Industrial Decarbonisation: Hard to Abate Sectors

Power Session Webinar

29 April 2025

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Agenda and Housekeeping

Agenda

- Housekeeping and Introductions
- Review of the Australian Federal and State CO2 Targets
- Identification of Industrial Fuel Consumption and CO2 Emissions
- Examination of Key End Uses and Industrial Electrification Pathways
- Outlook for Key Abatement Options
- Takeaways and Recommendations
- Next Power Session Webinar

Housekeeping

This webinar is being recorded and distributed to all registrants along with this presentation

Add your questions to the chat. My colleague, Sara Gonzales, is monitoring the chat for the Q & A session

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CO2 Emissions Targets

Paris Agreement

Australian Emissions

State Targets

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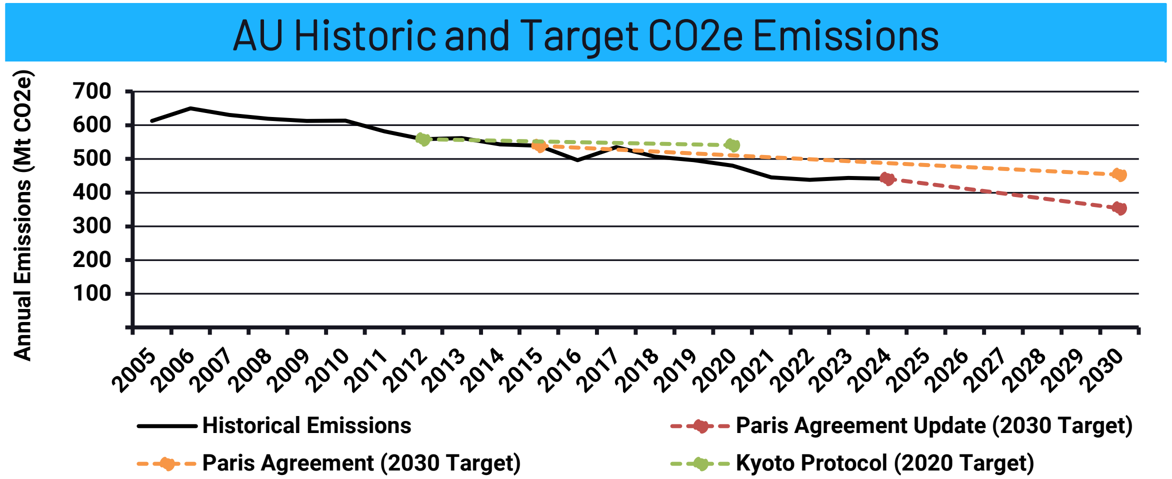
Paris Agreement and the AU



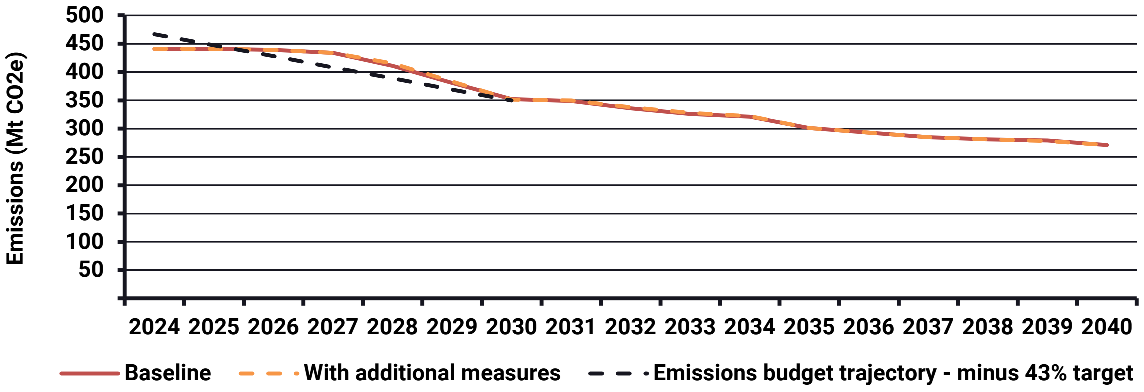
Source: DCCEEW (2024), Note: Note: Target trajectories are shown from the year the target was set to the target year

- The Paris Agreement targets limiting global warming below 2°C, with an additional goal to keep global temperatures below 1.5°C, from pre-industrial levels
- The current AU targets include a 43% reduction in 2005-level (baseline) emissions by 2030 and a net-zero goal for 2050
  - Energeia notes that the Department of Climate Change, Energy, the Environment and Water (DCCEEW) has modelled AU emissions projections as achieving both their GHG emissions reduction target and emissions budget target by 2030
- Every 5 years, each country must submit a climate action plan, known as a Nationally Determined Contribution (NDC), with the latest NDC submitted in June 2022 and the next NDC to be submitted in 2025
- While countries are not legally obligated to achieve their targets under the Paris Agreement, Australia is committed to meeting both its single year target to reduce GHG emissions and multi-year emissions budget by 2030
- Some AU states, which are detailed later, have committed to more ambitious emissions reduction targets, such as the ACT

Source: The Paris Agreement, United Nations (2015)

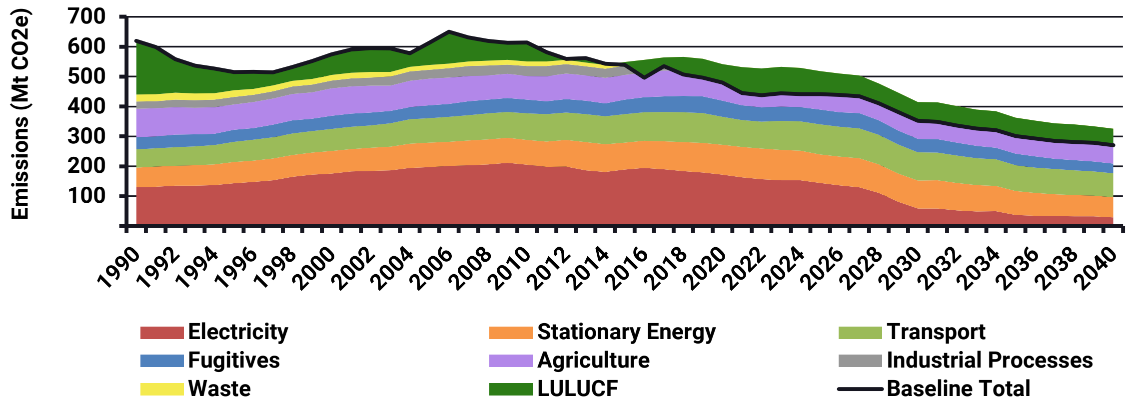
Australia's Emissions Projections

AU Baseline Emissions Projections by Scenario



Source: DCCEEW (2024)

Australia's Emissions Projections by Sector



Source: DCCEEW (2024)

- Baseline AU emissions projections show a sharp decline to 2030 followed by a steady fall to 2040, with minimal change between the baseline and 'with additional measures' (WAM) scenario, despite taking into account additional policies
  - **Baseline** – includes Australia, state and territory policies and measures which have been implemented or where detailed design is well progressed
  - **With Additional Measures** – builds on the baseline by providing insights into the impact of some policies that have been announced but where design or consultation are ongoing, including:
    - National Hydrogen Strategy
    - Critical Minerals Production Tax Incentive
    - Industrial Transformation Stream of Powering the Regions Fund
- The electricity generation sector continues to be the largest emitter of GHG in Australia, followed by the transport sector
  - The strongest emissions decline is projected in the electricity sector, driven by the expanded Capacity Investment Scheme (CIS) and state renewable energy targets
  - Transport emissions are also expected to decline over the forecast period, primarily due to the New Vehicle Emissions Standard (NVES), which will improve the fuel efficiency of the light vehicle fleet

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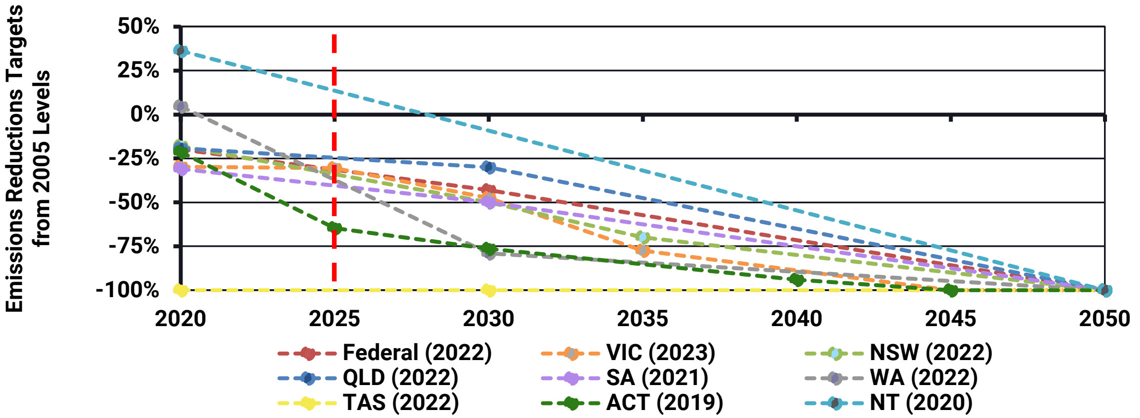
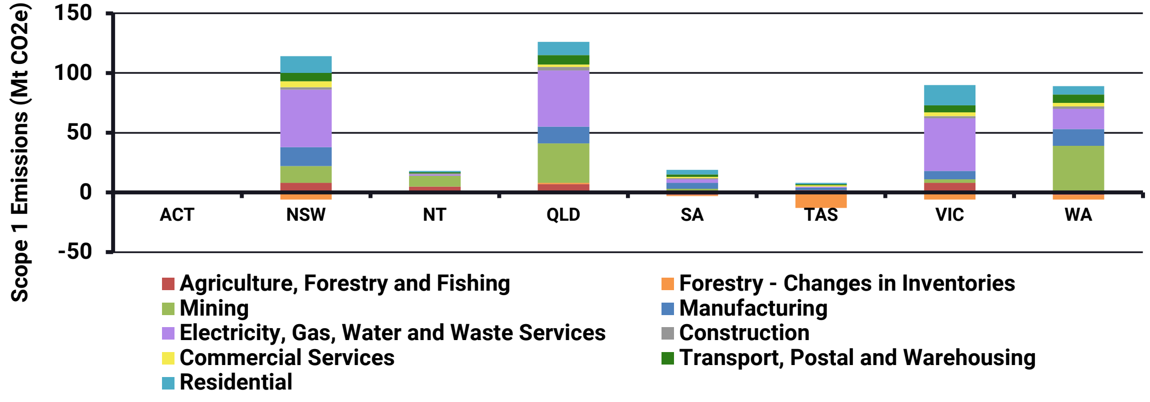
Australian CO2 Targets by Key State

Leading State and Federal CO2 Targets



Source: DCCEEW (2024), State Governments, Note: Energeia legend includes "State" ("Baseline Year") – = Current Year, 2020 datapoint is historical, TAS has already exceeded net zero target and are net negative

Leading States Emissions by Economic Sector (2022)



Source: DCCEEW (2022)

- State government targets vary across Australia, with each committing to individual targets to meet overall federal emission targets. Currently, only ACT and VIC are committed to a 2045 target
  - Energeia expects more to follow suit in the coming years
- As shown in the graphic to the left, the second highest sources of emissions after the power and transport sectors are other industrial sectors, e.g. mining, construction, manufacturing, etc.
- *A key question is how much will it cost the industrial sector to transition, and if a CO2 price is used, what level will it need to be to achieve emissions targets*

Industrial Energy Usage and Emissions

Energy Usage by Sector

Fuel Usage by Sector

Emissions by Sector

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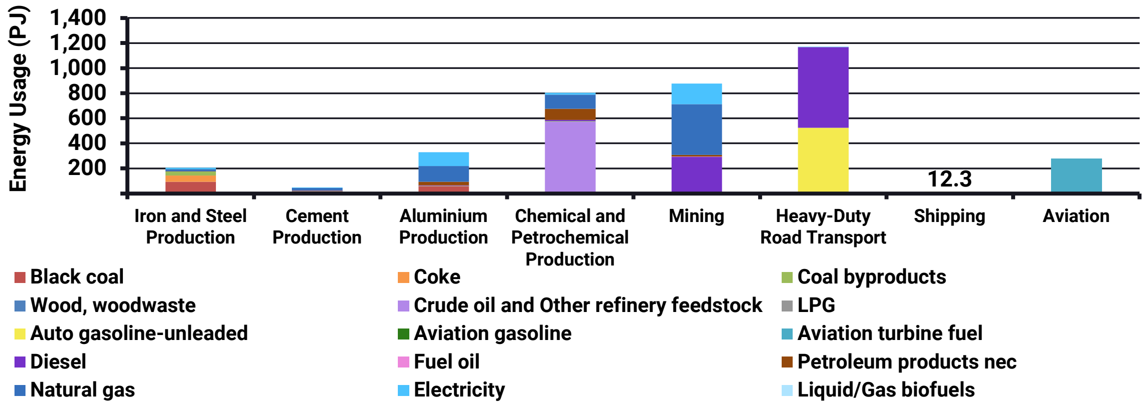
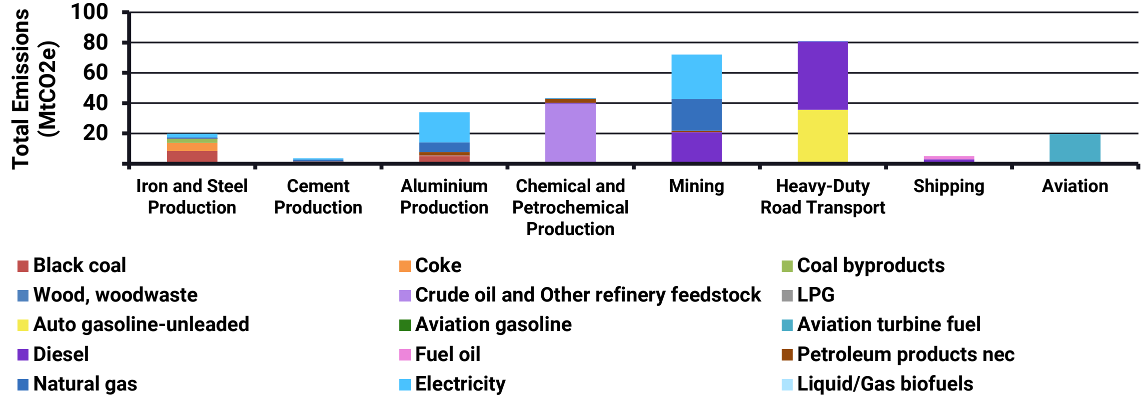
Industrial Energy Consumption and Emissions

Industrial Energy Usage by Type and Segment in 2023



Source: DCCEEW (2024)

Industrial CO2 Emissions by Type and Segment in 2023



Source: DCCEEW (2024)

- Industrial energy usage is shown by industrial segment and fuel type along with corresponding emissions
- Heavy duty transport, mining, chemical and petrochemical production, and aluminium production have the highest total energy use

- These same sectors generate more than double the level of CO2 than most other sectors
- We have focused on a subset of these, where more than electrification is likely to be required for a range of reasons

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CO2 Abatement Challenges and Pathways

Challenges by Sector

Potential Solutions by Sector

Costs to Abate by Sector

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What Makes Industry Sectors Hard to Abate?

Summary of Hard to Abate Industry Sectors

Sector	Main Hard-to-Abate Process	How It Produces Emissions
Iron and Steel Production	The conventional reduction of iron ore pellets uses the blast furnace or direct reduced iron (DRI) method to produce liquid iron. Both use high temperatures (1,650°C and 900°C) and carbon monoxide as the reducing agents	Fossil fuels are burned to achieve extreme temperatures, creating CO2, and are required to produce the carbon monoxide reducing agent, which can escape
Cement Production	The calcination of limestone in cement kilns utilises extreme heat (1,450°C) to produce clinker - a key ingredient in cement	Fossils fuels are burned to achieve extreme temperature, creating CO2, and additional CO2 naturally escapes from within the limestone in which it was once trapped
Aluminium Production	Alumina is refined from bauxite in a process involving high-temperature calcination (1,000°C+) which is then used in a molten (950°C) reduction-oxidation reaction with a carbon anode to produce pure aluminium	Fossil fuels are conventionally burned to refine alumina and are also burned to produce the molten bath chemistry to produce aluminium, where CO2 is a product of the oxidisation of the carbon anode
Chemical and Petrochemical	Production of olefins, produced through high-temp (750-900°C) steam cracking of hydrocarbons, and aromatics, produced through catalytic reforming using high-temp (500°C+) dehydrogenation	Fossils fuels are conventionally used to produce the extreme heat required, generating emissions and are often utilised in the production process (e.g. natural gas for steam methane reforming in ammonia production)
Mining	Energy-intensive processes, including extraction (e.g. boring, drilling, blasting), pulverisation (e.g. surface griding, volume grinding) and on-site material transport (haulage), are conducted using heavy machinery	Heavy machinery typically powered by emissions generating fossil fuel engines, explosives produce carbon monoxide, and broken rocks can release trapped gasses (e.g. methane)
Heavy Duty Transport	The engine combustion process to convert the chemical energy of fuel into thermal energy which is transformed into mechanical energy	When diesel fuel is injected into the combustion chamber, it mixes with the hot, compressed air and ignites at high temperature and releases carbon dioxide (CO2), nitrogen oxides (NOx), and particulates into the atmosphere
Shipping	The engine combustion process to convert the chemical energy of fuel into thermal energy which is transformed into mechanical energy	Low sulphur fuel oil (LSFO) and Heavy fuel oil (HFO) are injected into the engine's combustion chamber, where it mixes with hot compressed air and ignites and releases CO2, NOx, SOx, particulate matter, and other pollutants
Aviation	The expanding high heated gases from the combustion process push the turbine blades, converting the chemical energy of the fuel into mechanical energy	Jet A or Jet A-1 fuel is injected into the combustion chamber of the engine. The injected fuel mixes with the extreme hot, compressed air and ignites and produce CO2, Nox and SO2

Source: Energeia research

- Each of the hard to abate processes generally involve one of the following:
  - Very high temps, which have to date been relatively high cost for electricity to achieve
  - CO2 as a feedstock
  - Petrochemicals as a feedstock
  - CO2 as a byproduct
  - Relatively light-weight fuel (aviation)
  - Relatively dense fuel (shipping)

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Key Solutions for Hard to Abate Processes

Summary of Solutions for Hard to Abate Industry Sectors

Abatement Solution	Description
Energy Efficiency	Emissions are reduced by increasing efficiency of current process
Electrification	Electricity used for heating or motor
Alternative Processes	Alternative processes avoids emissions
Green Hydrogen	Used as synthetic feedstock into chemical production
Biofuels	Used as synthetic feedstock as well as high density or light fuels
CCUS	Uses or buries emissions
Offsets	Offsets emissions, e.g. Land Use, Land-Use Change and Forestry (LULUCF)

Source: Energeia, Note CCUS = Carbon Capture, Utilisation and Storage

Potential Solutions by Section

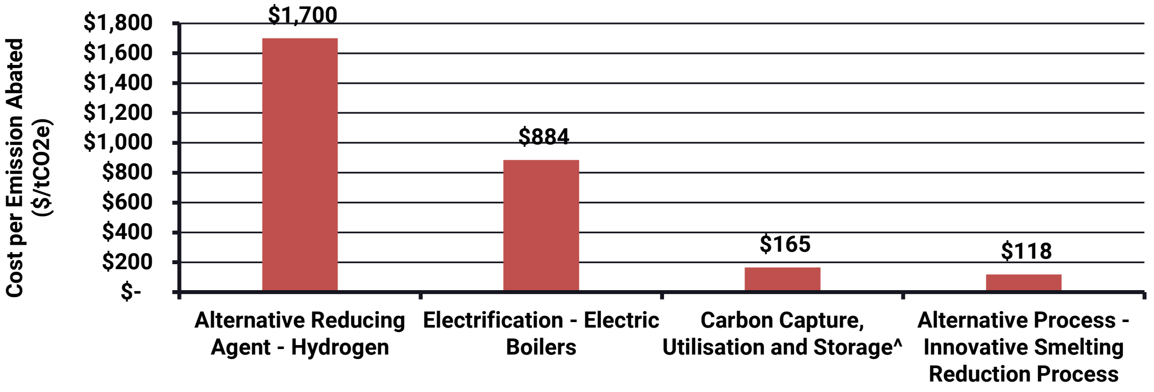
Sector	Decarbonisation Options						
	Electrification	Energy Efficiency	CCUS	Alternative Processes	Hydrogen	Offsets	Green Fuels
1. Iron and Steel Production	✓	✓	✓	✓	✓	✓	✓
2. Cement Production	✓	✓	✓	✓	✓	✓	✓
3. Aluminium Production	✓	✓	✓	✓	✓	✓	✓
4. Chemical and Petrochemical	✓	✓	✓		✓	✓	✓
5. Mining	✓	✓	✓		✓	✓	✓
6. Heavy-Duty Road Transport	✓	✓			✓	✓	✓
7. Shipping	✓	✓			✓	✓	✓
8. Aviation	✓	✓			✓	✓	✓

Source: Energeia analysis

- Different hard-to-abate sectors benefit from different solutions for emissions abatement
- Mixed solutions may be required for different processes within the same industry
  - Energy efficiency and alternative processes may not abate all emissions

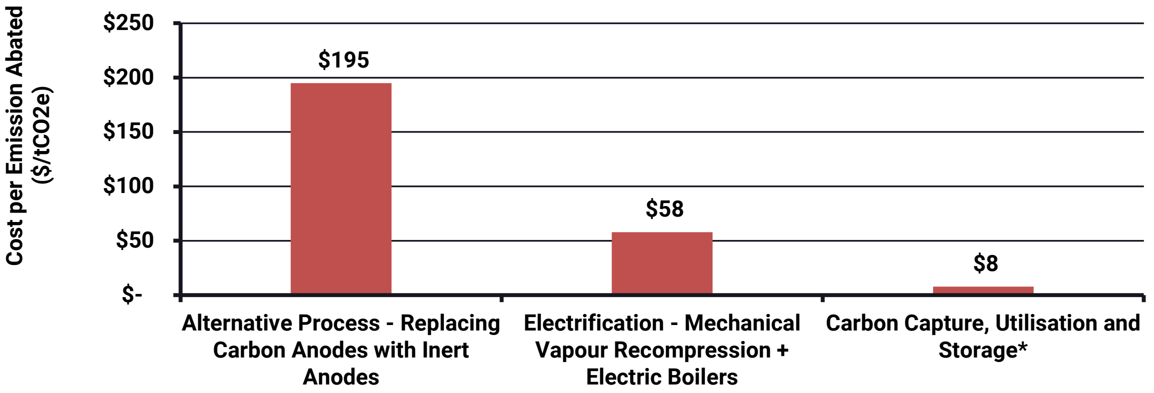
Cost to Abate by Solution and Sector (1 of 3)

Iron and Steel Production Costs by Key Abatement Solution



Source: Zuberi et al. (2022), IEA (2021 & 2020), ARENA (2021), Note * indicates a solution that can address all stages of production, ^ indicates a simplified levelised cost

Aluminium Production Costs by Key Abatement Solution

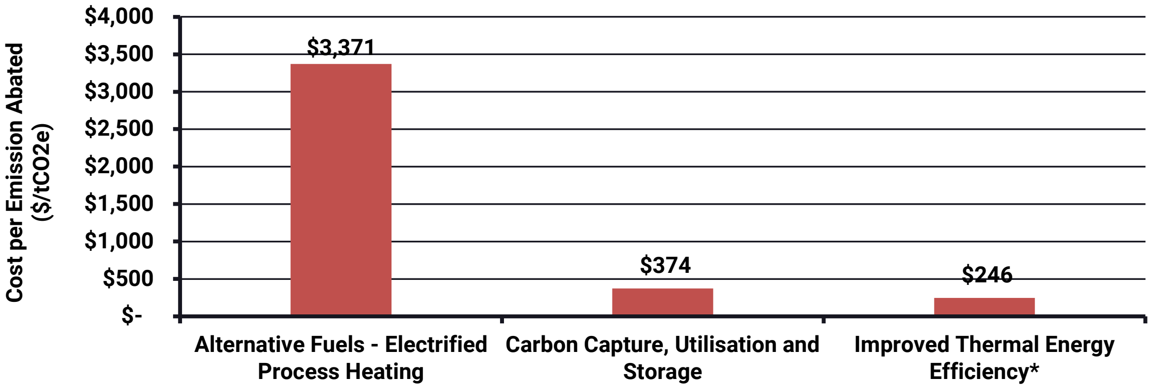


Source: Zuberi et al. (2022), Mission Possible (2022), ARENA (2022), Note * indicates a solution that can address all stages of production

- Energeia's analysis shows a wide range of costs among potential decarbonisation pathways for hard-to-abate industry sectors
- Importantly, many of the identified key solutions here, will not be able to reduce 100% of sector emissions, requiring a portfolio approach, and/or offsets
- Key Iron and Steel abatement options can be extremely expensive at $884-1,700/CO2e, with carbon capture, utilisation and storage (CCUS) or offsets reported to be more cost-effective solutions
- For Aluminium, there are a number of options at much lower cost, but as is the case for Iron and Steel, CCUS is the only solution (other than offsets) capable of achieving 100% abatement net of lower cost alternative process solutions
    - Note that the CCUS costs are vastly different between Steel and Iron vs. Cement, mainly due to the difference in capture and utilisation costs

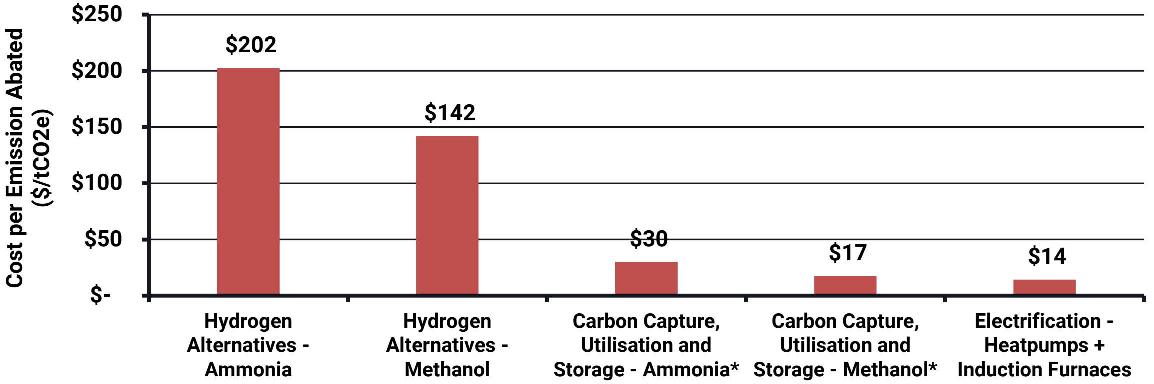
Cost to Abate by Solution and Sector (2 of 3)

Cement Production Costs by Abatement Solution



Source: Zuberi et al. (2022), Mission Possible (2022), ARENA (2022)
Note * indicates a solution that can address all stages of production

Petrochemical and Chemical Production Costs by Abatement Solution



Source: IEA (2021 & 2023)
Note * indicates a solution that can address all stages of production

- For cement, electrification of the heating process, CCUS and improving thermal efficiency are the key pathways, of which only CCUS can achieve the remaining abatement net of the lower cost, improved energy efficiency (EE)

- In the chemical sector, the pathway seems to be some electrification, but mostly CCUS as the most cost-effective solution that can deliver 100% abatement

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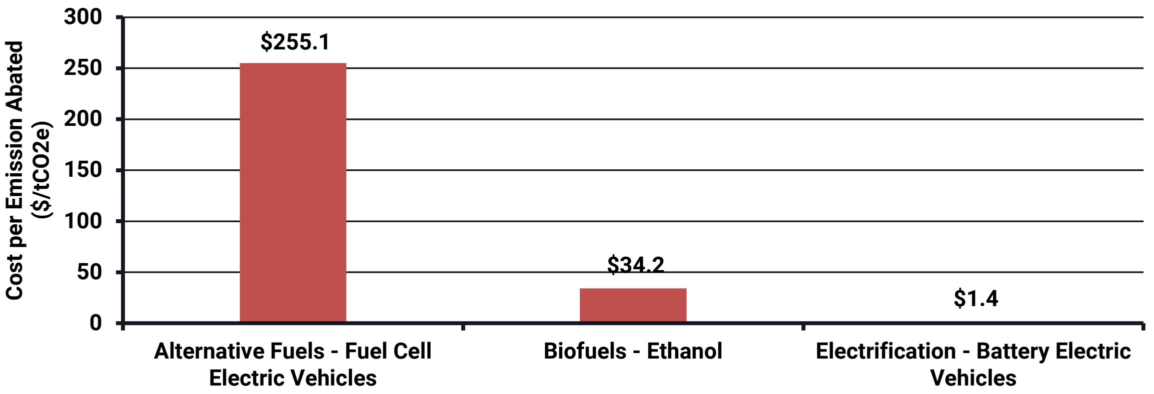
Cost to Abate by Solution and Sector (3 of 3)

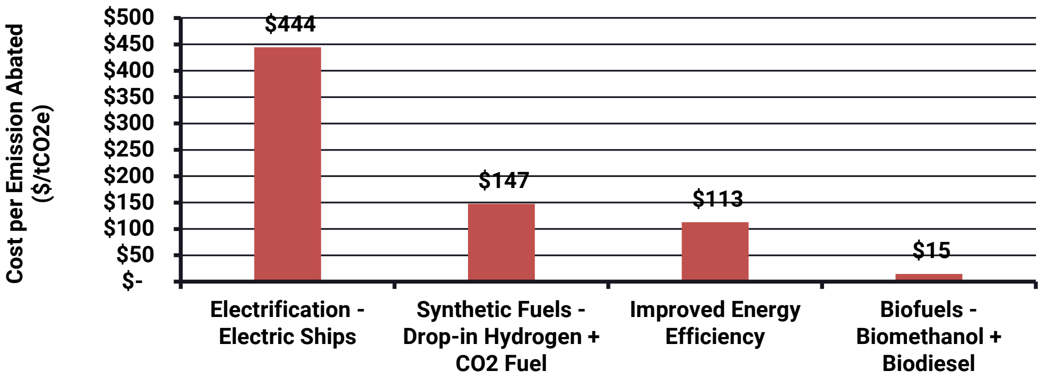
Heavy Duty Transport



Source: European Commission (2022), European Parliament (2023), freethink (2024), Energeia Research

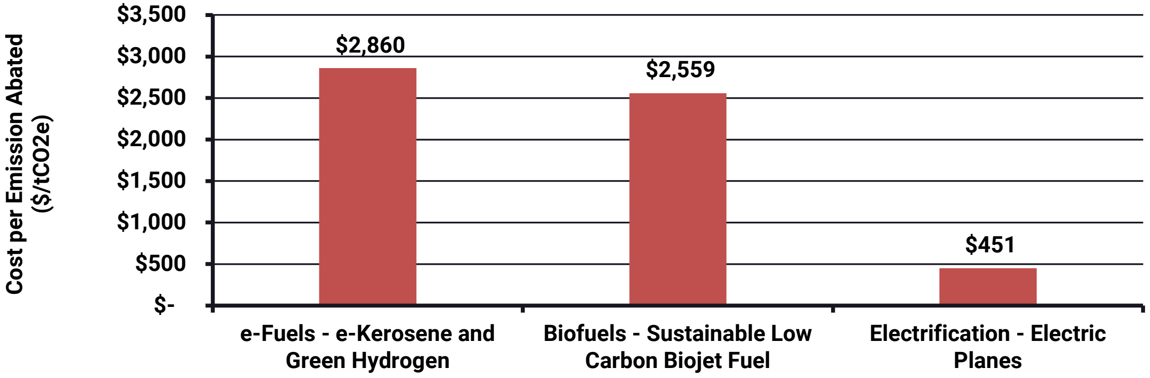
- Transport remains one of the largest emitting sectors that many countries are looking to decarbonise moving forward
  - Electrification least cost for short-distance road applications but becomes constrained by energy density for heavy duty transport
  - Biofuels provide a cost-effective solution for reducing emissions in existing fleets across all sectors despite its lower energy density
  - Alternative fuels (ie. hydrogen) offer potential but face infrastructure and scalability issues due to the immaturity of the technology
- Heavy duty and shipping appear capable of decarbonisation without CCUS or offsets, aviation remains high cost

Shipping



Source: ARENA (2024), Concawe (2022), Rony et al. (2023), NatureEnergy (2024), Energeia Research

Aviation



Source: ARENA (2024)

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Outlook for CO2 Prices and Abatement Solution Costs

CCS

LULU

Biofuels

Green Hydrogen

Carbon

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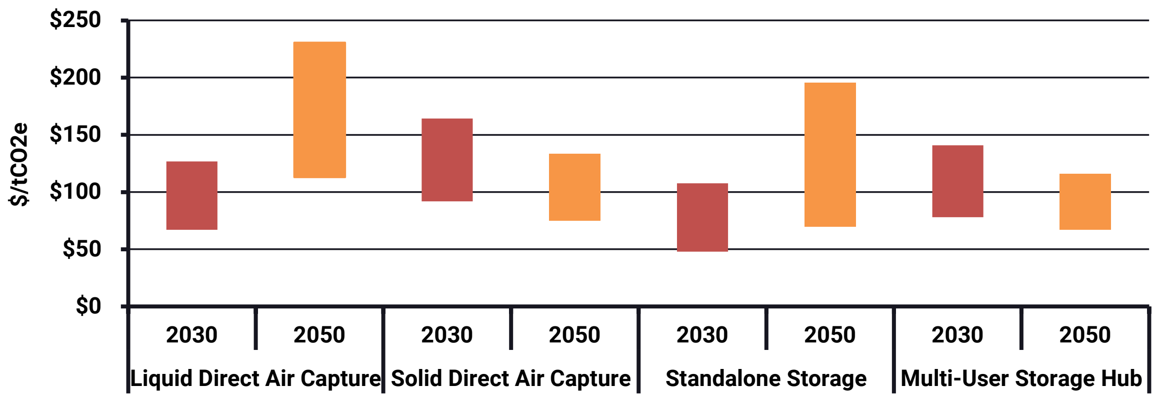
Cost of CCS and LULUCF Abatement

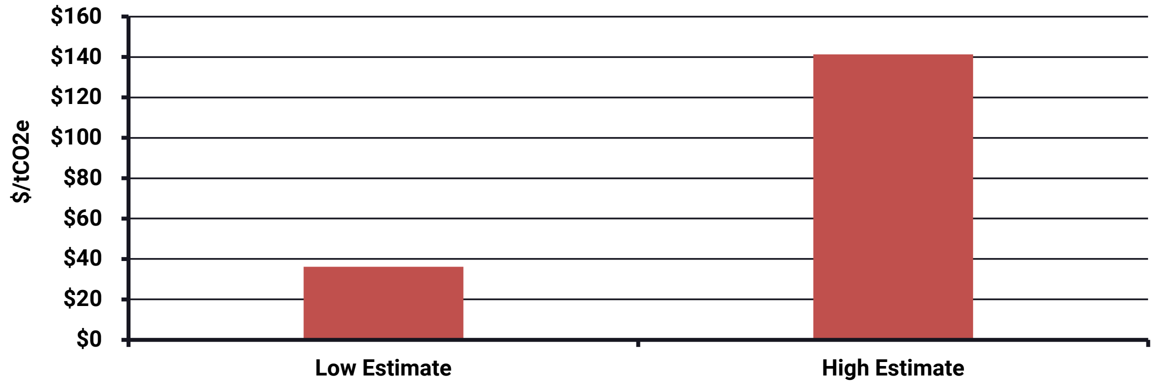
Carbon Capture and Storage (CCS)



Source: IEA (2022), Wood Mackenzie (2021)

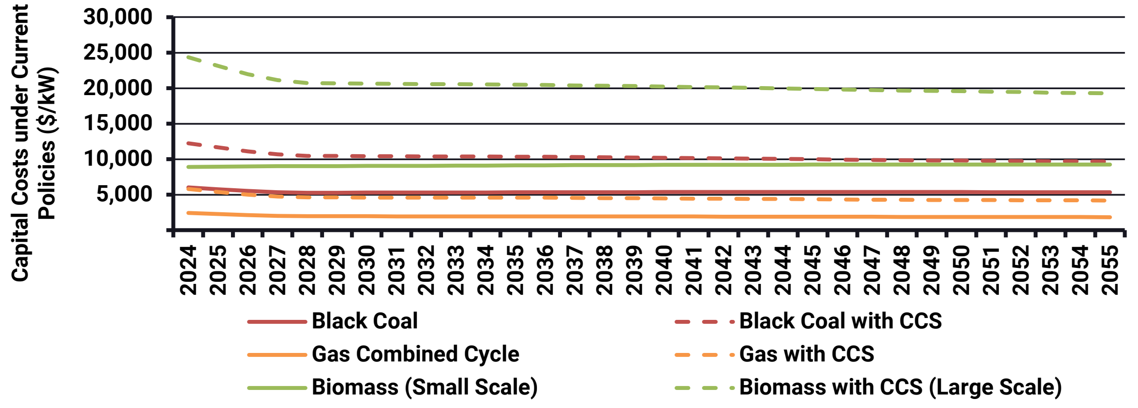
- The charts show the cost of carbon capture and storage and afforestation and storage as solutions for abatement
  - These are generic CCS abatement costs, which will vary by sector due to differences in the cost of capture
  - Even high estimates of emissions abatement through afforestation are lower cost than carbon capture
- Carbon capture costs are consistent with forecast CO2 prices, suggesting they are likely to be the marginal abatement source
- CSIRO also projects that the capital costs of fossil fuel generation technologies will be roughly double with CCS

Land Use, Land-Use Change and Forestry (LULUCF)



Source: MIT (2024)

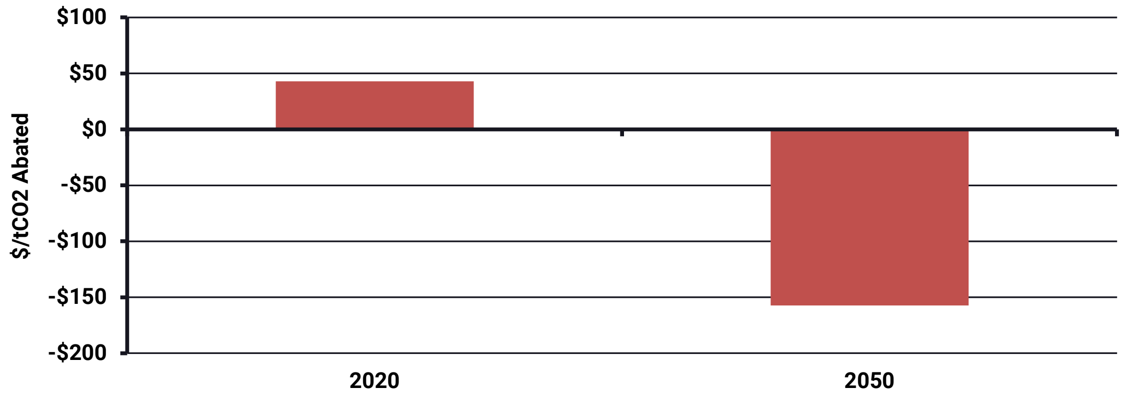
Projected Capital Costs for Technologies w/ and w/o CCS



Source: CSIRO Gen Cost 2023-24 Report

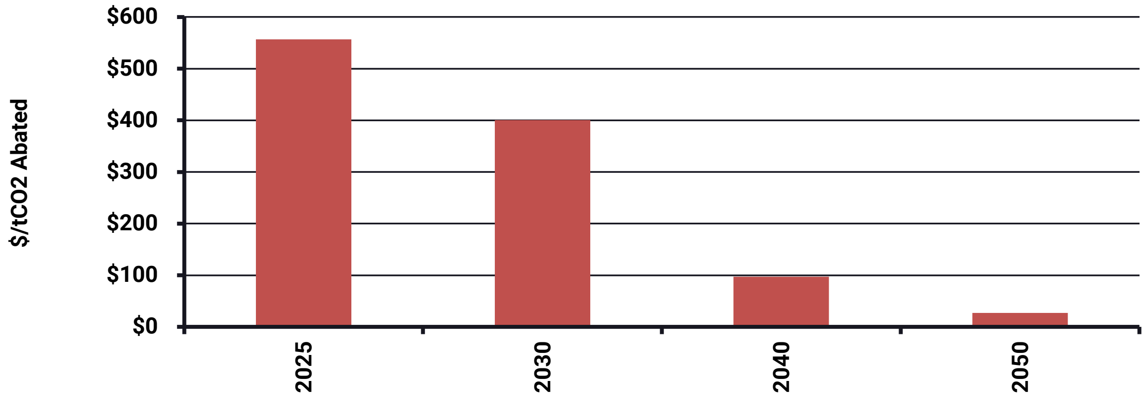
Cost of Biofuels and Green Hydrogen

Biofuels



Source: ARENA (2021), DCCEEW

Green Hydrogen



Source: PWC, AEMO, ACIL Allen

- The following charts show the cost of abatement when fuel switching
  - Abatement is dependent on the incumbent fuel source that is being replaced
- The upper chart shows diesel to biodiesel fuel swap over time
  - It is forecast that biodiesel will be an economic abatement solution between now and 2050
  - This assumes lifetime scope 1 emissions for biodiesel, which assumes 100% of CO_2 emissions are in balance. i.e. net emissions of production and use are 0 tCO_2
- The lower chart shows green hydrogen as an abatement option compared to natural gas
  - Forecasts currently show that hydrogen is not forecasted to be competitive with alternative fuel options for transport

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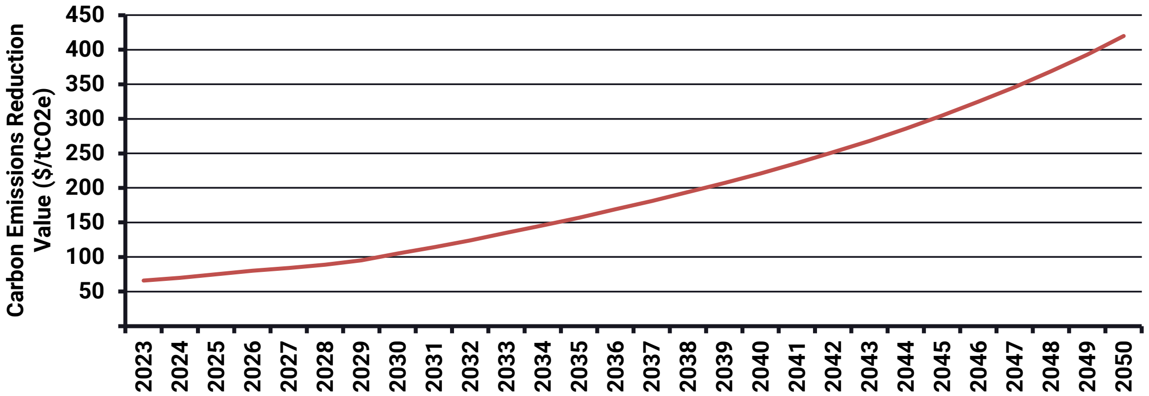
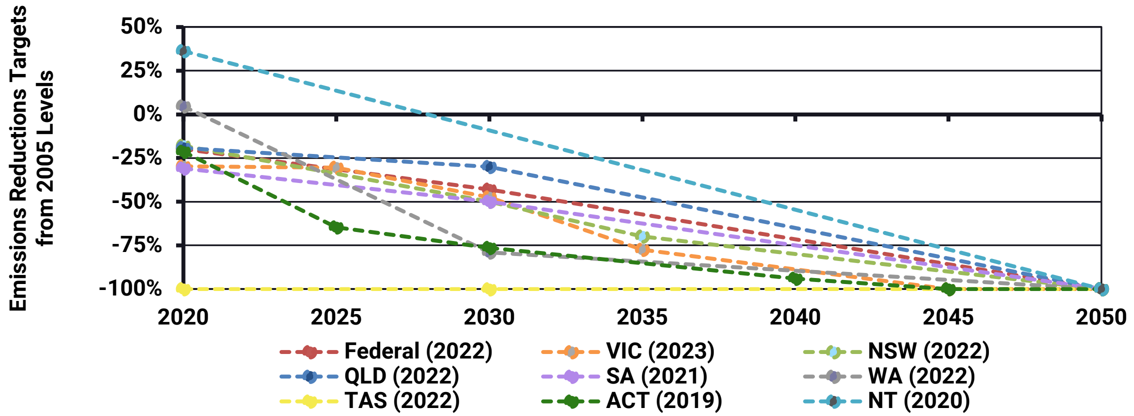
Cost of Carbon Abatement

Carbon Price ($ 2023)



Source: AEMC, MCE statement about the interim value of greenhouse gas emissions reduction (2024), https://www.aemc.gov.au/sites/default/files/2024-04/MCE%20statement%20on%20interim%20VER.pdf

Leading State and Federal CO2



Source: DCCEEW (2024), State Governments, Note: Energeia legend includes "State" ("Baseline Year") — — = Current Year, 2020 datapoint is historical, TAS has already exceeded net zero target and are net negative

- The value of emissions reductions, shown at left, increases over time and is based on an interim methodology established by the Ministerial Council on Energy (MCE)
- The CO2 price will need to be high enough to drive sufficient decarbonisation in each state to hit its target
- Based on the previous analysis, it suggests that electrification will be needed to achieve the reductions
  - A lower price, consistent with CCS/CCUS would indicate that CCS/CCUS would be the marginal source of CO2 abatement

Takeaways and Recommendations

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Takeaways and Recommendations

- **Takeaways**
  - Energy, stationary energy, and transport sectors represent 2/3 of baseline emissions in Australia
  - Of these, a large proportion of them are not suited to electrification for a range of reasons
  - While specific solutions are being developed in each case, they can be very high cost
  - CCS/CCUS and offsets are general approaches that may be needed to achieve abatement targets
  - A key question is how accurate the CCS / CCUS cost estimates are
- **Recommendations**
  - Electric high temp heat technologies are a key solution that will be essential to the transition
  - R&D focus will be key to bringing its cost down
  - While biofuels are relatively low cost, there are not enough of them to meet all needs
  - Green hydrogen will be needed to provide feedstock, and the focus should be on this application
  - Much is riding on CCS / CCUS and LULUCF, and additional effort should be focused on them to bring cost down and ensure capacity

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Q & A

Next Power Session Topic

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  - Heavy/Medium Transportation Electrification
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  - Electrification Workforce Analysis and Planning

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Bridging the Skills Gap:
Workforces for Electrification

17 June 2025
9:30 AM – 10:00 (AEDT)

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