makes these emissions challenging to abate. Many technologies with the potential to abate these emissions have been developed or are under development, and deployment of multiple technologies will likely be necessary to abate agricultural methane emissions.
- + **Barriers/enablers:** A key barrier is the technical development of an efficient mechanism to deliver vaccines to cattle. This development could be stimulated in response to social licence pressure from

<sup>1</sup>CSIRO/Meat & Livestock Association 2018, *Greenhouse gas mitigation potential of the Australian red meat production and processing sectors* and Walter Willett et al. 2019, *Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems*.

## Exogenous scenario setting

## AGRICULTURE AND LAND

Emission Intensity Reduction		2C Deploy	2C Innovate	1.5C All-in
Enteric fermentation treatment	Sheep and cattle	30% by 2050	73% by 2030	73% by 2030, 92% by 2050
	Dairy Farming	26% by 2050	63% by 2030	63% by 2030
Composting and manure treatment	Other animals	21% by 2030	41% by 2030	66% by 2030
	Other non-livestock agriculture & services	10% by 2030	21% by 2030	33% by 2030

businesses and individuals, providing an incentive for producers to seek out and deploy methane reduction technologies. Further efforts from across the supply chain to reduce waste and a shift towards lower emissions protein sources could then act as a further enabler to methane mitigation in agriculture.

### Key assumptions<sup>1,2,3</sup>:

- + Enteric Fermentation accounts for 99% of non-energy emissions from sheep and cattle, and 86% of non-energy emissions from dairy farming.
- + Methane emissions from sheep and cattle can be reduced by up to 73% by 2030, and 63% for dairy. The impact of diet choices on sheep and cattle is reflected in the further emissions reduction to 92% by 2050.
- + Composting and manure treatment could reduce emissions from these sources by up to 80% by 2030, which accounts for approximately 80% of emissions from other animals (excluding sheep and cattle) and approximately 40% of emissions from other agriculture and services.

<sup>2</sup>Source 1 and *National greenhouse Gas inventory* (DoEE 2018)

<sup>3</sup>Department of Agriculture and Water Resources 2017, *Boosting Farm Productivity: Improved soils and reduced greenhouse gas emissions* and Chen et al. 2008, *Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: A review of enhanced efficiency fertilisers*

# Agricultural emissions

## Precision agriculture

- + **Solution description:** Deployment of a suite of options to maximise the efficiency of agricultural operations and emission reductions. Options include the use of nitrification inhibitors in fertilisers, and technology-driven process improvements from the use of sensors, remote sensing, cattle identification, GIS data, crop and livestock health tracking, yield management and monitoring systems, the use of drones or robots and the optimisation of existing processes.
- + **Solution abatement impact and rationale:** Agriculture makes up a large portion of Australia’s overall land use, and the strategies by which this land is managed have a significant impact on agricultural productivity, energy productivity and non-energy emissions. Advancements in productivity technology have significant applications for agriculture as well as industry, with the potential to minimise wasted product, time, effort and energy.

<sup>1</sup>ClimateWorks literature review and analysis  
<sup>2</sup>Chen et al. 2008, *Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: A review of enhanced efficiency fertilisers*  
<sup>3</sup>ClimateWorks Australia 2015, *Pathways to Deep Decarbonisation in 2050*

## Exogenous scenario setting

## AGRICULTURE AND LAND

		2C Deploy	2C Innovate 1.5C All-in
Precision agriculture	Grains and other non-livestock agriculture	5% emissions reduction by 2050	15% emissions reduction by 2050
Nitrification inhibitors	Grains	16% emissions reduction by 2030	39% emissions reduction by 2030
	Other non-livestock agriculture	3% emissions reduction by 2030	8% emissions reduction by 2030

- + **Barriers/enablers:** The desire to continually improve processes to enhance productivity is a key enabler of these solutions. Technological advancement brining about cost reduction in the abatement solutions could be instrumental in their uptake, and this could be reinforced by business and individual demands/ concerns about the sustainability of their produce.

### Key assumptions<sup>1,2,3,4,5</sup>:

- + Data-driven technology and automation could lead to a 15% reduction in emissions across agriculture broadly by 2050.
- + Nitrification inhibition can reduce up to 60% of non-energy emissions from fertilisers, which accounts for around 66% and 13% of emissions in grains and other agriculture respectively.

<sup>4</sup>CSIRO’s Land Use Trade-offs (LUTO) model as described in Bryan, B. A. et al. 2016, 'Land-use and sustainability under intersecting global change and domestic policy scenarios: Trajectories for Australia to 2050', *Global Environmental Change*, vol. 38, pp. 130-152.  
<sup>5</sup>Department of Agriculture and Water Resources 2017, *Boosting Farm Productivity: Improved soils and reduced greenhouse gas emissions*

# Land emissions

## Carbon Forestry

- + **Solution description:** Profitable sequestration of emissions through forestation to offset the difference between the cumulative emissions budget and the remaining emissions.
- + **Solution abatement impact and rationale:** This solution sequesters the volume of carbon that would be profitable to supply, where delivery of carbon credits would provide higher economic return than competing agricultural land uses.
- + **Barriers/enablers:** Carbon forestry could deliver greater economic returns than using certain land for agriculture in some cases, provide alternative source of income for farmers and diversify their holdings to protect them against losses from under-performing crops or livestock, making it an

## Exogenous scenario setting

2C Deploy	2C Innovate	1.5C All-in
137 MtCO <sub>2</sub> -e emissions sequestered by 2050	96 MtCO <sub>2</sub> -e emissions sequestered by 2050	344 MtCO <sub>2</sub> -e emissions sequestered by 2050

attractive option for them. Emissions reductions need to be valued sufficiently to make the labour-intensive activity of planting cost-effective. It also needs to be well managed to balance trade-offs with other land uses.

### Key assumptions<sup>1,2</sup>:

- + Carbon forestry can sequester 344 MtCO<sub>2</sub>-e of emissions by 2050, equivalent to 24Mha of area of plantings.
- + The amount of sequestration is based on the most profitable plantings (plantings that are at least five times as profitable as the next most economic land use).

<sup>1</sup>ClimateWorks Australia 2015, *Pathways to Deep Decarbonisation in 2050: How Australia can prosper in a low carbon world*

<sup>2</sup>CSIRO's Land Use Trade-offs (LUTO) model as described in Bryan, B. A. et al. 2016, 'Land-use

and sustainability under intersecting global change and domestic policy scenarios: Trajectories for Australia to 2050', *Global Environmental Change*, vol. 38, pp. 130-152.

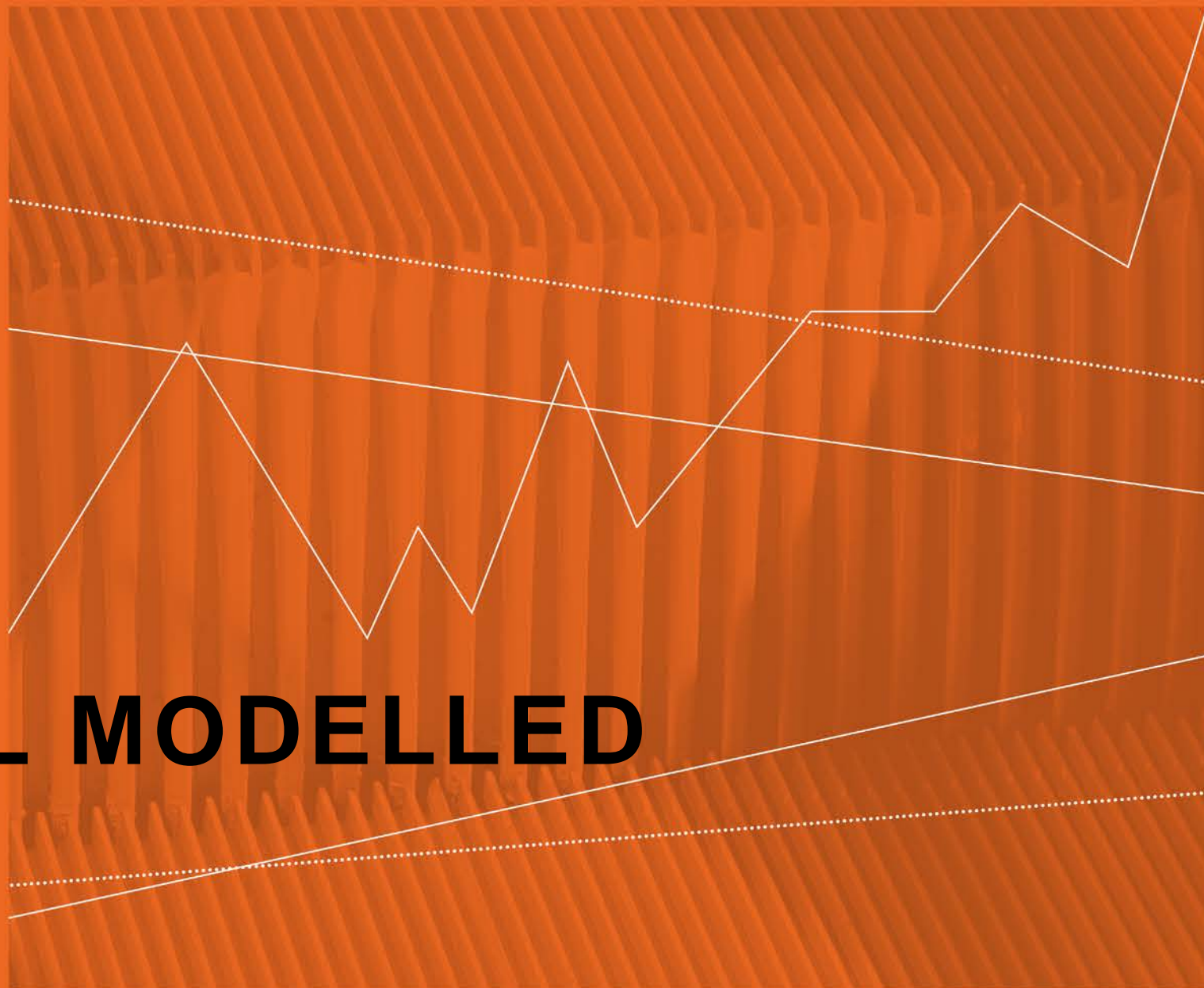


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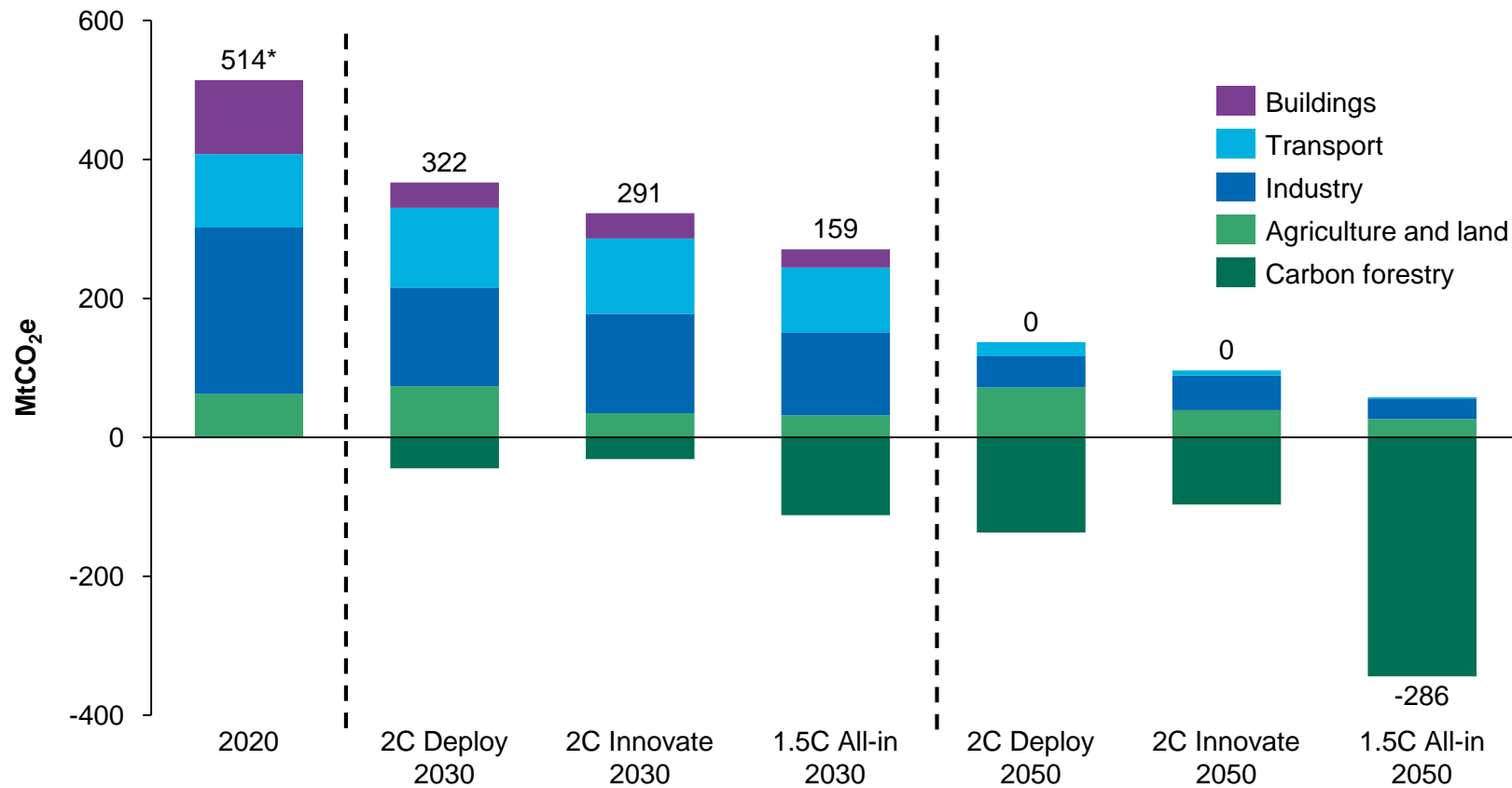
05

# ADDITIONAL MODELLLED RESULTS

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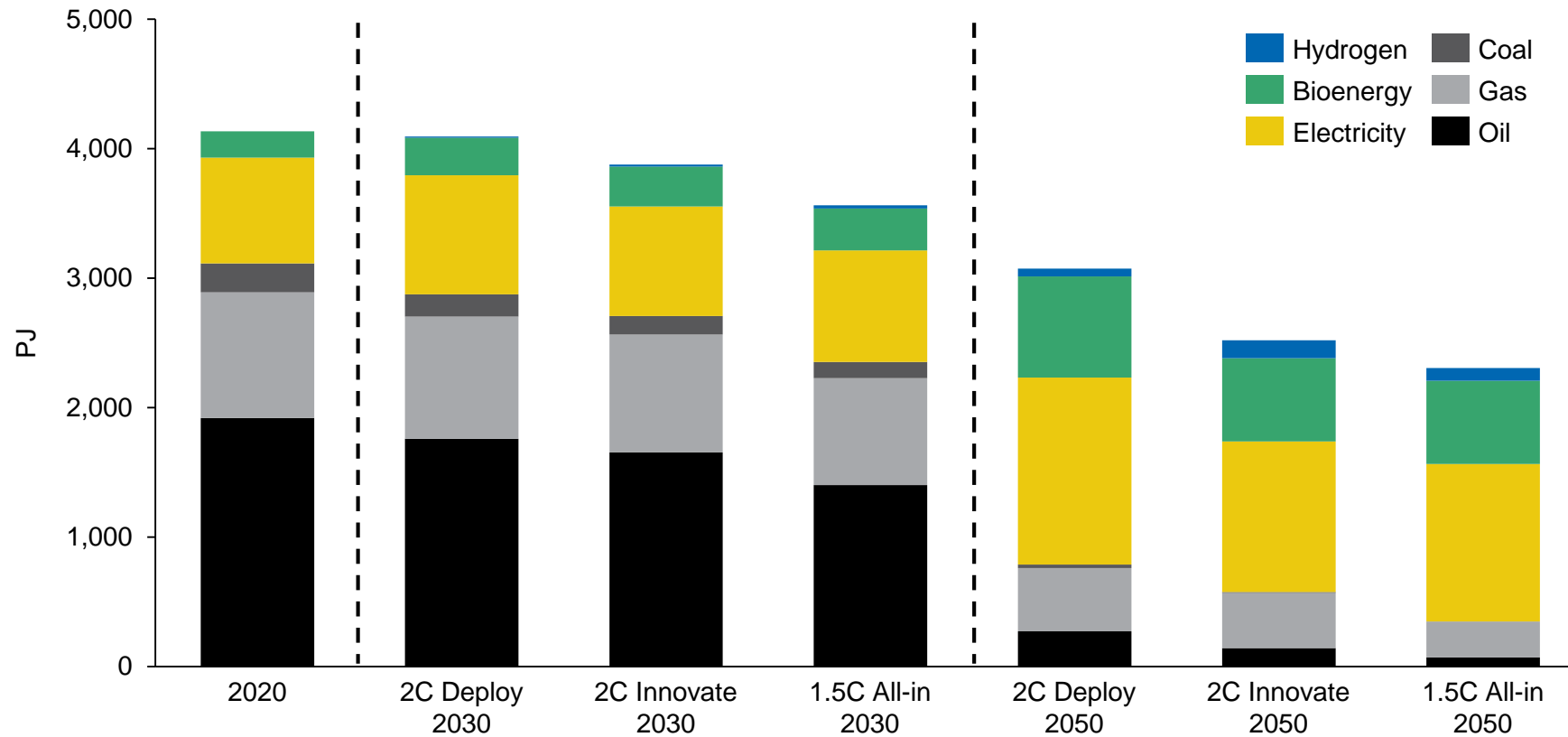


# Emissions by sector in the modelled scenarios (Scope 1 & 2)

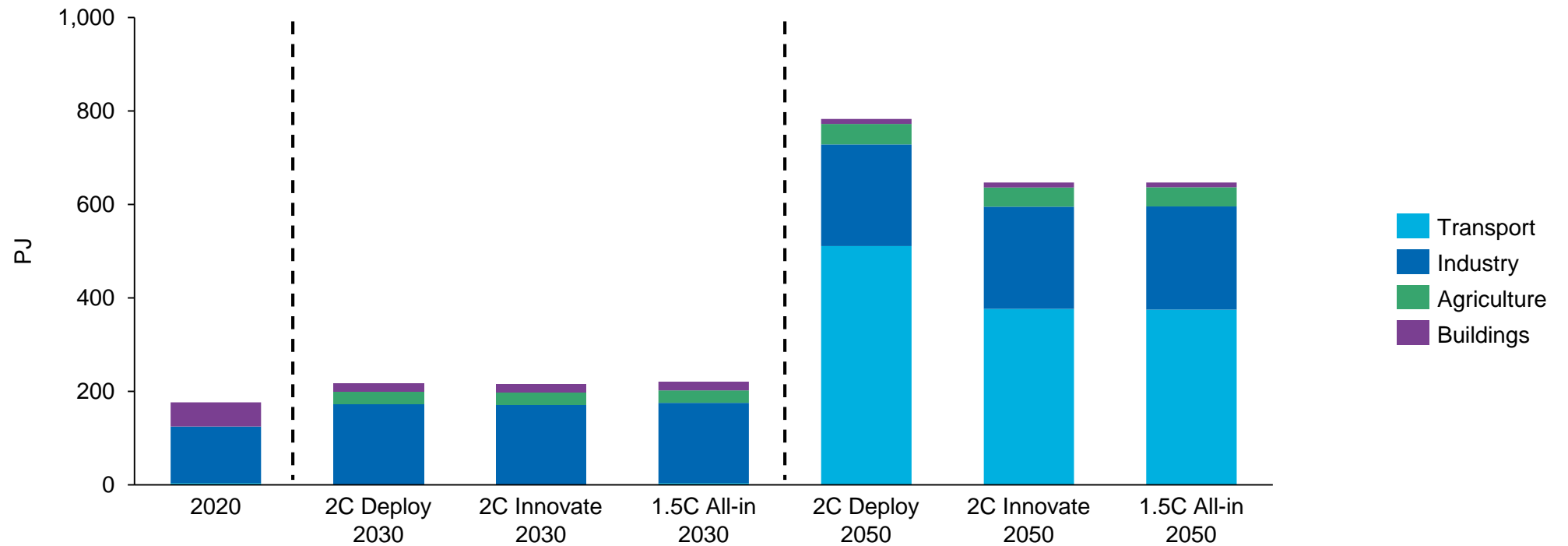


\* totals represent net emissions

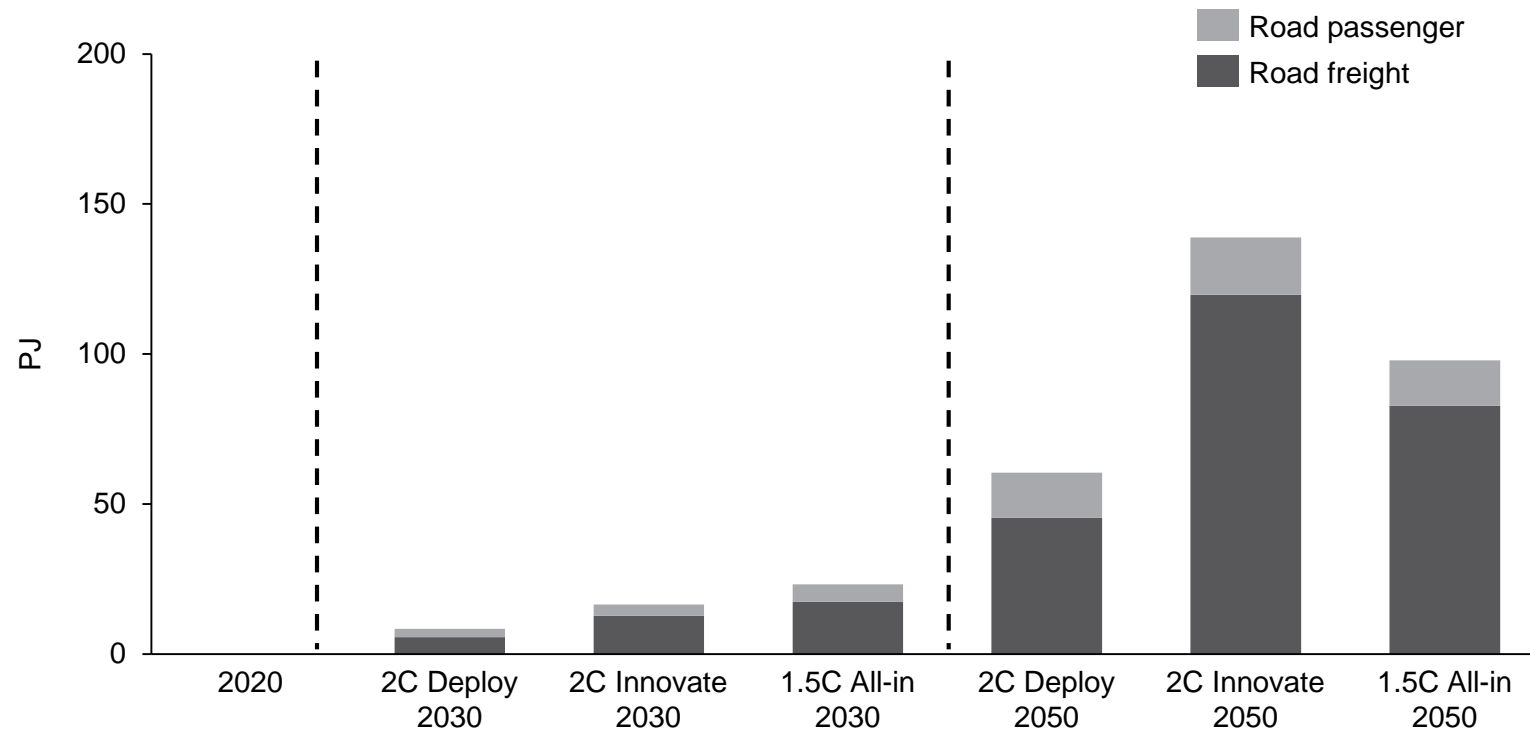
# Final energy use by fuel type in the modelled scenarios



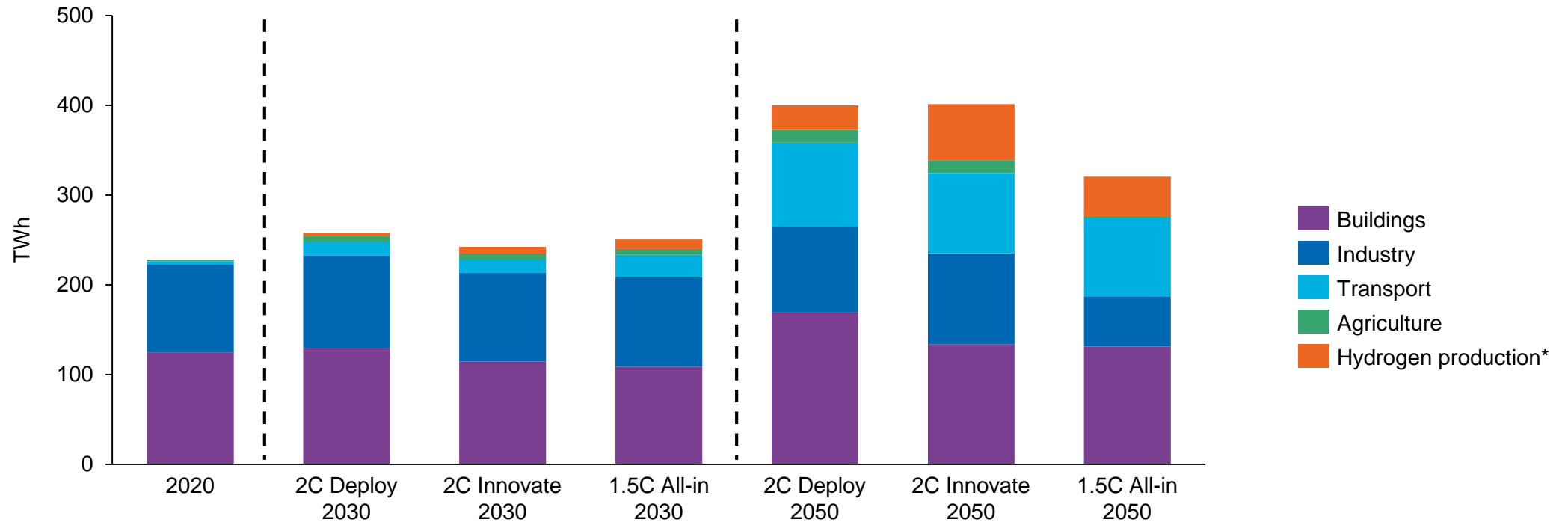
# Bioenergy use by sector in the modelled scenarios



# Hydrogen use in the modelled scenarios

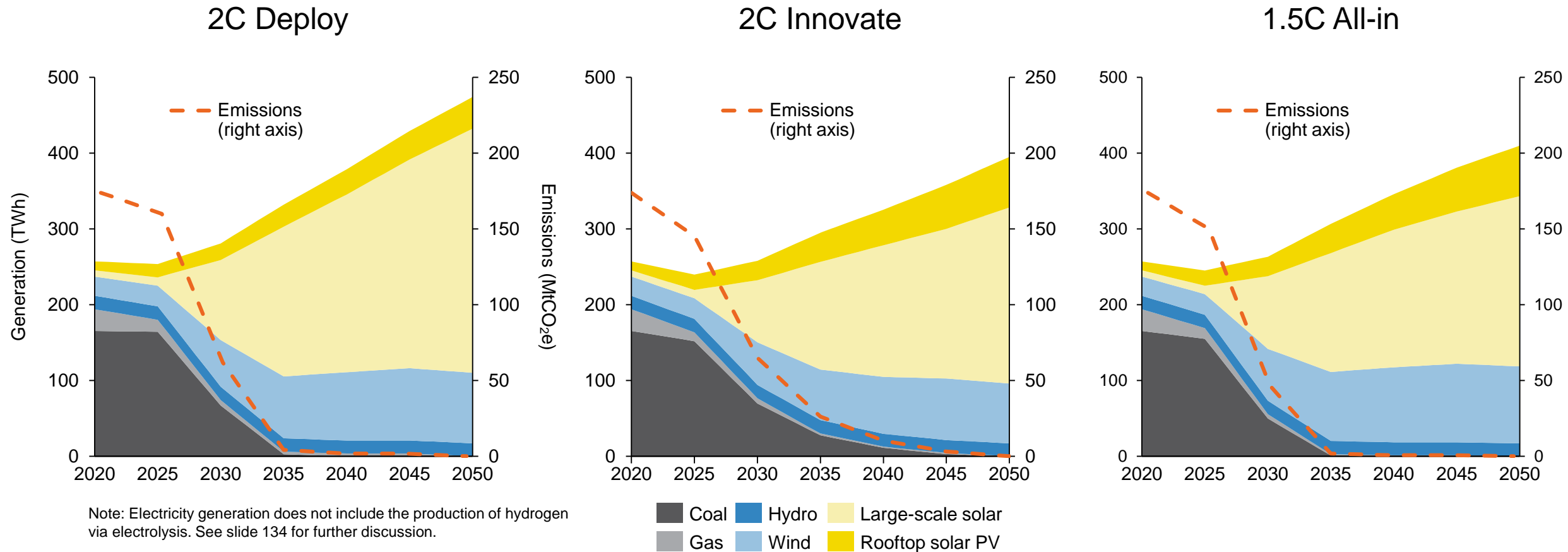


# Electricity use by sector in the modelled scenarios

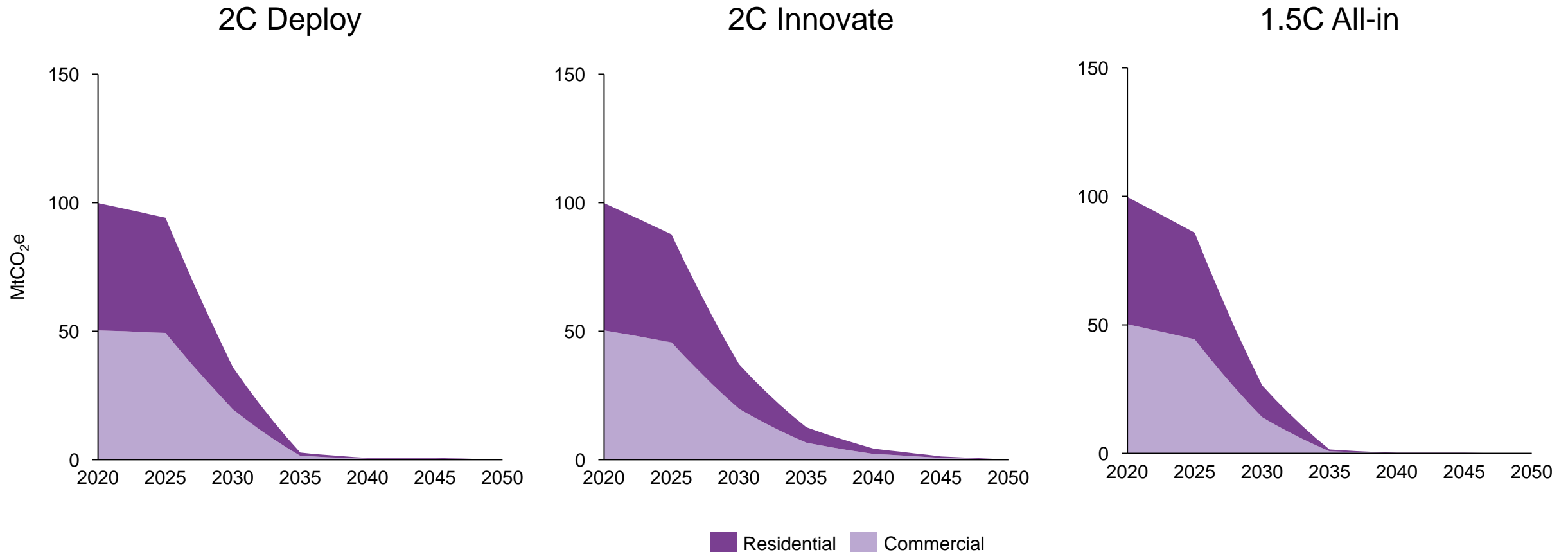


Note: Additional electricity demand from the production of hydrogen via electrolysis was not included in total electricity generation due to limitations at the time of modelling. Explicit hydrogen production pathways (electrolysis and steam methane reforming) are currently being implemented in Aus-TIMES model as part of an IEA project. Indicative electricity demand for hydrogen production is provided above, based on the level of hydrogen uptake in transport (see slide 133) and assuming 100% production via PEM electrolysis.

# Electricity generation and emissions by source in the modelled scenarios



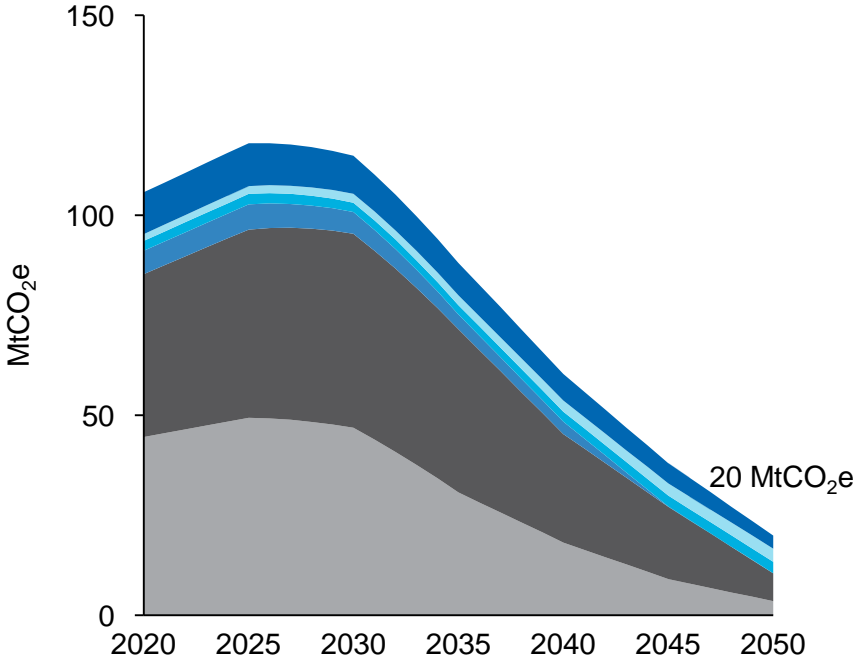
# Building emissions by sector in the modelled scenarios (Scope 1 & 2)



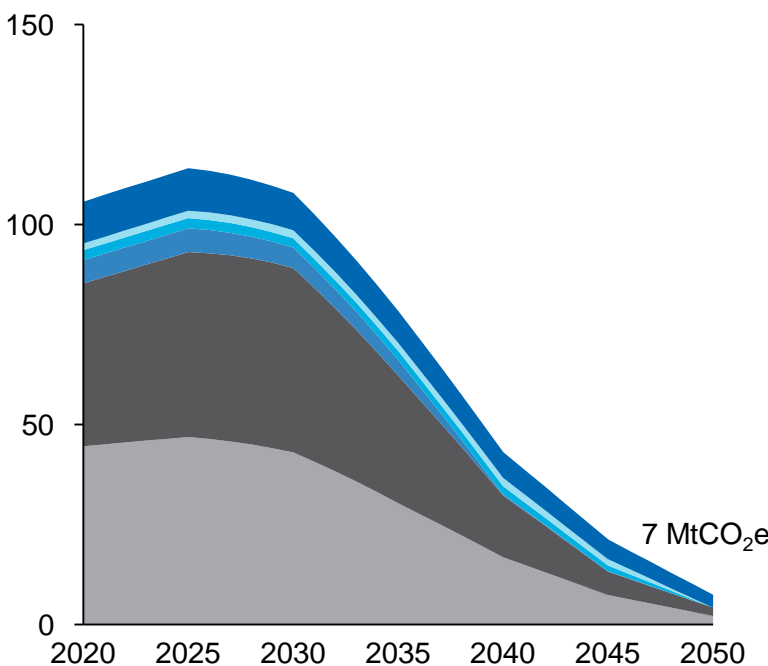


# Transport emissions by sector in the modelled scenarios (Scope 1 & 2)

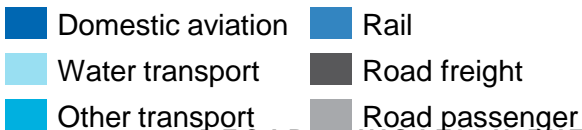
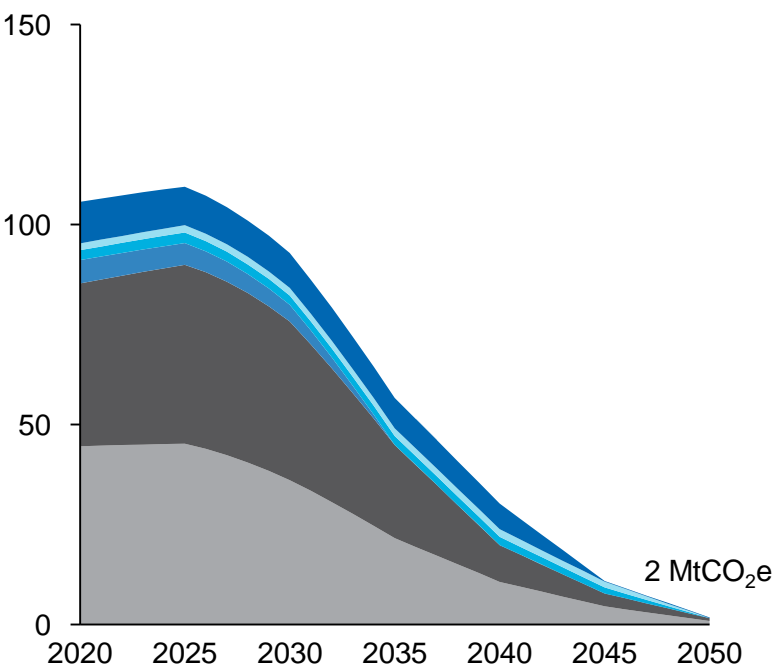
2C Deploy



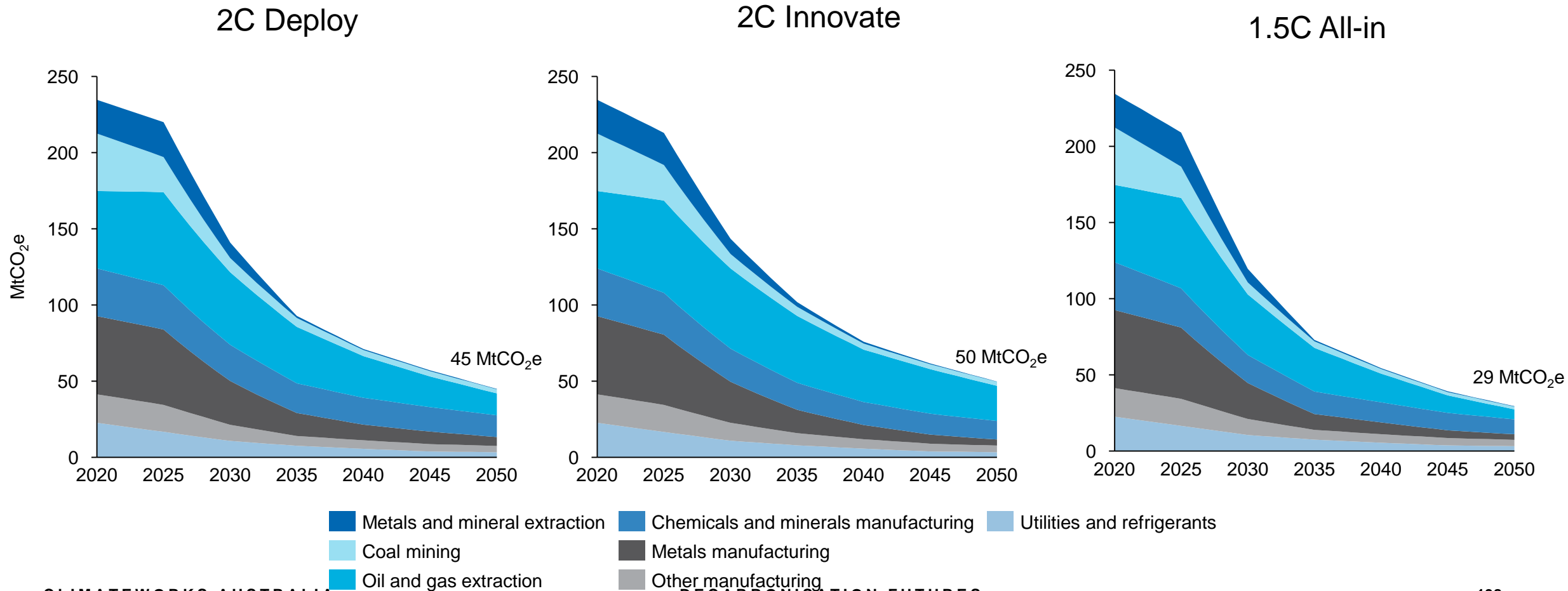
2C Innovate



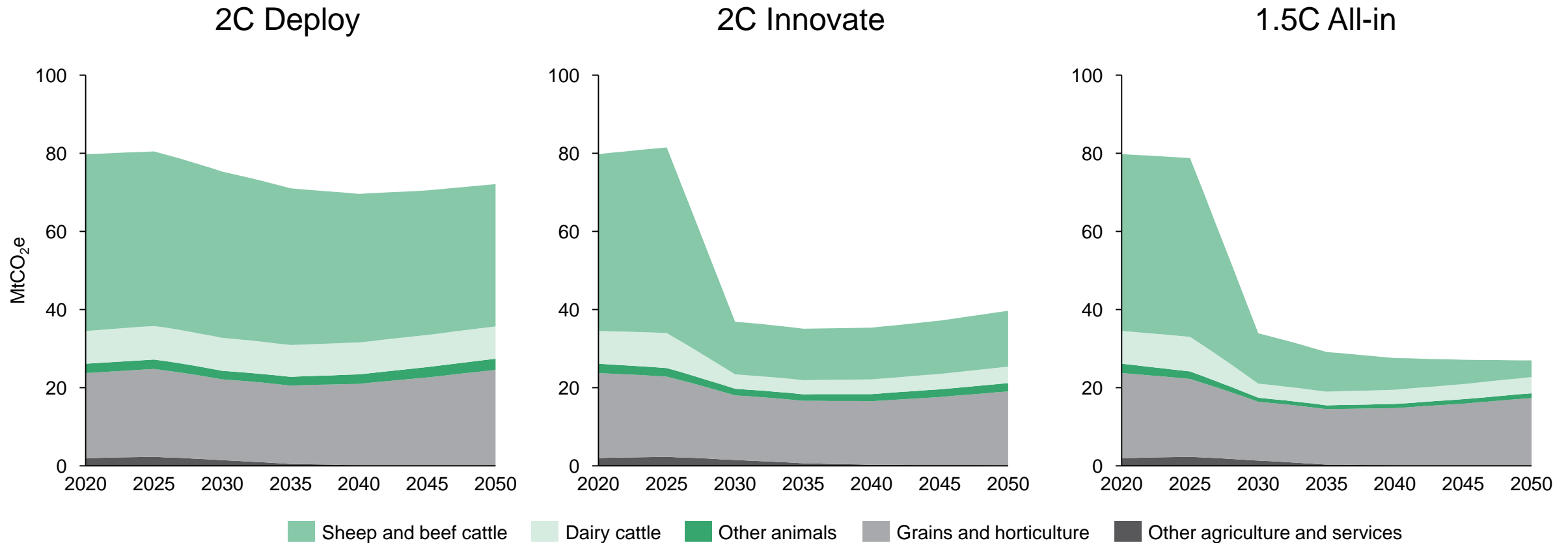
1.5C All-in



# Industry emissions by sector in the modelled scenarios (Scope 1 & 2)



# Agriculture emissions by sector in the modelled scenarios (Scope 1 & 2)



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ClimateWorks Australia was co-founded by Monash University and The Myer Foundation and works within the Monash Sustainable Development Institute



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