Beneath the surface:
The economic potential for carbon capture and storage in Australia's eastern states

Low Emission Technology Australia

July 2025

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Readers are advised that the outcomes provided are based on many detailed assumptions underpinning the scenarios, and the key assumptions are described in the Report. These assumptions were selected by the Client. The modelled scenarios represent three possible future options for the development and operation of the CCS Market, and it must be acknowledged that many alternative futures exist. Alternative futures beyond those presented have not been evaluated as part of this Report.

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Executive summary

Carbon capture and storage (CCS) is a vital technological development for mitigating the impacts of climate change, especially by removing emissions from heavy industrial activities like metal refining, mining, cement production and fertiliser manufacturing. As an engineered carbon dioxide removal method, alongside nature based solutions, CCS plays a key role in addressing climate change.

These technologies, which have been applied across the world for several decades, enable the capture, compression, and transport of carbon dioxide (CO_2) for alternative uses, or to permanently store in geological formations. Leading global and Australian organisations including the International Energy Agency (IEA), the Intergovernmental Panel on Climate Change (IPCC), Australia's Climate Change Authority (CCA) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) demonstrate a pivotal role for CCS in reducing hard-to-abate emissions and promoting energy security.

Australia has three flagship CCS operations — the Chevron operated Gorgon CCS facility on Barrow Island (offshore from Western Australia), the Santos operated Moomba CCS project (South Australia), and the CO2CRC operated Otway International Test Centre (Victoria). These facilities, and others in development, showcase the technical and economic feasibility of domestic CCS to utilise Australia's large scale geological storage resources.

However, the local industry currently lags leading countries like the US, UK and China which are actively developing integrated CCS hubs as part of their broader industrial and climate action strategies. A particular challenge for Australia is developing CCS on the east coast where progress has stalled but where much of the country's industrial and manufacturing base is located.

There is a distinct opportunity, now and over the next decade, to develop and deploy CCS to deliver cost effective industrial decarbonisation and support Australia's transition to net zero emissions by 2050.

Encouraging foundations for local CCS

Reinforcing its importance in the transition to a low-carbon economy, the foundations for a large and vibrant CCS industry in Australia appears to be encouraging.

- **High-quality geological formations** for CO_2 storage with considerable prospects for new storage resources to be discovered, including through the Australian Government's long term Resourcing Australia's Prosperity initiative which is assessing options for geological storage of hydrogen and CO_2.
- **Existing infrastructure** that is (mostly) strategically located and could be potentially repurposed for CCS.
- **Proven deployment** of local CCS projects.
- **Robust regulatory and legal frameworks** for CCS underpinned by Commonwealth legislation covering offshore CCS and various state regimes governing onshore CCS (Note: onshore storage of CO_2 is effectively banned in Queensland).
- **A skilled workforce** with strong transferability with Australia's gas and broader resources industries.

Key carbon removal technologies are expected to improve carbon management

A range of carbon removal technologies are being advanced and installed by industry to reduce industrial emissions at their source and remove CO_2 directly from the atmosphere at meaningful volumes.

- Engineered CCS solutions involve capturing the exhaust gases of industrial facilities and power plants using techniques such as post combustion, oxy-fuel combustion and direct air capture, transporting, and injecting the gases into underground formations like depleted gas fields and saline aquifers. Close to 100 CCS projects are now operating or being built around the world.

- Nature based solutions are a complementary form of carbon removal and involve techniques like afforestation, soil carbon sequestration, and ocean-based carbon removal. These approaches can provide an effective method of removing carbon from the atmosphere and can often deliver other environmental benefits.

While many forms of carbon removal are proven and deployable now, the large-scale rollout of these technologies faces challenges in terms of cost, technical development, and integration. Not all forms of carbon removal may be commercially viable and suitable for Australia. In broad terms, engineered solutions, predominantly due to their ability to be retrofitted to existing industrial and power plants, offer the greatest carbon abatement potential for Australia out to 2050.

Engineered solutions also provide permanent carbon storage. In contrast, nature based solutions can 're-emit' carbon during natural lifecycle processes, particularly during hotter and more dry periods of El Niño when growth is limited, and bushfires are more frequent.

Potential development pathways for CCS on the east coast

Given the volume of emissions reductions required to meet Australia's climate change commitments by 2050, the deployment of industrial CCS technologies at scale is likely to be crucial. Indeed, for many industries like cement, steel, and chemicals manufacturing — which are covered under the Safeguard Mechanism — CCS is likely to represent an important prospective pathway to decarbonise.

These hard-to-abate industries are major economic hubs, supporting approximately 130,000 jobs along Australia's eastern coast and generating over $130 billion in export value[1] in the past year, while also supporting a range of sectors, supply chains, and sovereign manufacturing capabilities. Indeed, the economic and environmental sustainability of these sectors is crucial to Australia's economic and strategic interests in the renewable energy transition, housing and infrastructure, and defence manufacturing.

This report sets out three scenarios (outlined below) for the potential development of CCS on the east coast as Australia transitions to net zero emissions by 2050. The scenarios showcase how CCS could develop over the next few decades based on the current volumes and location of industrial emissions, where storage basins are being developed (say in Victoria's Otway basin) and how, ultimately, a fully integrated industrial CO_2 transport network linking large scale storage facilities could emerge.

Importantly, the scenarios shown are not additive but represent discrete pathways (see Table 1) and are deviations from the base case. Due to investment lead times, achieving network and scale efficiencies, and the need for supportive regulatory conditions to be in place, the pathways diverge from around 2030. They are all consistent with achieving net zero target by 2050.

[1] EY analysis of DFAT trade statistics and ABS Labour Force Detailed data (EQ06)

Table 1: Overview of the east coast CCS development scenarios

Conditions	Moderate growth	Accelerated deployment	Sequestration nation
How CCS might develop on the east coast	Gradual expansion of CCS in industrial clusters	Coordinated efforts and investments enable widespread CCS adoption across industries and regions, lowering barriers for smaller-scale facilities	CCS becomes a cornerstone of Australia's decarbonisation strategy, supported by strong policy alignment, advanced technologies, and significant investment, positioning Australia as a global leader in CCS
How CCS could support industries on the east coast	Steady adoption in select industrial clusters in Victoria, with minimal expansion into other regions or industries	CCS technologies deployed at scale across states, with an emerging storage as a service and H_2-CCS industry	Industrial onshoring, decarbonisation of metallurgical coal mining through VAM CCS, and development of a domestic hydrogen sector increases the demand for CCS
Minimal scale thresholds for facilities which can afford to access CCS	Very large facilities producing around 1 $MtCO_2$ per year	Large facilities producing around 0.5 $MtCO_2$ per year	Medium-large facilities producing around 0.25 $MtCO_2$ per year
Regulatory conditions	Few changes from current settings	Supportive – Carbon storage permitted in Queensland from 2035	Supportive – Carbon storage permitted in Queensland from 2030

Source: EY analysis

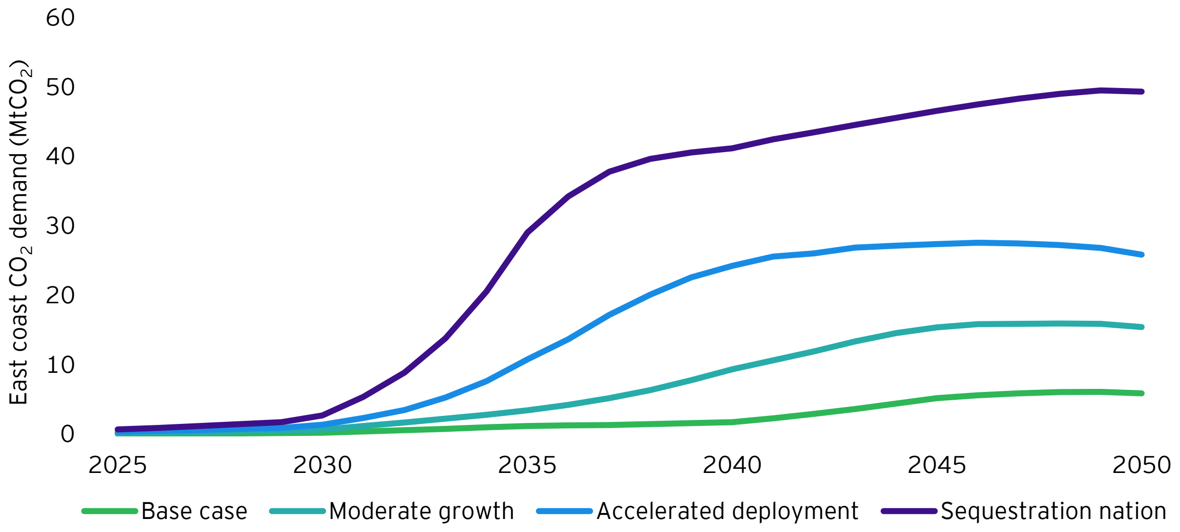
Note: These scenarios aim to explore the potential of CCS on Australia's east coast and were developed for the purpose of this study only.

Under the high growth 'Sequestration Nation' scenario where the right mix of regulatory, technology, and commercial settings are introduced, CCS deployment along the east coast could rapidly accelerate to 50 $MtCO_2$ in 2050.

A fully networked CCS industry along the east coast could increase economic activity by around $66 billion and support an additional 15,250 jobs over the coming decades.

Such a scenario would require a significant but achievable scale up in common-use infrastructure, reductions in upfront capital and ongoing costs, particularly for emerging technologies such as direct air capture, and effective coordination across government and industry.

Figure 1: Potential east coast demand for CCS under each scenario



Source: EY analysis

The potential economic dividends of capturing growth in CCS could be meaningful. Many hard-to-abate sectors such as cement manufacturing and steelmaking have limited decarbonisation technologies and are likely to be heavily reliant on CCS solutions to meet their emissions reduction targets. Accelerating the deployment of CCS could reduce the costs of decarbonisation for these important industries, improving their overall commerciality and sustainability, mitigating risks of deindustrialisation.

Industry expansion under each of the CCS development scenarios is projected to lift economic output (see Table 2). The lower trajectory CCS scenarios (Moderate growth and Accelerated deployment) also show meaningful economic gains but do not reflect the dividends for widespread adoption of CCS across Australia's east coast industrial landscape.

Table 2: Economic impact summary of results, deviation from base case, 2024 - 2050

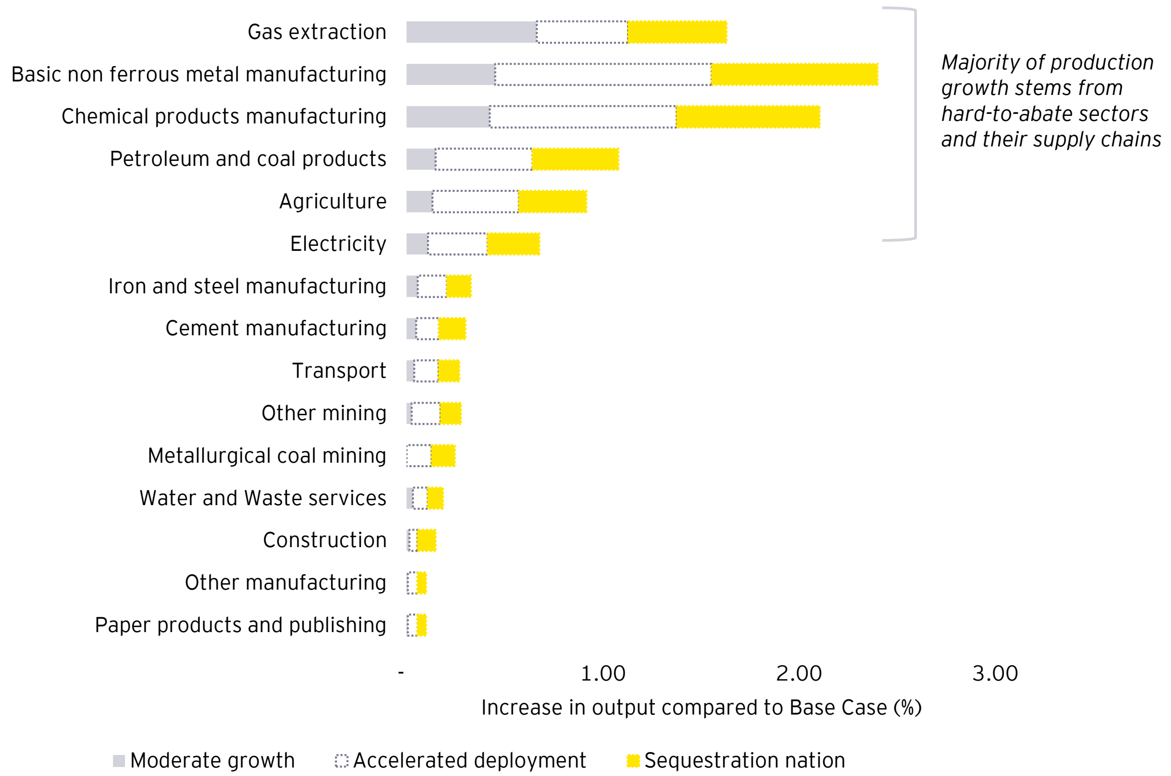
Economic outcome	Moderate growth	Accelerated deployment	Sequestration nation
GDP (NPV, $m)	13,777	39,822	66,231
Employment (average FTE)	3,800	10,200	15,261

Source: EY analysis

With increased deployment of CCS and lower economy-wide carbon abatement costs, economic output across a series of major industries could grow significantly (see figure below). This directly benefits heavy industries using CCS and their upstream and downstream supply chains, particularly construction and electricity generation – where economic output is projected to grow by up to $14.7 billion and $5.6 billion respectively under the Sequestration Nation scenario by 2050.

These industrial spillover benefits are crucial for advancing Australia's sovereign industry development agenda which will be heavily reliant on securing cost-effective decarbonisation, including for major industrial feedstocks.

Figure 2: Potential uplift in economic output across key sectors (deviation from base case)



Source: EY analysis

A foundation for industry in a net zero economy

CCS, especially its engineered forms, require long-term and capital-intensive investments. As such, there are a myriad of timing and coordination challenges to be managed if the technology is to be networked, derisked and made commercially accessible for smaller scale industrial facilities.

In realising these potential gains, there remain important barriers related to the technical and regulatory aspects of individual components of CCS:

- Some aspects of CCS are highly location-specific and will benefit less from international developments. This is especially the case for carbon storage, in which there are typically unique geological and spatial factors. Importantly, proving up storage resources is likely to involve larger development hurdles and longer lead times than commercialising capture and transport components. This places an increased emphasis on Australia making meaningful domestic contributions to demonstrate and prove up storage resources to accelerate the process of CCS commercialisation.

- Technical progress is needed to promote confidence in the performance of capture and storage technologies at industrial scale in Australian conditions. This would also bring down costs - with volume-weighted abatements costs projected to fall by almost $40 per ton of CO_2 in 2050 if CCS technologies are further developed. There is less technical risk on the network aspects of CCS and, accordingly, it appears there is greater confidence that the transport of CO_2 can be delivered at scale.

- Similar to much of the early development of Australia's gas pipeline infrastructure, it is feasible that government may derisk project economics or take an ownership stake in the 'backbone' of the CO_2 transport network.

- In addition to the barriers associated with individual components of CCS, there are substantial challenges for CCS from a whole-of-system perspective, especially on the east coast. For instance, delays on the availability of any single CCS component — capture, transport or storage — are likely to hold back deployment of the overall technology. Similarly, deployment of the technology may be impeded if there are delays on any of the separate technical, regulatory and market-related facets of commercialisation. The benefits in overcoming these issues, supported by the right policy settings, was a feature of the scenario analysis.

Ultimately, the existence of major economic spillover benefits and its contribution to Australia's climate change commitments provides a strong rationale for policy actions to encourage greater deployment of CCS — in both its engineered and nature based forms.

CCS deployment is integral in sustaining the growth and global competitiveness of Australia's hard-to-abate sectors, while still ensuring industry alignment with national climate goals under the Safeguard Mechanism. Indeed, the IEA projects that nearly half of the emissions reductions required to achieve net zero by 2050 will depend on technologies still in development—highlighting the urgency of accelerating innovation and large-scale deployment.

1. Introduction

Driving global decarbonisation and achieving net zero emissions will rely on securing affordable and accessible forms of carbon capture and storage (CCS). Analysis from leading global and Australian organisations such as the International Energy Agency (IEA), the Intergovernmental Panel on Climate Change, Australia's Climate Change Authority and Commonwealth Scientific and Industrial Research (CSIRO) demonstrate a clear role for CCS in reducing hard-to-abate emissions and providing energy security.

There are multiple methods of capturing or sequestering carbon emissions. These encompass engineered removals which involve carbon capture, transport, and storage in underground geological formations, as well as nature based solutions such as avoided land clearing, reforestation, and fostering Australia's carbon 'sinks'. The importance of deploying both forms of carbon capture and storage alongside other decarbonisation technologies — in effect, applying all the emissions abatement tools we have available — is a strong and consistent message from major international and Australian agencies.

Australia has excellent, world class geological storage and nature based resources for CCS and is well positioned to benefit from the development and deployment of these abatement technologies. EY has been engaged by Low Emission Technology Australia (LETA) to assess the economic potential for CCS technologies on the east coast of Australia. The report examines the commercial and regulatory factors impacting CCS deployment, their respective roles in targeting hard-to-abate sectors, and the economic dividends of coordinating and enabling investment into the technologies.

A focus on Australia's east coast

This report focuses on the opportunities for CCS in Australia's eastern states — Queensland, New South Wales and Victoria. These states are Australia's most populous and contain several large industrial hubs including Gladstone, the Hunter Valley, and the La Trobe Valley. These industrial hubs host significant emissions source points including Safeguard Mechanism-covered facilities which will be required to reduce their emissions over time.

As such and recognising that the east coast's CCS sector is still nascent, this report seeks to draw attention to the emissions abatement challenges facing major industries along the east coast, and their prospects should CCS and carbon removals grow and mature over time. In doing so, the report aims to complement similar work undertaken by the CSIRO that considers the role of CCS in the Northern Territory and Western Australia.

Key features of our approach

To inform our analysis and scenario development, we undertook a comprehensive program of research and economic modelling. This program featured the following core activities:

- Reviewing a broad suite of net zero modelling from global and Australian agencies to examine the role for CCS in global net zero transitions.
- Engaging with key stakeholders and experts in geosciences, heavy industrial processes (including steel and cement manufacturing), and Australia's energy transition.
- Conducting industry-specific modelling of the potential demand for CCS, the capital and ongoing costs associated with the technology, and its emissions reduction potential.
- Whole-of-economy modelling using EY's General Equilibrium Model (EYGEM) — a market-leading computable general equilibrium (CGE) model, which aligns with similar modelling techniques used across government to inform policymaking.

Report structure

This report is structured in the following chapters:

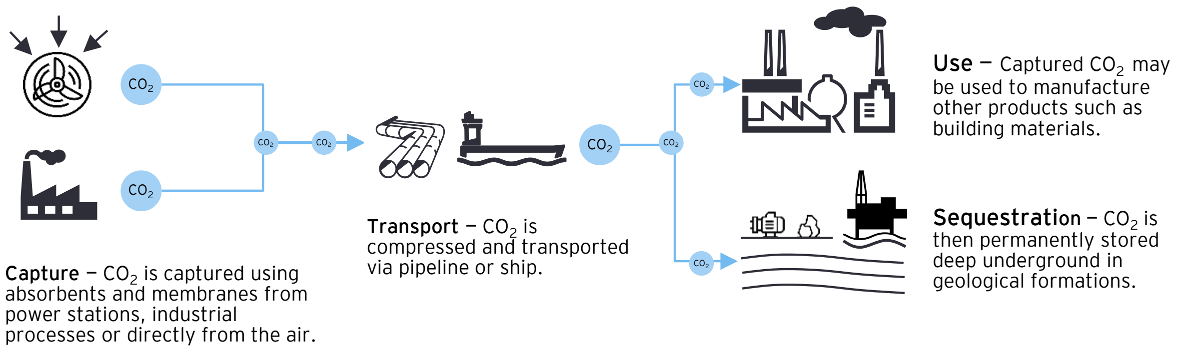
- **Chapter 2 – The policy and technology landscape** provides an overview of the technology and policy drivers for both engineered and nature based carbon removals. It showcases how these technologies operate, their current levels of deployability and where they can be optimal to lower emissions. The role of CCS abatement in key global emissions reduction scenarios is also discussed.
- **Chapter 3 – The cost and economics of CCS** examines the economics of CCS including its current and future costs, deployment options and where efficiencies of scale and scope are available. It highlights the role of building hubs to capture, aggregate and abate industry emissions over time across the east coast.
- **Chapter 4 – Future development scenarios for CCS on the east coast** present a series of development scenarios for CCS which consider alternative commercial, technological, and regulatory factors and how these could impact the growth of engineered and nature based carbon removals.
- **Chapter 5 – The potential economic impact of CCS deployment** build on the preceding analysis and examines the industry and broader economic outcomes of the scenarios. It shows how the development of CCS across the eastern states can help sustain and enhance Australia's heavy industrial activities and promote regional and sustainable development.
- Finally, some concluding perspectives are set out in **Chapter 6.**
- Technical details including scenario and modelling assumptions are provided in the appendices.

2. The policy and technology landscape

Carbon removal refers to a suite of engineered and nature based processes that facilitate the capture and storage of CO_2 emissions. These technologies are globally recognised as crucial to reach net zero emissions. Particularly, they will be critical in targeting emissions from hard-to-abate sectors such as heavy manufacturing, aviation, and fugitive emissions from cattle grazing. There are some important distinctions between engineered and nature based technologies:

- **Engineered carbon removals** refers to the use of technology to separate CO_2 from a gas stream at either the point of emission, or earlier in the industrial process, or by directly removing it from air (see figure below). Once captured, it is sequestered permanently underground in geological formations or may be used in the manufacture of other products. This is often referred to as carbon capture, utilisation and storage (CCUS). Carbon utilisation technologies are not a focus of this report.
- **Nature based carbon removals** focus on leveraging and enhancing the natural abilities of plant biomass, oceans and rocks to act as carbon sinks that capture CO_2 from the atmosphere and sequester it in plant biomass, seawater or as carbonate rock.

Figure 3: The engineered CCS lifecycle from capture to sequestration



Box 1: Carbon utilisation - potential use cases for captured carbon

Carbon utilisation refers to the process of capturing CO_2 emissions and converting them into useful products or materials, rather than sequestering it underground. There are numerous potential use cases for capture CO_2, including:

- As a feedstock for producing low-emissions or zero-emissions concrete and cement
- Synthetic fuels (methanol and ethanol) which can be used as alternatives to fossil fuels
- The food and beverage industry which can use captured CO_2 for carbonating drinks
- Enhanced oil recovery (EOR), which involves injecting captured CO_2 into oil reservoirs to assist in oil extraction – this is already a common carbon utilisation technique in the US
- As a raw material for producing chemicals such as urea, which is widely used in fertilisers, and other industrial chemicals
- Polymers and plastics, reducing petroleum-based feedstock requirements and abating some carbon emissions from plastic production

Carbon utilisation technologies are still in early development, and there are limited commercial examples currently available. While they are likely to be proved up and commercialised over the coming decades, this report focuses on carbon capture and storage technologies which are more widely commercialised.

2.1 The net zero transition, in Australia and abroad

The global response to climate change is underpinned by a network of international agreements, frameworks, and national commitments, all designed to reduce greenhouse gas emissions and mitigate the impacts of global warming.

Central to these efforts is the Paris Agreement, a pivotal mechanism that has unified countries under a shared goal of limiting global warming, fostering climate resilience, and driving sustainable national action. The agreement establishes a framework for countries to set nationally determined contributions (NDCs), which are essential for measuring progress toward emissions reductions. Its success depends on sustained international cooperation, robust policy implementation, and ongoing technological innovation.

In recent years, CCS has been increasingly recognised as a key technology for decarbonisation and achieving the goals set out in the Paris Agreement. The following global bodies underscore the importance of deploying CCS alongside renewable energy, energy efficiency, and other solutions as part of a comprehensive strategy to combat climate change.

- **The Intergovernmental Panel on Climate Change** (IPCC) has emphasised the necessity of CCS in multiple pathways to limit global warming to 1.5°C or 2°C, particularly in hard-to-abate sectors such as heavy industry and energy.
- **The International Energy Agency** (IEA) has outlined detailed roadmaps showcasing how CCS can contribute to reducing emissions by capturing billions of tonnes of CO_2 annually by mid-century.
- **The United Nations Framework Convention on Climate Change** (UNFCCC) recognises CCS within its mechanisms, particularly as part of discussions on technology transfer and innovation.
- **The World Resources Institute** (WRI) also advocates for CCS as part of an integrated approach to carbon management and climate action.
- **The Clean Energy Ministerial** (CEM) promotes CCS through its *Carbon Capture, Utilization, and Storage Initiative*, fostering collaboration between governments, industries, and stakeholders to scale up deployment.
- **Numerous governments including the US, UK, Norway, and Indonesia** have set the regulatory and commercial preconditions to attract significant investment into their domestic CCS sectors.

Carbon capture and storage is globally recognised as a fundamental net zero solution

Achieving net zero emissions by 2050 is a vital goal in the global objective to mitigate the impacts of climate change and limit global warming. While major emissions reductions across all sectors will be essential, carbon removals are expected to play a critical role in reaching net zero.[2] Hard-to-abate sectors in particular produce emissions that are technically or economically challenging to eliminate entirely. CCS technologies represent one of the only viable opportunities to address these residual emissions, helping hard-to-abate sectors to reach net zero.

Modelling undertaken by the IPCC, IEA and World Bank all demonstrate the important role of CCS in reaching net zero. The figure below shows the spread of CCS demand across global scenarios, ranging from around 6 Gt to 8.5 Gt in the core scenarios outlined below, which includes both nature based and engineered removals.

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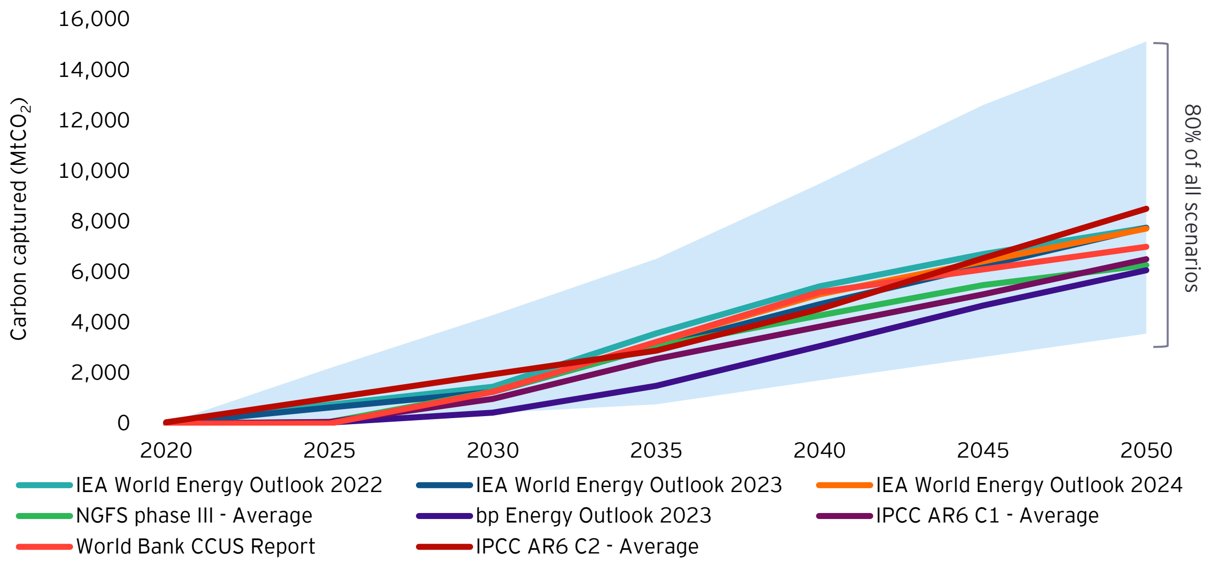
[2] Brunner C, 2024, Durability of carbon dioxide removal is critical for Paris climate goals

Figure 4: Carbon removals (nature based and engineered) under net zero scenarios (Includes IPCC AR6 C2 Scenarios)



Source: EY Analysis of the IPCC AR6 scenario data, NGFS phase III scenario data, IEA World Energy Outlook 2022, IEA World Energy Outlook 2023, IEA World Energy Outlook 2024, bp Energy Outlook 2023 and, the World Bank Decarbonizing Natural Gas through Carbon Capture, Utilization and Storage, 2023[3]

The mix of carbon removal technologies differs across scenarios, but highlights the importance of scaling up capture technologies

The scenarios outlined above each involve different mixes of carbon removal technologies, including from nature based solutions, direct air capture, hydrogen production, and industrial emissions.

Under the IPCC's C2 scenarios, nature based solutions make up roughly two-thirds of carbon stored, and engineered removals making up the remaining one-third of carbon stored. While nature based solutions could play an important role, growth in engineered carbon removals is critical to global decarbonisation:

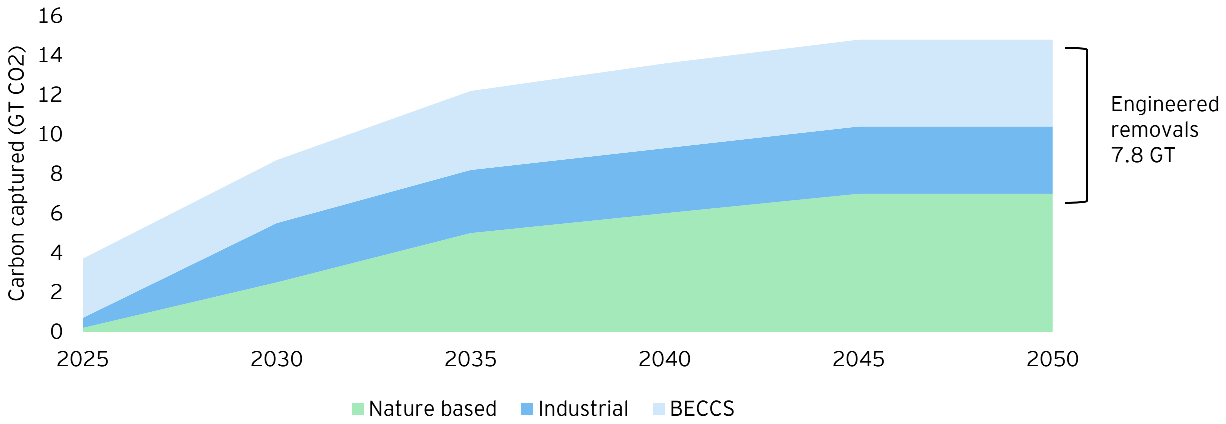
- A massive scale up of engineered CCS technologies is required to meet net zero – between 2030 and 2050, engineered removals will need to increase carbon captured by tenfold, whereas nature based solutions will only need to increase carbon captured by 2.7 times.
- Engineered removals are crucial for the economic and sustainability longevity of hard-to-abate sectors, such as cement manufacturing, steelmaking, and critical minerals processing.
- Engineered removals, particularly DAC, are critical towards making progress to a well below 2°C net zero pathway.
- A reliance on land-intensive nature based carbon removals could put pressure on other land-intensive sectors, particularly agriculture and land prices.

An alternative framework for modelling decarbonisation pathways, which illustrate the tradeoffs between decarbonisation and the United Nation's sustainable development goals (SDGs), highlights some of these issues. There are a total of 17 SDGs, with some examples being zero hunger, affordable clean energy and reduced inequalities.

[3] The IPPC C2 scenarios project less than 1.5C of global warming - with high overshoot, average peak warming at 1.7C and average net zero achievement year from 2055-2060.

When considering both environmental and sustainable development objectives, engineered carbon removal technologies play a much larger role than nature based removals. Engineered removals are favoured as they are less land-intensive, and their deployment helps to reduce competition for land, mitigating pressure on food prices and food security. This modelling highlights the importance of having both engineered and nature based carbon removal solutions available to mitigate reliance on any single technology.

Figure 5: The mix of carbon removal technologies under an SDG decarbonisation pathway



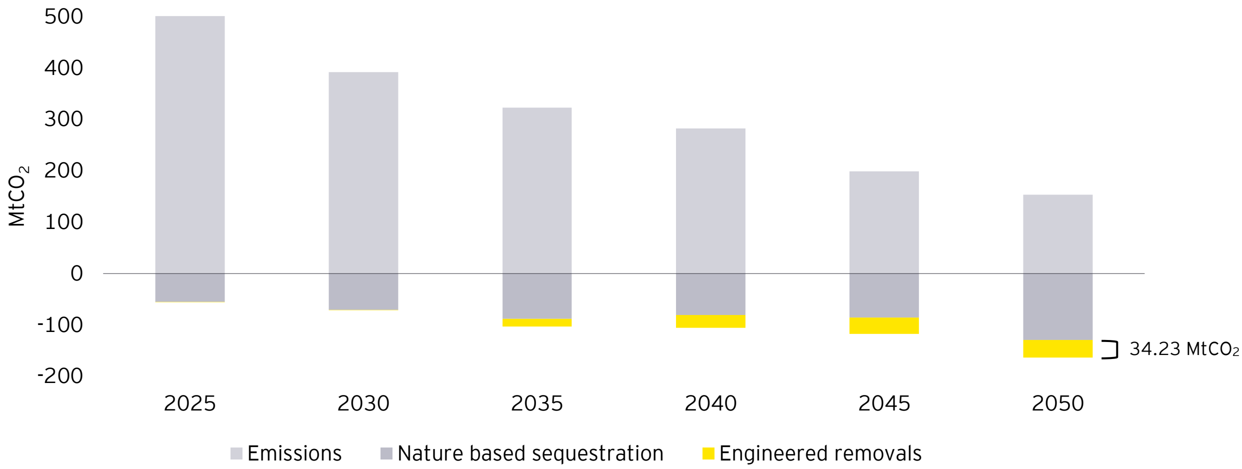
Source: EY analysis of IRP data (2019)

Several Australian studies have identified the importance of carbon removals in meeting our emissions targets

Insights from the Climate Change Authority and Net Zero Australia highlight that carbon removal must play a role in reducing emissions as the nation progresses toward its 2050 climate goals.

The Climate Change Authority highlights the role of both nature based (green) and engineered carbon removals (yellow). According to this modelling, Australia will still produce more than 150 $MtCO_2$ in 2050, which will be offset by around 150 $MtCO_2$ of nature based removals, and almost 40 $MtCO_2$ of engineered removals. This highlights the importance of carbon removals in reaching net zero emissions.

Figure 6: Carbon emissions and removals required to meet net zero by 2050[4]



Source: EY analysis of CCA projected CCS abatement including direct air capture

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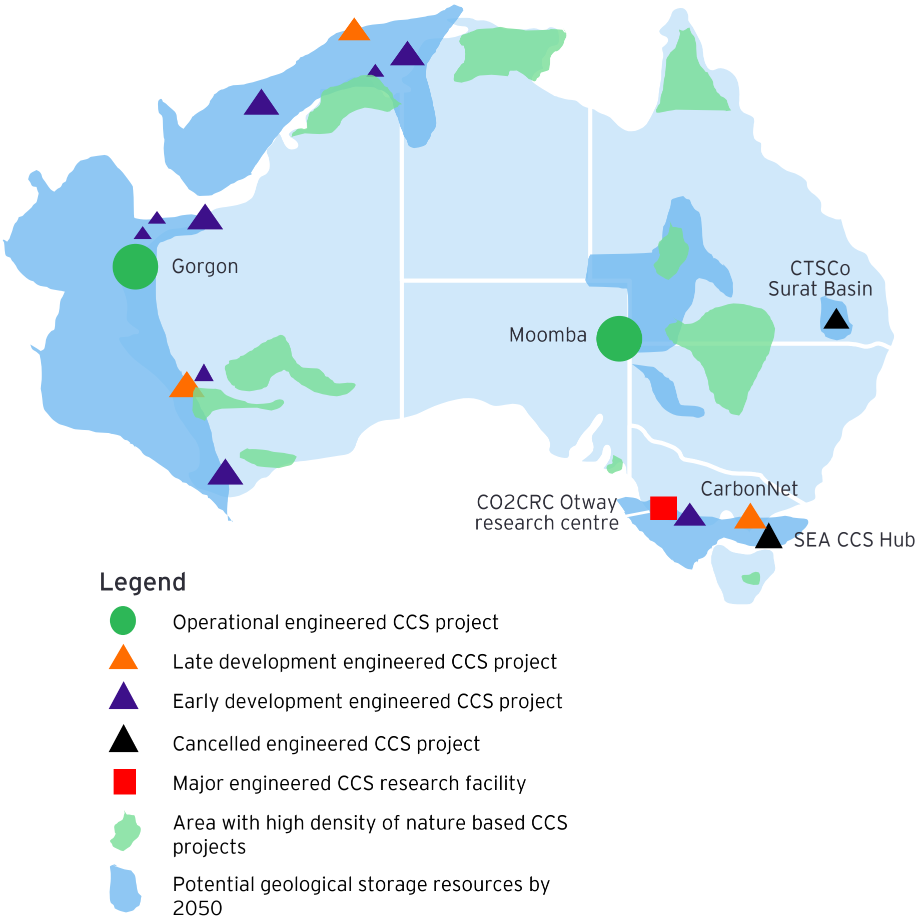
[4] Engineered removals include Direct Air Capture and CCS technologies

A significant share of the carbon that must be sequestered will depend on engineered solutions, particularly CCS technologies. By 2050, CCS is expected to sequester over 34 $MtCO_2$ annually, playing a pivotal role in mitigating emissions from hard-to-abate sectors.

However, the current pipeline of engineered CCS capacity falls short of what is required to achieve net zero by 2050 based on CCA modelling. Australia's current operational CCS capacity is limited to a handful of projects, such as the Gorgon and Moomba projects (outlined on the map below), which capture approximately 5.7 $MtCO_2$ annually through post extraction amine-based gas separation CCS and gas stream separation CCS respectively.

Figure 7: Australia has over 400 Mt of demonstrated carbon storage capacity



Source: Geoscience Australia, 2024, *Carbon capture and storage*

A further 14.1 $MtCO_2$ per annum in capacity could come online over the next 5-10 years but will be contingent on securing regulatory and environmental approvals.[5] Australia will need to increase its geological carbon sequestration capacity by 19 $MtCO_2$ by 2050 to meet the CCA's 2°C scenario.

Without coordinated efforts, there is likely to be a significant risk that Australia may not be on track to develop the carbon sequestration capacity required to reach net zero emissions. This could pose additional challenges to heavy industry in meeting their Safeguard Mechanism obligations, increasing the costs of the net zero transition, and requiring deeper emissions cuts in other sectors.

[5] Geoscience Australia, 2024, Australia's Energy Commodity Resources 2024, https://www.ga.gov.au/aecr2024/carbon-capture-and-storage

Box 2: CO2CRC and the Otway International Test Centre

The CO2CRC (Cooperative Research Centre for Greenhouse Gas Technologies) is Australia's leading research organisation dedicated to CCUS. Established in 2003, CO2CRC works closely with industry, government, and research institutions to advance technologies that can reduce carbon emissions and support Australia's transition to a low-carbon economy.

The Otway International Test Centre

A key initiative of CO2CRC is the Otway International Test Centre, located in Victoria, which serves as one of the world's foremost field research sites for CO_2 storage. The Otway Centre commenced in 2006 as Australia's first demonstration of geological carbon sequestration. The project has since evolved through multiple phases, advancing the understanding of CO_2 injection, storage, and monitoring in deep underground reservoirs.

The Otway Centre focuses on testing and improving CCUS technologies in real-world conditions. To date, over 100,000 tonnes of CO_2 have been safely injected and monitored within geological formations at the site, demonstrating the feasibility and long-term security of underground carbon storage.[6] The centre has played a crucial role in developing internationally recognised best practices for monitoring and verification, which are essential for ensuring public and regulatory confidence in CCUS.

Currently, the Otway Centre is conducting Phase 3 of its research program, which focuses on developing cost-effective and highly accurate monitoring technologies. This phase aims to enhance real-time tracking of CO_2 movement in the subsurface, reducing the long-term costs associated with carbon storage projects. By improving efficiency and safety, the centre is helping to make large-scale CCUS deployment more commercially viable.

Current operational services

- 7 purpose drilled CO_2 storage wells (>1.5km deep) within a 1km area for CO_2 injection and monitoring activities
- Readily available supply of CO_2 from an in-situ CO_2 gas field
- Variety of storage reservoir types, structures and seals
- State-of-the-art seismic monitoring array for observing and benchmarking subsurface technologies and processes
- All necessary regulatory approvals and support of local communities to complete CCUS investigations

Looking ahead, CO2CRC plans to expand its research efforts to support broader CCUS implementation across Australia, including the potential for storage sites on the east coast. Future work will explore optimising CO_2 injection techniques, improving storage site selection, and integrating CCUS with other low-carbon technologies such as hydrogen production.

The success of the Otway Centre provides a strong foundation for developing CCUS projects in eastern Australia, where industrial emissions from sectors such as energy, manufacturing, and cement production remain high. By leveraging insights from Otway, policymakers and industry stakeholders can make informed decisions about the feasibility and risks associated with large-scale CCUS deployment in key economic regions.

Source: CO2CRC, 2024, Celebrating a milestone

[6] CO2CRC, 2024, Celebrating a milestone, https://co2crc.com.au/about-us/100000t-stored-co2-celebration/

Global demand for carbon storage presents Australia with a significant economic opportunity

Demand for carbon sequestration is likely to be significant in heavily industrialised countries with limited landmass and geological storage such as Japan and Korea. These countries are currently reliant on fossil fuels for energy production and have established hard-to-abate industries such as cement and steel production while also being the world's seventh and thirteenth largest CO_2 emitters.[7] They have also set net zero emissions targets by 2050.

Australia has a potential to provide carbon storage services to these countries, which includes leveraging the natural resources and geological storage potential. However, several regulatory and commercial preconditions are critical to capturing this growth opportunity, including providing assurance of any carbon stored in Australia. The recent COP29 conference signalled global interest in a carbon credit trading framework, which could help open opportunities for Australia in this emerging and important market.

Box 3: The impact of global carbon credit trading and its opportunities

Global carbon credit trading could emerge as a transformative decarbonisation mechanism

Currently, carbon credit trading has enabled the channelling of billions of dollars into projects designed to combat global warming while creating substantial export revenue streams. The recent COP29 conference marked a significant milestone by operationalising Article 6 of the Paris Agreement, laying the foundation for a global carbon credit trading framework.

This presents a potential opportunity for Australia to position itself as an attractive destination option for carbon offset projects. Australia's vast landscape and natural resources provides opportunity for large-scale reforestation, afforestation and soil carbon storage. These initiatives enable countries to meet their emissions offset needs by purchasing Australian-generated carbon credits. Furthermore, Australia also has some of the world's most suitable geological basins for safely storing CO_2, making it an attractive partner for global companies seeking reliable carbon sequestration solutions.

Australia could also leverage its ESG credentials. Australia's robust carbon accounting standards, exemplified by the Australian Carbon Credit Units (ACCUs), are internationally recognised, and underpinned by a strong regulatory framework. This not only instils confidence in the integrity of Australian carbon credits but also positions the nation as a preferred choice for investment inflows into carbon offset initiatives.

By leveraging its natural advantages, regulatory frameworks, and commitment to innovation, Australia could benefit significantly from a global carbon market while advancing its economic and environmental objectives.

2.2 Cost and readiness of CCS technologies

Technology Readiness Levels (TRL) are a globally recognised barometer for assessing the maturity and deployability of technologies. This section provides an overview of the maturity (or readiness) and costs of nature based and engineered removals. The table below sets out the various engineered and natured-based carbon removal technologies, their storage duration, abatement potential, and TRL, and provides a few important insights:

[7] CarbonBrief, 2020, The Carbon Brief Profile: South Korea, https://www.carbonbrief.org/the-carbon-brief-profile-south-korea/

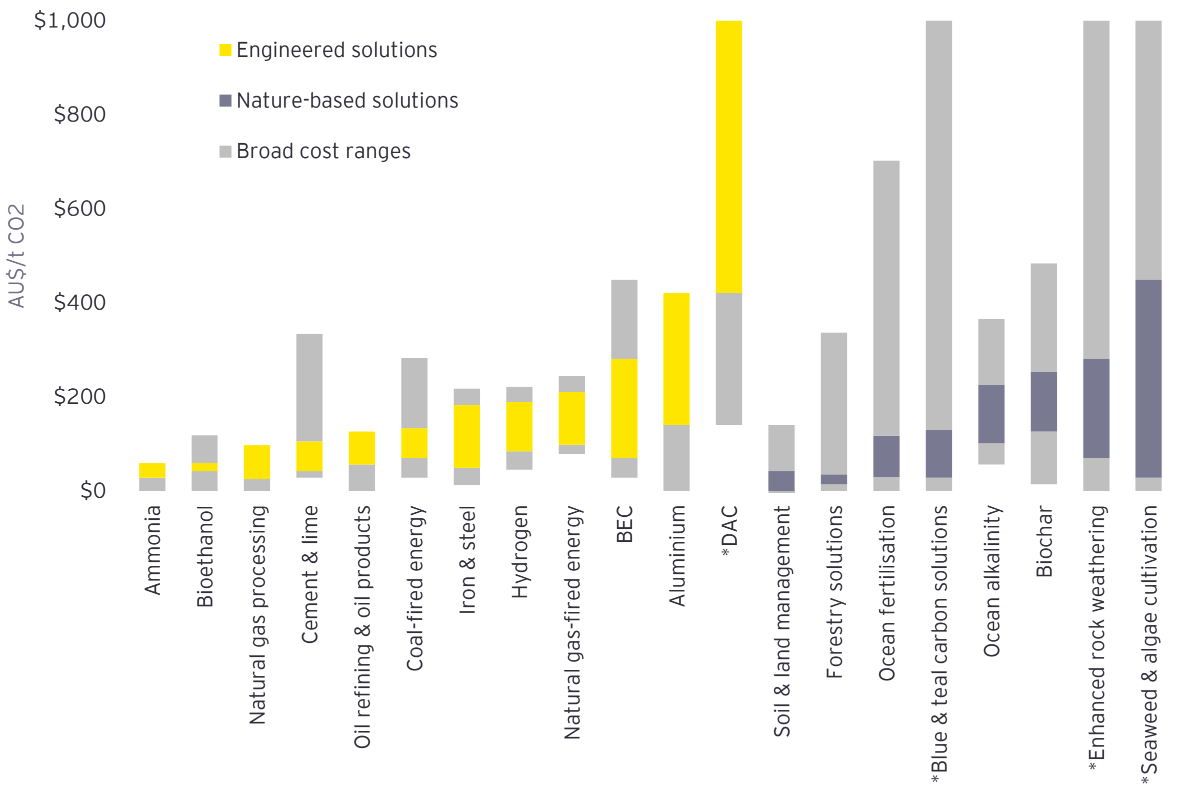
- Nature based solutions are typically mature and appear to represent a low-cost carbon removal option in the short-term. Some nature based solutions are still in development phase.

- Engineered solutions offer virtually permanent carbon storage, which provides greater certainty in carbon removal compared to nature based solutions. Nature based solutions can 're-emit' carbon during natural lifecycle processes, particularly during periods of El Niño when growth is limited and wildfires are more frequent.

- Engineered solutions offer the greatest carbon abatement potential out to 2050 and beyond – and both sets of technologies will be crucial to reducing emissions. Australia's Climate Change Authority (CCA) has recommended prioritising the development of long-lived geological storage technologies to complement nature based solutions.

Each of these technologies can be compared against estimates of their average cost of abatement. This measures the cost of abating one tonne of CO_2 emissions using each technology. The graph below displays cost estimates for the range of CCS solutions, highlighting some variability both within and across different technologies. These differences are influenced by factors such as the TRL, project scale and the specific technologies deployed in each solution.

Figure 8: Estimates of average costs of abatement for carbon removal solutions



Source: Multiple – See Appendix C for full source list

*High end of cost range > $1000

Many of these engineered carbon removals have medium to high TRLs, suggesting that they could be commercially available in the next 5-10 years. As such, the costs of CCS solutions are expected to decline as innovation progresses and economies of scale are expected to be realised, particularly for engineered technologies like DAC. However, without a broad set of decarbonisation technologies available, some established land-based natural solutions such as soil sequestration and forestry may experience cost increases. This trend highlights the importance of diversifying CCS approaches to ensure resilience in carbon removal strategies as demand for abatement solutions grows.

Table 3: The range of carbon capture and sequestration solutions

Carbon removal type	Summary	Storage duration	TRL	Abatement potential ($MtCO_2$/year)	Indicative cost (AUD/tCO_2)
Industrial CCS	CO_2 produced during industrial processes such as cement and hydrogen production is captured.	>10,000 years	Low-High	>50	$25 - $420
Post-combustion capture	CO_2 produced during the combustion of fossil fuels to produce energy such as metallurgical coal and natural gas is separated from impure flue gas.		High		
Oxy-fuel combustion capture	Fossil-fuels are combusted in an oxygen-rich environment to produce CO_2 and water with few other impurities. CO_2 is then separated from water using condensation rather than absorbents or membranes.		Medium		
Pre-combustion capture	Fossil fuels are converted into a synthetic gas consisting of CO_2 and hydrogen. CO_2 is then separated prior to the hydrogen being combusted cleanly.		High		
Bioenergy capture (BEC)	CO_2 produced during the conversion of biomass into energy or biofuels is captured.		Medium	25 - 38	$70 - $280
Direct air capture (DAC)	Uses large vacuums to push ambient air through absorbents and membranes to extract CO_2 directly from the atmosphere. May be deployed adjacent to industry or energy production.		Low	Uncertain	$280 - $1000+
Forestry solutions	Involves planting trees to create new forests (afforestation), replanting trees in deforested areas (reforestation) and integrating new trees into agricultural land (agroforestry).	10-100 years	High	87	$15 - $35
Soil & land management	Rehabilitating degraded soils, protecting grasslands and adopting regenerative agriculture practices such as cover cropping and crop rotation.	10-100 years	High	28.7 - 57.7	$0 - $40
Biochar	Enriching soil by mixing it with biochar which is a by-product of biomass production.	100-1000 years	Medium	30 - 60	$125 - $250
Blue & teal carbon solutions	Protecting and restoring coastal ecosystems such as mangroves, seagrasses and tidal marshes (blue carbon) and inland wetlands (teal carbon).	10-100 years	Medium	3 - 4	$30 - $130
Seaweed & algae cultivation	Farming seaweed and algae which may then be used for food, fuel or sunk to the ocean floor.	10-1000 years	Medium	Uncertain	$30 - $450
Ocean fertilisation	Adding micronutrients to the ocean such as iron to increase wild seaweed and algal growth.	100-1000 years	Low	Uncertain	$30 - $115
Ocean alkalinity enhancement	Adding alkaline materials to the ocean to increase the natural CO_2 absorption rate of seawater	1000+ years	Low	Uncertain	$100 - $225
Enhanced rock weathering	Alkaline rock powders are spread over agricultural soil or along coastlines.	>10,000 years	Low	36	$70 - $280

Legend	Engineered solutions	Land-based plant biomass	Water-based plant biomass	Natural ocean processes	Natural rock processes

Source: CSIRO, 2022, Australia's carbon sequestration potential

2.3 Six hard-to-abate sectors could deploy CCS at scale

Hard-to-abate sectors face significant challenges in reducing emissions due to technical and operational constraints. Some of these industries inherently release carbon as a byproduct of essential chemical processes or rely on fossil fuels to generate the high temperatures required for production. This reliance makes large-scale decarbonisation difficult, and there are relatively limited technologies available.

There are six hard-to-abate sectors which could deploy CCS at scale on Australia's east coast:

1. Cement manufacturing
2. Steelmaking
3. Chemicals (and fertiliser) manufacturing
4. Gas extraction
5. Metallurgical coal mining
6. Low carbon hydrogen production

These sectors, while involving very different industrial and chemical processes, each share some common factors which could lead to a material uptake of CCS.

- These sectors often involve high-temperature processes (greater than 400°C) which are currently difficult to electrify and may rely on coal or gas feedstocks, particularly in steelmaking and cement manufacturing.
- Some sectors require fossil fuels as essential feedstocks into chemical processes, making fuel switching challenging. For instance, steel production using blast furnaces depend on metallurgical coal as both a chemical input and an energy source. While switching to electric arc furnace could substantially lower emissions, this option is constrained by the insufficient supply of scrap metal in Australia.
- The majority of emissions produced in gas extraction and metallurgical coal mining are fugitive emissions which occur during extraction — these emissions are not created from fuel consumption and cannot be abated through fuel switching.
- Many facilities within these sectors fall under Australia's Safeguard Mechanism, which requires them to reduce their emissions each year based on a predetermined baseline. Facilities which are not able to meet this emissions reduction baseline are required to purchase carbon credits, providing them with an economic incentive to decarbonise (see box below).
- These sectors are also trade-exposed and compete in global markets on costs and emissions. Enabling the low-cost decarbonisation of these sectors is critical for them to maintain (or expand) their market share and remain economically viable.

Box 4: An overview of the Safeguard Mechanisms

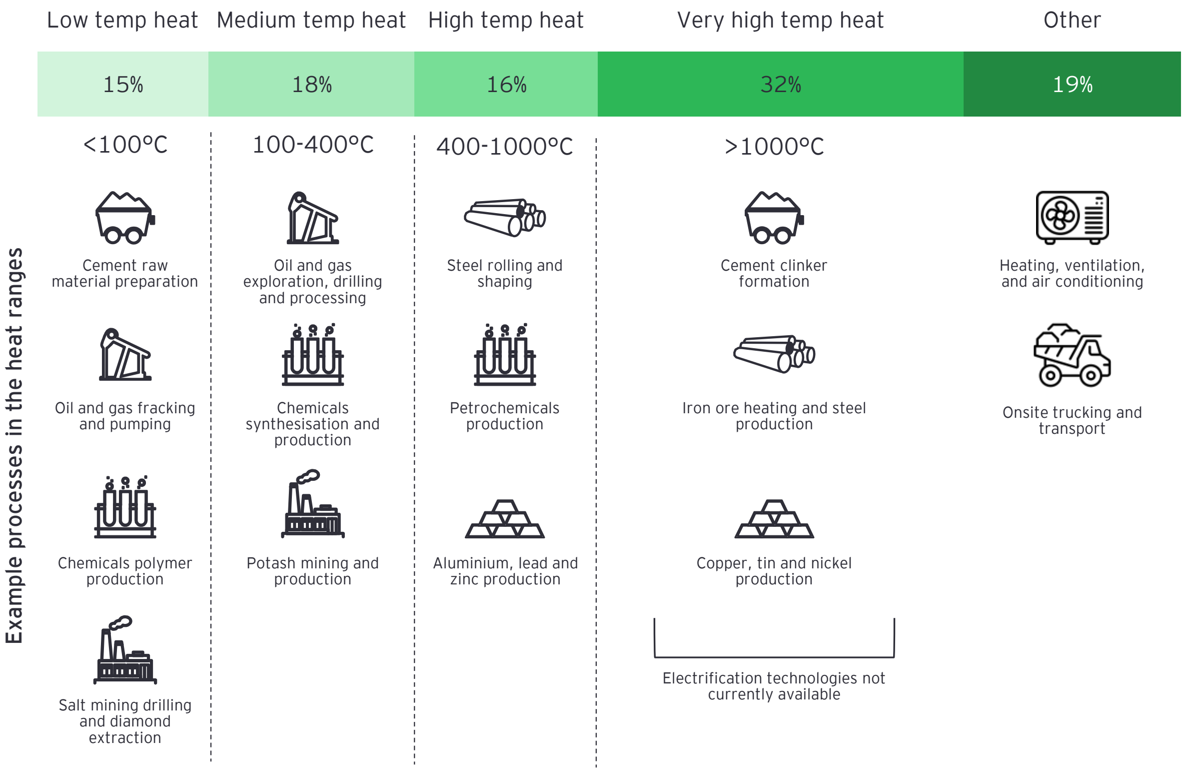
Facility specific baselines

Each facility is assigned an emissions baseline or ceiling, determined using historical data or industry-specific benchmarks. These ceilings are designed to decline over time, reducing by an average of 4.9% per year. They align with Australia's broader emissions reduction targets.

> **When a facility is above its baseline target – ACCUs**
>
> Facilities exceeding their emissions ceiling must offset the excess by either purchasing Australian Carbon Credit Units (ACCUs) or using previously earnt Safeguard Mechanism Credits (SMCs), ensuring accountability for additional emissions.
>
> **When a facility is below its baseline target – SMCs**
>
> Facilities emitting below their baseline automatically earn SMCs. These credits can be traded, creating financial incentives for facilities to exceed their emissions reduction goals.

Source: Australian Energy Regulator, 2024, Safeguard Mechanism

Figure 9: An overview of energy consumption across low to very high heat industrial processes



Source: EY analysis of IEA ETP Clean Energy Technology Guide

Alternative abatement options are available, yet are difficult to implement

There are a range of green technologies apart from CCS being considered by industry for deployment in these hard-to-abate sectors as they strive to reduce emissions. Some of these alternative technologies include:

- **Electrification**, where retrofitting existing infrastructure with electrification technology may be able to reduce emissions for low-heat industrial processes. This may be unsuitable for many hard-to-abate industries, where electrification technologies are not yet able to produce the necessary high temperatures.

- **Low carbon hydrogen,** which offers a long-term, scalable solution for deep decarbonisation. There is significant investment and interest in hydrogen pilots and projects. However, these projects are centred around hydrogen production. At this stage, projects focused on transitioning hard-to-abate sectors to hydrogen-based machinery remain rare. This reflects the technical and commercial challenges in implementing hydrogen in these hard-to-abate industries.

- **Bioenergy,** where clean renewable energy derived from biomass, such as biomethane, are used interchangeably with conventional energy technologies. There are a small number of bioenergy projects underway in Australia, both focused on the production and use cases for the biofuels. Yet, scaling up bioenergy increases land demand, potentially putting upwards pressure on land and food prices. Moreover, bioenergy technologies struggle to meet the heat requirements of these hard-to-abate sectors.

As heard in consultations with key stakeholders, these technologies not only face significant uncertainty in their development pathways but also demand extensive retrofitting and substantial infrastructure investment. Their feasibility in heavy industry remains uncertain, particularly for electrification and bioenergy, which may struggle to meet the specific energy and process requirements of these sectors. CCS is also predominantly applied to processes with inherent emissions rather than processes requiring fossil fuels. Given these challenges, hard-to-abate industries may increasingly depend on low cost, readily available CCS to achieve their emissions reduction targets.

Hard-to-abate sector industry snapshots

The infographics over the next six pages present an overview of each hard-to-abate sector and their impact on Australian economic interests and climate goals. They discuss the impact of these industries across a wide range of other Australian sectors and highlight the importance of each industry in maintaining Australia's economic interests.

For each sector, they highlight:

- The economic and environmental footprint of the sector on the east coast, including employment, export revenue, and emissions produced.

- The decarbonisation technologies available to the sector, which each include CCS options.

- The strategic importance of the sector to Australia's interests.

- The potential uptake of CCS technologies under alternative development scenarios, which are described further in Section 4.

Iron and steel

1.3k jobs

$1b exports

6.4$MtCO_2e$ emissions

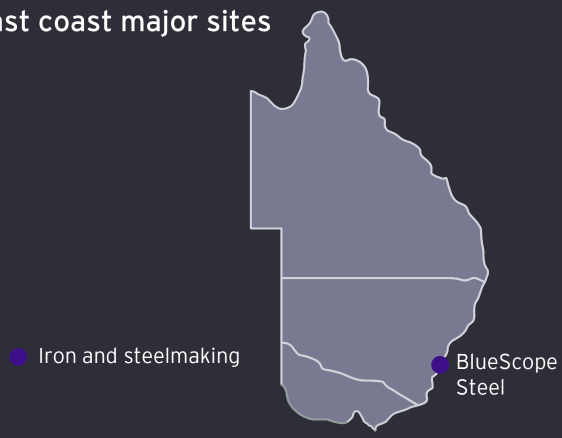
Carbon capture and storage can reduce iron and steel emissions. Implementing CCS technologies onto blast furnaces, integrating it with direct reduced iron plants, and enhancing electric arc furnaces are key strategies for achieving sustainability goals.

Iron and steel manufacturing are key components of Australian industry

There are technologies available now to decarbonise and lower iron and steelmaking emissions. Green hydrogen, electrification and CCS have been identified as viable solutions to meet Australia's emissions targets and industry requirements.

Our analysis suggests that up to 8.8 $MtCO_2e$ emissions could be captured each year in 2050 through various CCS technologies.

East coast major sites



Potential decarbonisation technology timeline

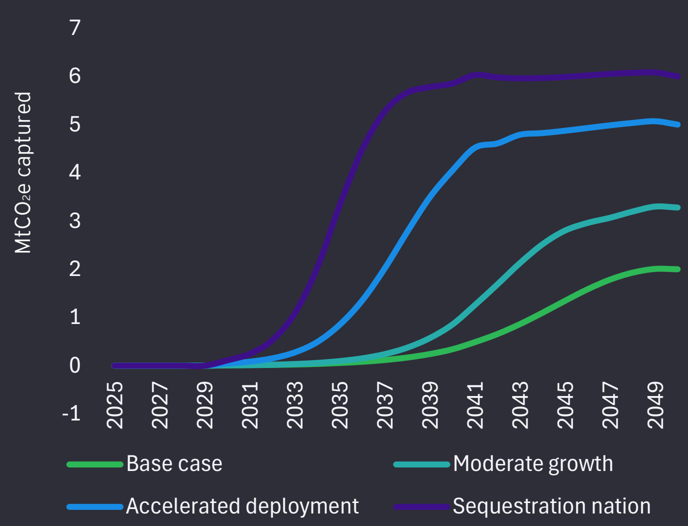
Technology readiness level	9	8	7	6	5
Technology (year of commercial-isation)	Scrap-based electric arc furnace (2020)	Direct reduced iron with CCS technology (2028)	Blast furnace with CCS technology (2030)	Direct reduced iron with green hydrogen (2038)	Electrolytic steel production (2040)

2020 → 2040

Electrification technology | Hydrogen technology | CCS technology

Expected iron and steel CCS demand

As industries accelerate decarbonisation efforts to meet emissions reduction targets, the demand for CCS is projected to grow exponentially as we approach 2050.



Iron and steel as an upstream industry

Australian iron and steel serves as a cornerstone for economic growth, supporting the development of industries that depend on domestically produced steel.

- The iron and steel industry plays a vital role in supporting Australian housing and driving major infrastructure projects.
- Steel is essential for mining infrastructure and heavy machinery, as well as freight and rail industries.
- Renewable energy projects are reliant on Australian iron and steel to provide cost-effective power generation.
- The ADF uses domestically produced steel for shipbuilding, military vehicles and aircraft frames.

Chemicals

3.8k jobs | **$377m** exports | **3.6Mt$CO_2$e** emissions

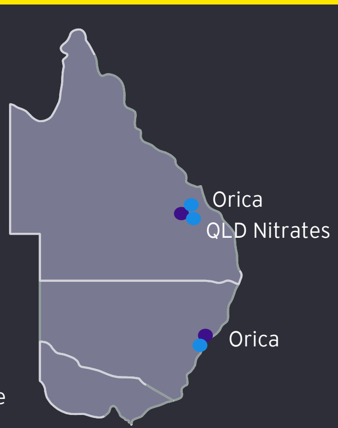
The chemical industry plays a vital role in global agriculture. As population growth drives increased demand for food, chemical production is expected to rise, leading to higher emissions. CCS can help mitigate these emissions, supporting agricultural growth while minimising environmental impact.

Urea, fertilisers and ammonium nitrate are produced from ammonia

The production of ammonia creates most of the emissions in this industry, however many of its emissions can be abated using CCS technology.

By 2050, over 400,000 tonnes of CO_2e emissions could be captured per year, based on CCS technology projections.

East coast major sites



Ammonia
Ammonium Nitrate

See Appendix D for more details

Potential decarbonisation technology timeline

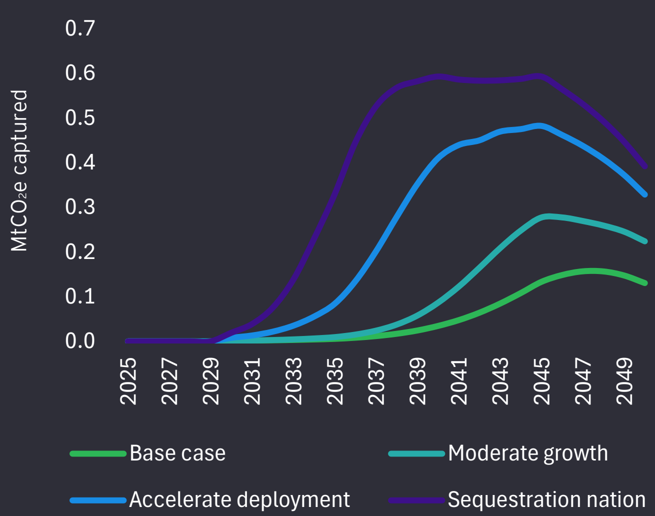
Technology readiness level	9	8	7	6
Technology (year of commercial-isation)	Hydrogen replacement for steam methane reforming (2021)	Chemical production with absorption-based CCS (2028)	Electrolytic hydrogen-based ammonia (2030)	Steam cracker electrification (2035)

2020 → 2040

Electrification technology | Hydrogen technology | CCS technology

Expected chemical CCS demand

As we approach 2050, Australian chemical manufacturers are expected to decarbonise to help meet Australia's climate commitments. CCS will thus be an important technology in hard-to-abate industries such as chemicals manufacturing.



Drivers of chemical demand

The chemical manufacturing industry is critical to various sectors in the Australian economy, supplying raw materials and processed chemicals for a range of applications.

- Agriculture in Australia is heavily reliant on fertilisers, pesticides and animal feed additives to enhance crop and livestock yields.
- Explosives are an integral component of the Australian mining industry, alongside chemicals needed to separate and process ores.
- Industrial gasses are needed for metal and food industries, while adhesives and synthetic materials are essential in manufacturing processes.
- Lubricants and coolants, as well as battery chemicals are a necessity for renewable energy projects.

Gas extraction

67k jobs | $22b exports | 8.7MtCO$_2$e emissions

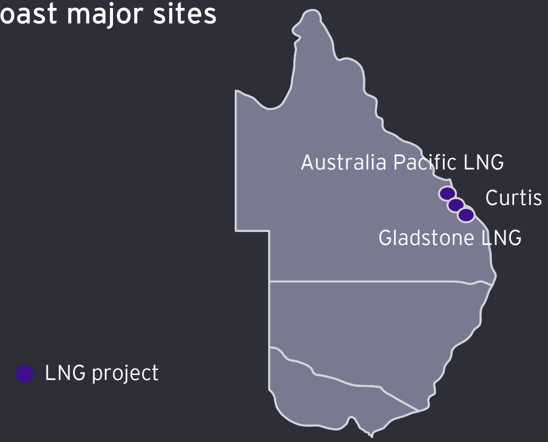
With the combustion of fossil fuels to produce liquefied natural gas (LNG) and liquefaction causing most of the emissions in this sector, a rapid deployment of new abatement technologies for LNG including CCS will be required to meet emissions targets.

Australia is the world's largest exporter of LNG

The majority of Australia's LNG is exported to be used for electricity generation, heat, transport and industrial feedstocks. A decline in global LNG trade has decreased emissions produced, however CCS technologies will still be required to fully decarbonise the industry in the future.

Despite the substantial fall in demand, it is estimated that around 1.2 MtCO$_2$e of emissions could be captured every year by 2050, falling from around 6.7 MtCO$_2$e by 2037.

East coast major sites



Potential decarbonisation technology timeline

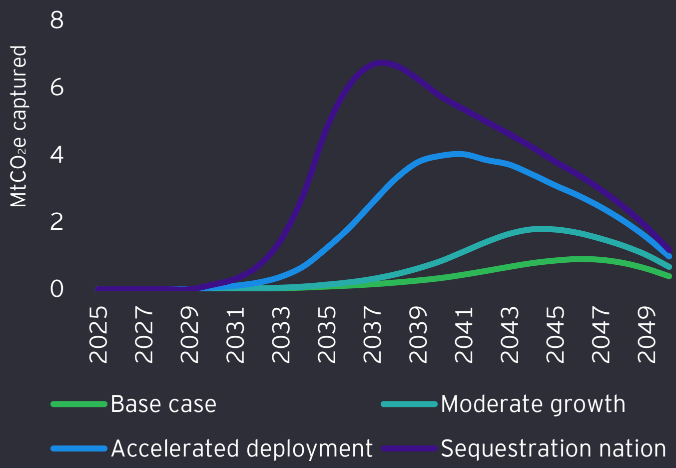
Technology readiness level	9	9	8	7
Technology (year of commercial-isation)	Blended hydrogen fired gas turbines (2022)	Electric drives and turbines (2023)	Post combustion CCS (2028)	Pure hydrogen fired gas turbines (2030)

2020 → 2040

Electrification technology | Hydrogen technology | CCS technology

Expected CCS demand for gas extraction

As Australia's gas production declines, the overall demand for CCS is expected to decrease. However, CCS will remain a critical component in reducing the carbon footprint of LNG operations and helping Australia meet its climate objectives.



Gas remains an important resource

Despite anticipated declines in demand, liquefied natural gas continues to be a vital energy commodity for both domestic use and export markets.

- Australia exports significant volumes of LNG to trading partners in Asia.
- Many gas-fired plants run on natural gas, which contributes to Australia's electricity mix.
- Gas is used in residential and commercial settings for heating and cooking in many parts of Australia.
- Regasified liquid natural gas plays a crucial role in many industrial processes.

Cement manufacturing

12k jobs | **$8.7m** exports | **2.5Mt$CO_2$e** emissions

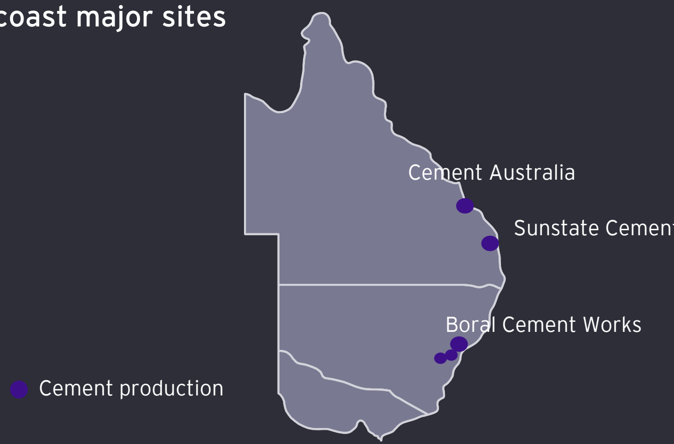
Chemical reactions with unavoidable emissions are a key part of cement manufacturing, making it a hard-to-abate sector. Integrating carbon capture and storage technologies into cement kilns and the calcination process is crucial for reducing emissions and achieving long-term climate targets.

Cement production is a cornerstone of Australian infrastructure

Cement plays a crucial role in construction and infrastructure development, being a key component in concrete production for buildings, roads, and other structures. It also supports mining operations and various environmental projects, making it essential for Australia's urbanisation and economic growth

It is projected that around 1.8 MtCO_2e of emissions from cement production could be captured by 2050 .

East coast major sites



Potential decarbonisation technology timeline

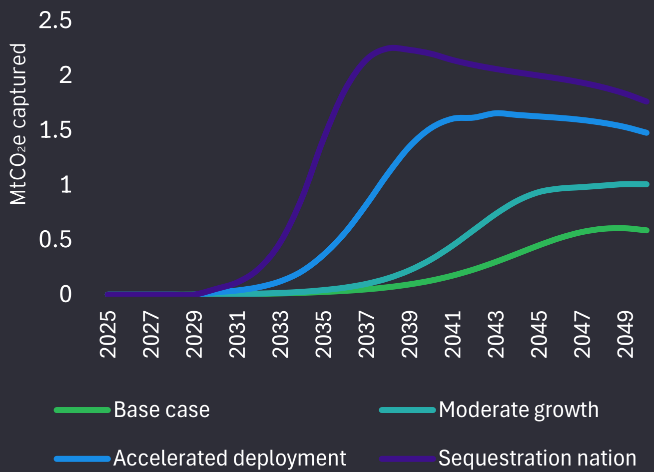
Technology readiness level	7	7	5	5
Technology (year of commercial-isation)	Cement production with absorption-based CCS (2030)	Calcium looping with CCS (2030)	Partial hydrogen substitution for fossil fuels (2040)	Electrified kilns (2040)

2020 → 2040

Electrification technology | Hydrogen technology | CCS technology

Expected CCS demand for cement production

Australia's growing population drives the need for continued infrastructure and urban developments. However, emissions from cement production must meet climate goals, driving exponential growth in cement CCS demand.



Cement as an essential resource

Cement manufacturing plays a crucial role in supporting a diverse range of industries, serving as the backbone for infrastructure development and urbanisation projects that drive economic growth.

- Cement is an essential ingredient in concrete, which is used in residential, commercial and industrial structures.
- Concrete is also extensively used in infrastructure projects such as roads, bridges, tunnels and airports.
- Cement is used in mining operations to provide structural support, ground stabilisation and backfilling.
- Cement plays a key role in waste management, immobilising hazardous waste and stabilising contaminated soils.

Metallurgical coal mining

40k jobs

$103b exports

31.6MtCO2e emissions

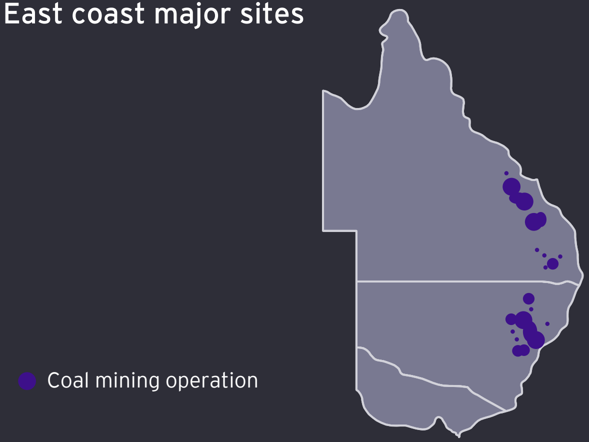
During mining operations, greenhouse gases trapped in coal seams and rock strata are released into the atmosphere, contributing significantly to carbon emissions. By implementing carbon capture and storage technologies, this hard-to-abate industry can reduce its emissions footprint.

Australia is the world's largest exporter of metallurgical coal

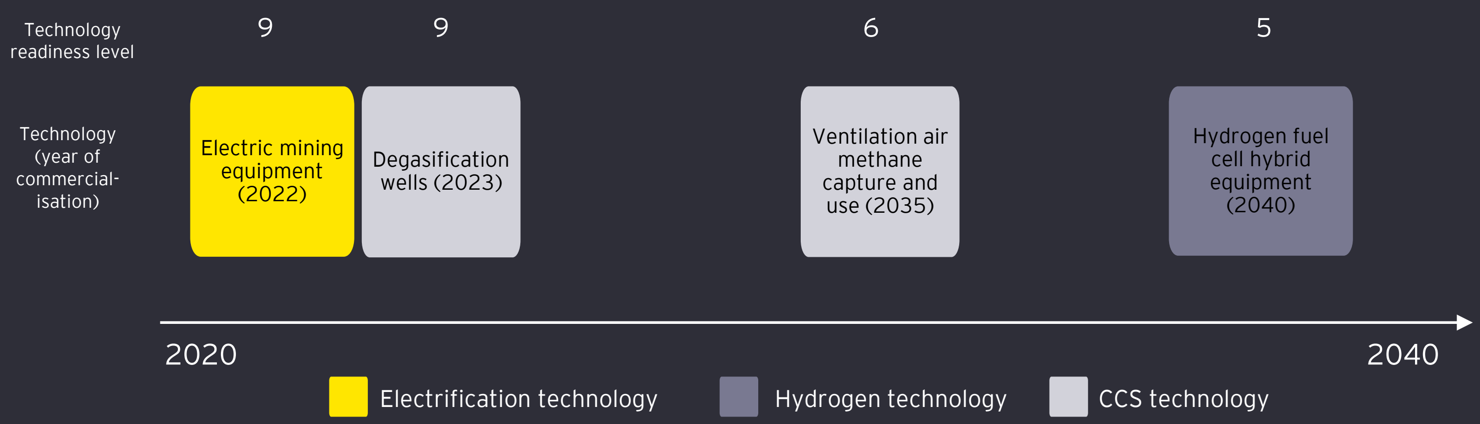
Australia's metallurgical coal is primarily exported for steel production. As nations prioritise meeting climate targets, global demand for coal is expected to plateau, potentially limiting emissions growth. However, CCS technology must be implemented to reach climate objectives.

By 2050, it is projected that up to 9 $MtCO_2e$ of emissions from metallurgical coal mining could be captured.

East coast major sites

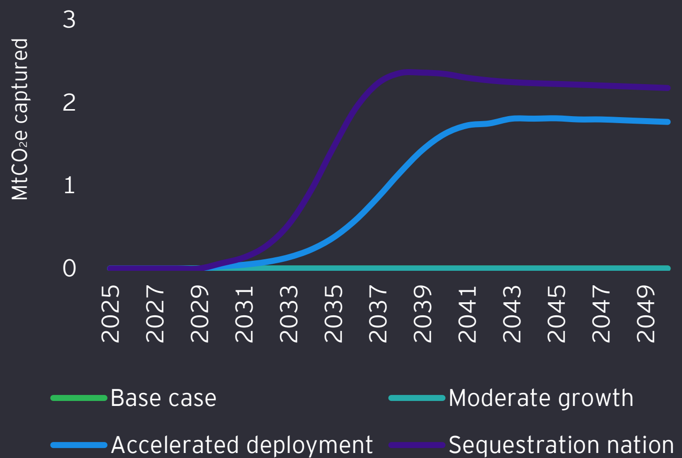


Potential decarbonisation technology timeline



Expected CCS demand for coal mining

The demand for CCS in the metallurgical coal mining industry is projected to rise significantly as we approach 2050, driven by the need to meet global climate targets and reduce emissions from this hard-to-abate sector.



Drivers of coal demand

Coal mining plays a crucial role in the Australian economy, serving as a key driver of growth by supporting multiple industries.

- Australia exports coal to many countries, such as China, Japan, South Korea and India. This includes both metallurgical and thermal coal.
- Metallurgical coal is a critical component in the steelmaking process, which is a key industry in Australia.
- Steel made from metallurgical coal is a critical material in a wide range of infrastructure projects.
- The production of specialty alloys and high-strength steels used in aerospace and defence requires metallurgical coal.

Hydrogen with CCS

20k jobs | **4.5Mtpa** exports | **7.1Mtpa** production

Forecasted by 2050

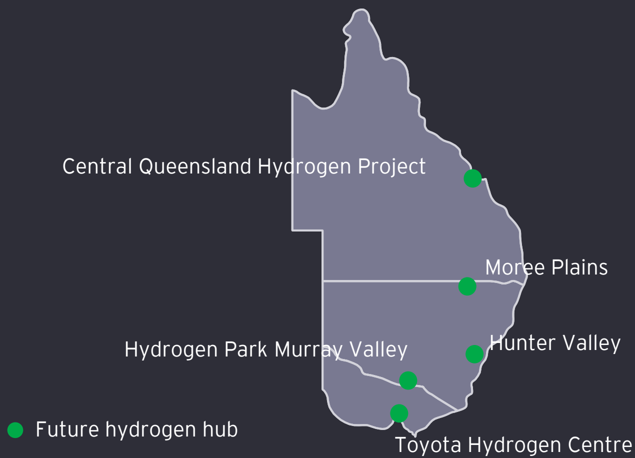
Grey hydrogen, commonly used as a raw input in industrial processes, produces significant emissions due to the release of carbon during production. Transitioning to green hydrogen by initially incorporating blue hydrogen is essential for reducing emissions and achieving climate goals.

Hydrogen as a growing export market

While hydrogen's traditional role has focused on ammonia production and refining, its importance as a clean energy carrier is rapidly increasing as Australia invests in the hydrogen economy to achieve net zero emissions and position itself as a hydrogen export superpower.

While policy efforts and financial support has been prioritised towards renewable hydrogen projects, fossil fuel-based hydrogen coupled with CCS technologies could play a role during initial industry growth by lowering initial costs.

East coast potential sites



Potential decarbonisation technology timeline

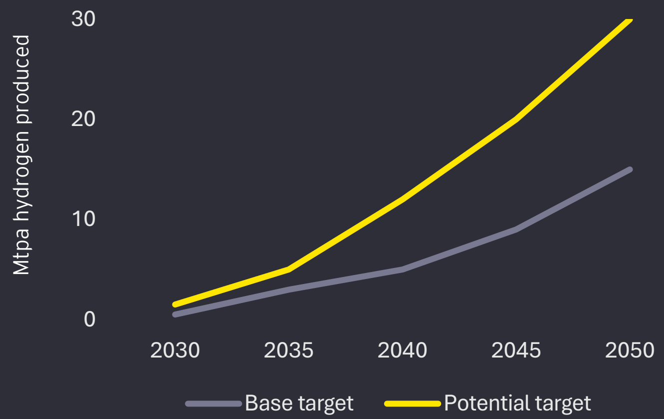
Technology readiness level	7	7	6
Technology (year of commercial-isation)	Steam methane reforming with CCS (2030)	Coal gasification with CCS (2030)	Hydrogen production with electrolysis (2035)

2020 → 2040

Electrification technology | CCS technology

Expected hydrogen production

As Australia aims to become a leading global hydrogen exporter, production is expected to grow significantly by 2050. While green hydrogen will dominate in the long term, blue hydrogen will play a key role in the early stages to offset high initial costs and support the transition to sustainable energy.



Hydrogen as an integral low-carbon energy

As Australia targets net-zero emissions by 2050, green hydrogen will play a pivotal role in helping various industries achieve decarbonization, driving the transition to a more sustainable economy.

- Low-carbon hydrogen supports key Australian industries, driving ammonia, petroleum, and steel production.
- Low-carbon hydrogen can be blended in with natural gas in existing pipelines to offset the carbon intensity of heating and power.
- Australia plans to export low-carbon hydrogen to many countries which are investing heavily in hydrogen as a clean energy source.
- Low-carbon hydrogen can be used in fuels to decarbonise aviation and shipping sectors.

These hard-to-abate sectors are important to Australia's economic and strategic interests

A range of geopolitical and technology drivers, as well as the supply chain disruptions which occurred during the COVID-19 pandemic, have demonstrated the importance of building and maintaining a sovereign manufacturing base.

The hard-to-abate sectors outlined above are critical to supporting several of Australia's economic and strategic interests, including:

- **Renewable energy transition** and technologies such as wind turbines, solar panels and pumped hydro energy storage which rely on steel and cement materials.
- **Housing and infrastructure development** to support Australia's growing population and cities, as well as improve housing affordability, depend on steel and concrete supply.
- **Defence manufacturing capabilities** which rely on sovereign steel and chemicals to strengthen supply chain resilience and support national security and defence innovation.
- **Agricultural productivity** which could capture growth in emerging APAC markets is reliant on domestic chemical and fertiliser production.
- **Energy sovereignty** from Australian gas fields and potential hydrogen production, which minimises risk from price shocks in global energy markets and ensures reliability in national energy markets.

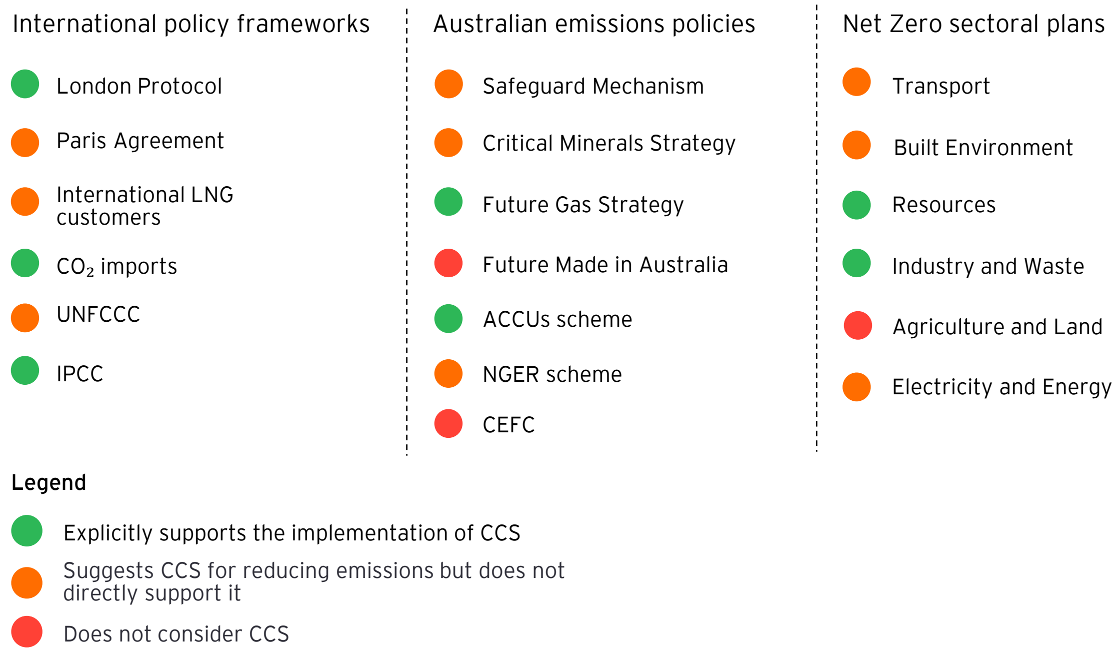
These hard-to-abate upstream industries are major employers, supporting approximately 130,000 jobs along Australia's eastern coast. They play a crucial economic role, driving growth across multiple other sectors and generating over $130 billion in export value in the past year alone. As they face increasing pressure to reduce emissions while meeting growing demand, it is essential to support their continued operation and competitiveness.

CCS can play a key role in this effort, enabling these industries to lower emissions while maintaining economic strength and securing jobs for the future. Unlike carbon credits or offsets, which seek to merely balance emissions, CCS technologies could enable these hard-to-abate sectors to directly reduce atmospheric emissions. This is particularly important in sectors with significant fugitive emissions, where traditional fuel-switching methods fall short. BECCS and DAC are vital for achieving a global emissions trajectory that is aligned with the Paris Agreement. By adopting CCS, these hard-to-abate sectors can aim to effectively reduce their direct emissions, comply with global emissions standards, and simultaneously maintain economic strength and job security for the future.

2.4 Policy and regulatory challenges may delay CCS investments

Australia's policy and regulatory landscape is somewhat patchy when it comes to CCS. Some policies recognise the importance of CCS and include the technology in their design, whereas others do not include it. For example, the CEFC, one of Australia's key funding mechanisms for low emission technologies, explicitly does not invest in CCS. The following graphic showcases some key policies in Australia, how they interact with CCS technologies, and highlights the lack of a cohesive, whole-of-government framework.

Figure 10: Policy drivers in Australia



Source: EY analysis

Further action could be taken to build out a comprehensive policy landscape which supports the development and deployment of CCS technologies. Areas that could be addressed include:

- **Lack of a clear national CCS strategy** – There is no comprehensive outline for how CCS can be integrated into Australia's emissions reduction plans, and minimal incentives for the development of CCS, especially for hard-to-abate sectors. Without a national strategy, Australia's policy landscape is likely to remain fragmented.
- **Regulatory challenges** – Regulatory frameworks for CCS remain inconsistent across state and council jurisdictions, raising barriers for investment and development.
- **Social licence challenges –** Limited public understanding, support and acceptance of CCS discourage the political will required to advance its implementation.
- **Boosting dedicated funding** – There are currently limited funding programs to support CCS technology development, pilots, or projects in Australia. The Carbon Capture Technologies Program provides $65 million over 8 years from 2023-24 to 2030-31 to promote carbon capture and utilisation technologies. In a global context, this funding could be considered somewhat modest, with some countries committing significant funds to drive development of an at-scale CCS sector, including to help derisk CCS networks aimed at decarbonising heavy industrial activities. Indeed, the UK has committed almost AU$34 billion to advancing CCS and low-carbon hydrogen production (see box below for more detail). Notably, the UK's CCS program excludes nature based carbon sequestration solutions and the use of carbon for enhancing petroleum recovery.

Box 5: An overview of the UK's hub-based CCS model

UK CCS investment and its hub based model

In March 2023, the UK Government committed £20 billion over two decades to support the development of CCS technologies, aiming to sequester 20 to 30 $MtCO_2$ annually by 2030. This investment is designed not only to reduce industrial emissions but also to lay the foundation for a competitive CCS market by 2035. In doing so, the initiative is expected to support up to 50,000 jobs and contribute £5 billion to the UK economy by 2050.

Central to the UK's CCS strategy is a hub-based model, which brings together major industrial emitters within key geographic regions. The model focuses on shared carbon transport infrastructure and centralised storage facilities to lower costs and reduce investment risks for companies. Key aspects of the hub-based approach include:

- The HyNet Cluster in Northwest England and North Wales, which focuses on hydrogen production, power generation, and chemicals.
- The East Coast Cluster, targeting industries such as steel and refining, with captured carbon stored in the North Sea.

These early-stage government initiatives are designed to evolve over time, unlocking private investment and stimulating further economic growth. By centralising infrastructure, the hub model lowers the barriers for industrial emitters to adopt CCS technologies and facilitates the potential monetisation of captured carbon through industrial reuse.

Source: UK Department for Energy Security & Net Zero, 2023, Carbon Capture, Usage and Storage, https://assets.publishing.service.gov.uk/media/6594718a579941000d35a7bf/carbon-capture-usage-and-storage-vision-to-establish-a-competitive-market.pdf?

A key point is that if policy, regulatory, and social license barriers remain unaddressed, Australia may risk falling short of its net zero by 2050 target. Despite being embedded in international climate frameworks, CCS is likely to struggle to gain traction domestically without attention to enabling conditions. As a result, CCS could remain underutilised, which might hinder Australia's ability to meet its climate commitments and transition effectively to a low emissions future.

2.5 Achieving decarbonisation through the integration of nature based solutions and CCS

Facilities in the hard-to-abate sectors outlined above are major point sources of emissions. Many produce over 100,000 tonnes of emissions each year, and are thus governed by the Safeguard Mechanism.[8] While nature based carbon storage solutions offer one option (particularly in the short-term) for reducing emissions from these facilities, these solutions alone cannot drive the low-cost industrial decarbonisation required. This is due to a few key factors:

- Most nature based solutions do not offer permanent carbon storage — Australia's natural capital (as well as other countries') fluctuates from being a carbon sink (storing carbon) to a carbon source (emitting carbon) based on weather patterns, rainfall, and La Niña/El Niño cycles. Engineered carbon removals on the other hand offer permanent carbon sequestration.
- Estimates of carbon captured from nature based solutions changes each year, and there is an overall lack of certainty around the volumes of carbon being stored (or produced during El Niño periods) — this lack of certainty impacts on carbon pricing mechanisms.

[8] Australian Energy Regulator, 2024, Safeguard Mechanism

This section explores the importance of a balanced approach that includes both nature based and CCS solutions for effective decarbonisation.

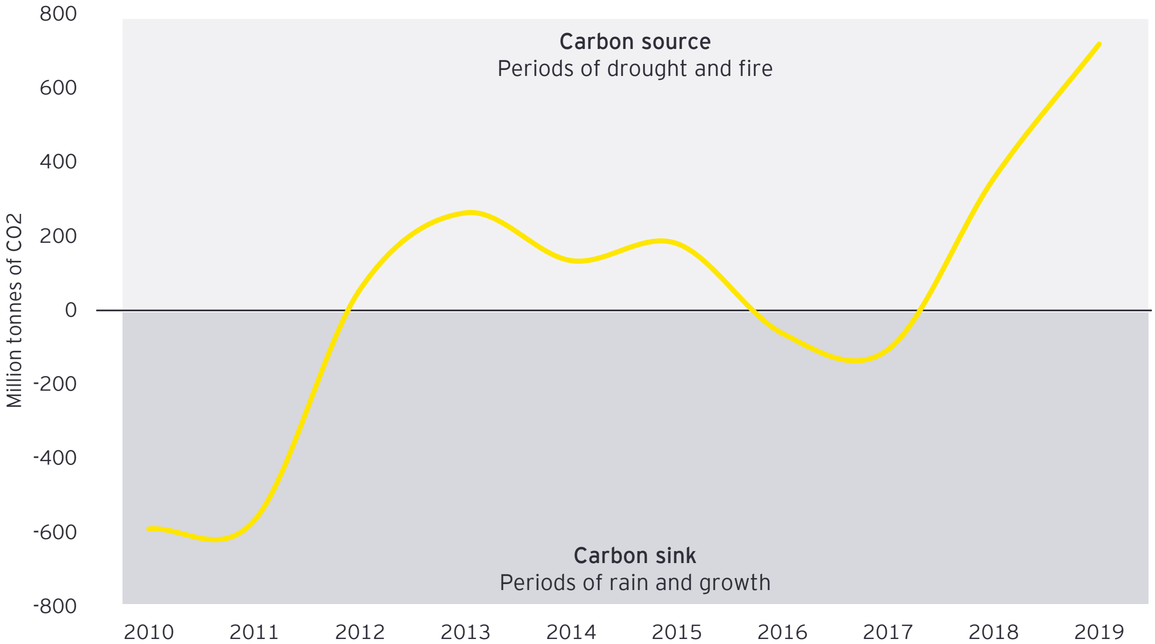
Nature based carbon removals have so far done the heavy lifting, but driving emissions reduction across industry is still critical

Nature based solutions are expected to play a vital role in the net zero effort due to their economic viability and storage potential. However, these solutions can often experience fluctuations in effectiveness.

During periods of favourable rainfall and growth (La Niña), the land sector acts as a carbon sink, sequestering large volumes of CO_2 through natural processes such as reforestation and soil carbon uptake. On the graph below, this is evident between 2010 and 2012, where land-based sequestration peaked at around 600 $MtCO_2$ annually. Conversely, they can also become a carbon source during times of drought and fire (El Niño), releasing emissions back into the atmosphere, which occurred during 2019.

Over the past decade, Australia's natural capital has sequestered a net total of around 70 $MtCO_2$. However, the recent shift from carbon sink to carbon source underscores the inherent volatility of nature based solutions, which are highly sensitive to climatic and environmental conditions. These variabilities are likely to intensify as climate change accelerates, bringing longer and more extreme El Niño and La Niña weather patterns. This reinforces the importance of integrating stable, engineered carbon removal solutions — such as CCS — to complement the land sector's role in emissions abatement.

Figure 11: The boom-bust cycle of nature based removals



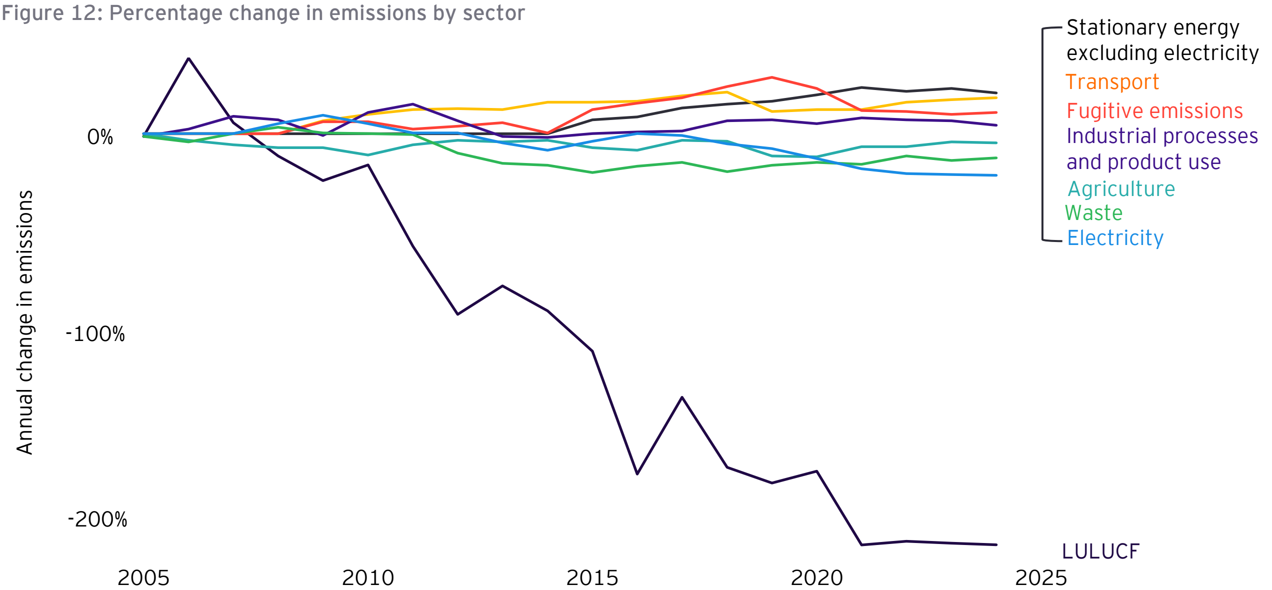
Source: Villalobos et al. 2023

Nature based solutions can increase demand for land, which may lead to higher land prices and upwards pressure on food costs. Integrating engineered CCS solutions into the decarbonisation approach can help mitigate these pressures, ensuring that the decarbonisation approach better aligns with food security and long-term economic stability.

Frequent revisions to nature based emissions accounting standards masks the needs for deeper industrial decarbonisation

Nature based removals, referred to below as land use, land use change, and forestry (LULUCF), has contributed the largest share of emissions reductions in Australia. Across all other sectors, emissions have remained relatively flat over the past 20 years. However, estimates of land sector emissions reduction are revised each year.

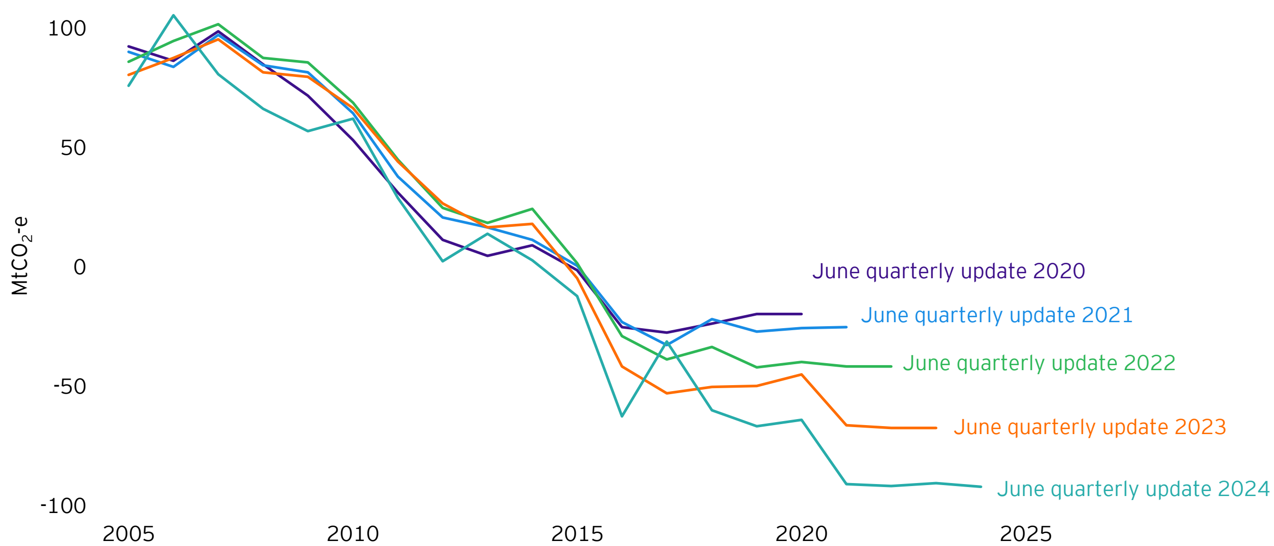
Figure 12: Percentage change in emissions by sector



Source: Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2024, Department of Climate Change, Energy, the Environment and Water

The figure below demonstrates how changes in reporting and calculations of the emissions reduction of nature based solutions has changed over the years. Each year, these revisions lead to an upgrade in the amount of emissions reduction being attributed to nature based solutions.

Figure 13: Australia's land sector emissions over time



Source: Climate Change Authority 2024 Annual Progress Report

Each adjustment suggests that Australia's emissions are falling year-on-year, effectively shrinking the need for decarbonisation across other industries. Although these changes are not unusual for sectors reliant on natural processes, the uncertainty underscores a key risk: **over-reliance on land-based emissions reduction to meet Australia's climate targets could obscure the need for deeper, more reliable cuts across other sectors.**

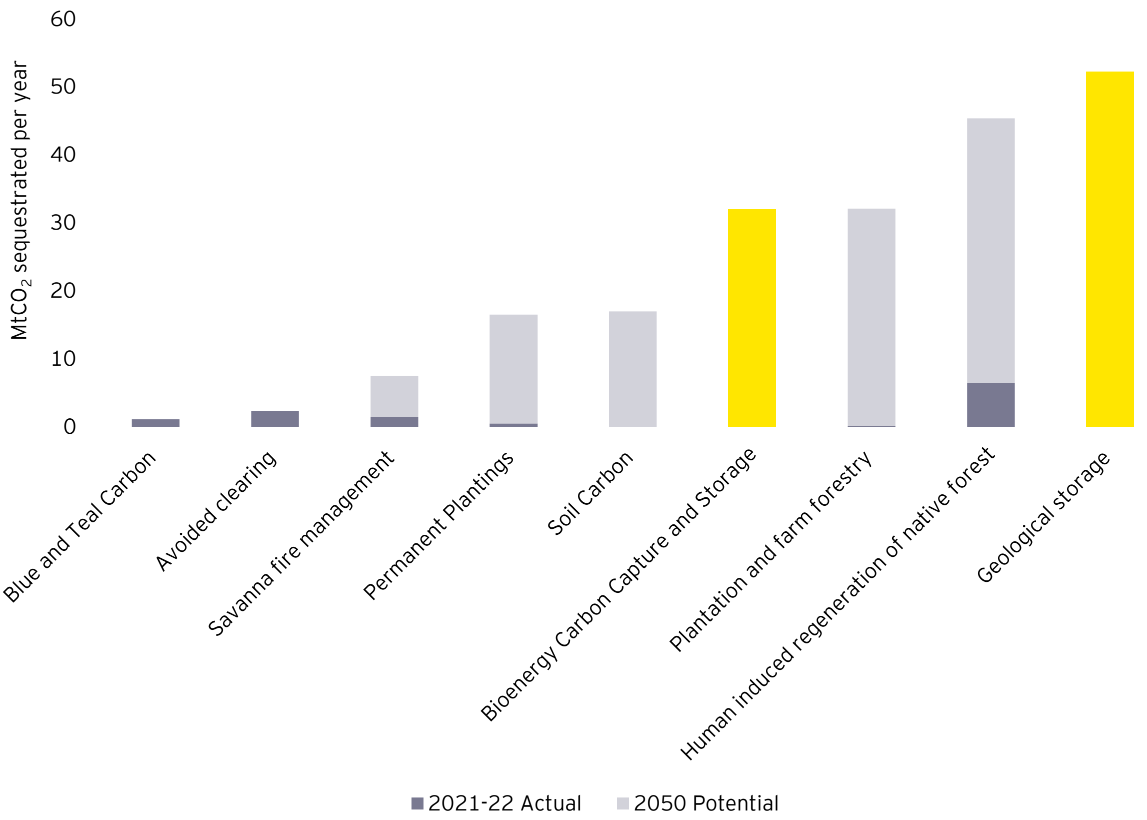
Nature based carbon sequestration is deployable and scalable in the short-run, but geological storage offers significant long-run potential

Nature based carbon sequestration, such as avoided land clearing and reforestation, offer a low-cost and deployable carbon storage solution. These solutions are scalable in the short-term and are already making important contributions to Australia's emissions reduction pathway.

The figure below shows the contribution of nature based solutions to Australia's emissions reduction, with the dark shaded area representing actual emissions abated in 2021-22. The light shaded area demonstrates annual abatement potential in 2050. Considering the relatively low-cost of some of these nature based solutions, it is likely that these solutions will continue to be deployed at a high rate.

Engineered removals (shaded in yellow), particularly geological storage, offer greater potential for emissions abatement. While engineered removals do face greater technical and regulatory barriers to deployment, scaling up and deploying these technologies are crucial to drive deep cuts in emissions in addition to these nature based solutions.

Figure 14: A comparison of actual (2021-22) carbon sequestration and potential across technologies/solutions



Source: EY analysis of CSIRO, 2022, Australia's carbon sequestration potential

3. The cost and economics of CCS

The decarbonisation of established economic and industrial processes presents a raft of challenges, which are commonly referred to as transition risks. Transition risks are risks related to changes in domestic and international policy and regulatory settings, technological innovation, social adaptation and market changes, which can result in changes to costs, income and profits, investment preferences and asset viability.[9]

Depending on the nature, speed, and scope of these changes, these risks can pose varying levels of financial and reputational challenge to industries and governments. Put simply, the global transition to net zero presents a series of policy, technology, and market risks which could materially impact on economic and financial outcomes.

This section highlights how the development and commercialisation of CCS technologies as part of a broad suite of decarbonisation technologies is crucial to helping hard-to-abate industries manage these transition risks. Additionally, it discusses how setting up CCS 'hubs' could help to keep infrastructure and technology costs down, further mitigating the impacts of transition risks.

3.1 The importance of technology choice in decarbonisation

Leading global scientific bodies have acknowledged the importance of a diverse set of decarbonisation technologies to drive emissions reduction across industry, energy generation, transport, and the built environment.

Not only will a diverse range of technologies be required across industries, it is also important to continue to develop and deploy a diverse portfolio of technologies *within* industries. Having multiple decarbonisation technologies available serves several purposes:

- **It helps to address major differences that may exist between facilities within the same industry** – Facilities can have different industrial processes and methods which may require specific decarbonisation technologies. For example, there a multiple different steelmaking processes, which use different feedstocks and fuels, each requiring specific decarbonisation options.

- **It diversifies technology risks** – Throughout the net zero transition, there are a range of technology risks present. The biggest risks are that emerging net zero technologies may not be technically or economically viable. This has been evident in the emerging hydrogen sector, which had attracted a significant amount of investment in Australia – including government funding – but has faced major cost hurdles. This has led to several companies withdrawing or scaling back their investments. By continuing to develop and enable a technology neutral portfolio of decarbonisation methods, it helps mitigate these technology risks.

- **It helps to drive down the costs of the transition** – A diverse set of commercially-viable decarbonisation technologies can help keep abatement costs down. Alternative technologies help to increase the 'supply' of abatement, leading to lower costs of abatement, which is described further in the box below. The availability of multiple alternative solutions helps mitigate demand-push cost increases which could occur if there are limited abatement options, i.e. if the only abatement technologies available are nature based solutions, the cost of these solutions could be pushed up by excess demand.

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[9] APRA, 2021, Prudential Practice Guide: CPG 229 Climate Change Financial Risks

The IPCC examined the economic impacts of limiting CCS deployment in four alternative scenarios. Across these scenarios, meeting net zero emissions was notably more challenging and expensive. To meet net zero, the costs of emissions reduction increased by more than double, and global energy demand would need to nearly halve over the next 30 years, which would have major and adverse socio-economic impacts.[10] This demonstrates the importance of developing and investing in a range of decarbonisation technologies.

Box 6: An overview of carbon pricing

How are carbon prices set?

Carbon prices are the monetary value of emitting one metric tonne of CO_2-equivalent within the carbon abatement market. These prices are primarily influenced by the dynamics of supply and demand in the market, signalling the willingness of emitters to pay for credits or offsets to fulfill compliance obligations or voluntary targets.

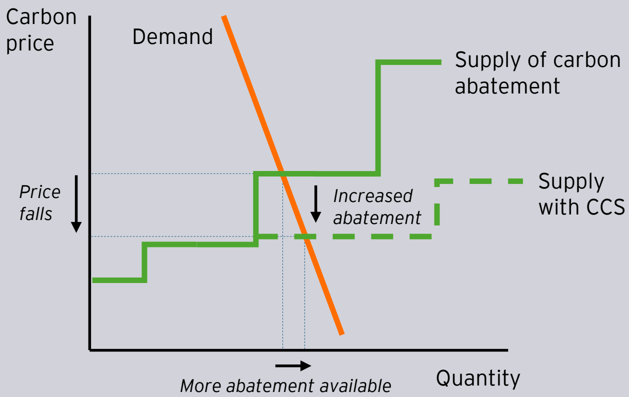
The demand for carbon pricing is driven by facilities that need to meet their annual baseline reductions under the Safeguard Mechanism. On the supply side, carbon abatement projects generate credits which can be purchased by facilities. This balance of supply and demand sets the carbon price.

Technological advancements can play a key role in expanding the supply of carbon abatement options, reducing the costs of abatement. As CCS technologies improve, the cost per tonne of carbon captured and stored decreases, enabling industries to achieve emissions reductions at a lower cost. Lower abatement costs help industry to manage transition risks and maintain economic viability.

What effect does CCS have on carbon prices?

The figure to the right illustrates the impact of carbon abatement technological advancements such as CCS on the supply curve.

The introduction of CCS expands the total supply, as shown by the outward shift on the new supply curve. This line represents the contribution of CCS, which increases the total available supply of emissions reduction technologies.



This lowers the marginal cost of abatement, driving down prices and making emissions reduction more affordable.

3.2 A hubs model is key to accelerating CCS

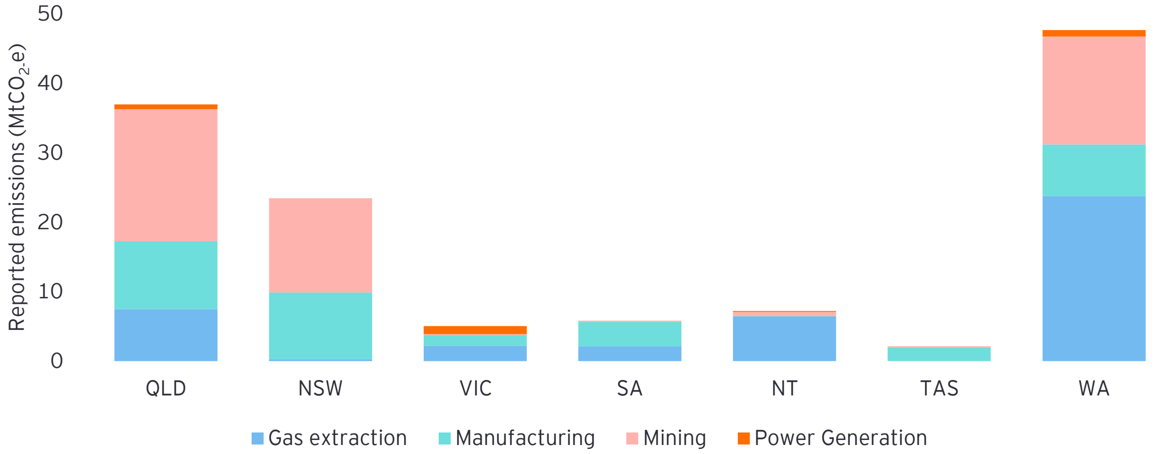
A hubs model – similar to the approach adopted in the UK as outlined in Chapter 2.4 – provides an efficient and scalable approach to deploying CCS by enabling multiple emitters to share transport and storage infrastructure. Centralising these systems reduces the financial and logistical burden on individual facilities, addressing a key barrier to widespread CCS adoption. This model is particularly critical for regions like the east coast of Australia, where high emissions levels are located a considerable distance from readily available storage capacity. By leveraging shared infrastructure, a hubs model addresses the challenges of transporting captured carbon to storage locations and ensures emissions reduction targets can be achieved more efficiently.

[10] IPCC (2014), Climate Change Synthesis Report

The east coast hosts the majority of emissions-intensive industries in Australia

The east coast contains several industrial hubs that represent a significant portion of the Australia's emissions profile. Manufacturing is a dominant sector on the east coast, contributing 62% of national manufacturing emissions, far outpacing WA's 22%. This includes emissions from aluminium smelting, steel production, and chemical manufacturing. Mining is another major contributor, with 66% of Australia's emissions from mining activities originating on the east coast.

Figure 15: A comparison of 2022-23 emissions by industry and state from facilities under the Safeguard Mechanism



Source: National Greenhouse and Energy Reporting Scheme (NGERs)

To meet potential east coast demand for CCS, additional geological storage must be unlocked

A major challenge for the east coast is the lack of currently available geological storage capacity to match its emissions profile. While the region generates over half of Australia's industrial emissions, it has fewer eligible storage sites compared to WA, which hosts the majority of the nation's large-scale storage infrastructure. Regulatory restrictions are one aspect which has limited available storage, particularly with the current prohibition of CCS and injection activities in Queensland's Great Artesian Basin. Unlocking geological storage on the east coast will be crucial to decarbonising heavy industry along Australia's most populous regions.

If this lack of readily available storage persists, this could create logistical and cost pressures for heavy industry along the east coast. Transporting captured carbon to storage hubs in WA, SA, or NT would require significant investment in infrastructure, such as pipelines or import/export terminals, adding complexity to decarbonisation efforts. While some offshore storage potential has been identified, such as in the Gippsland Basin, offshore storage sites often require additional exploration, investment, and regulatory approvals before they can support CCS at scale.

Achieving scale in CCS can be accelerated with coordination across industries

There are some significant coordination challenges facing CCS technologies. Currently, the industry landscape is fragmented across hard-to-abate sectors, which could be major point sources of demand, and large oil and gas firms which have the capture, transport, and storage know-how.

Stakeholder consultations conducted as part of this study found that facilities in hard-to-abate sectors do not have the know-how to adopt CO_2 capture technologies on their own. These consultations frequently emphasised the importance of coordination across hard-to-abate sectors and the oil and gas industry, which have access to technology and storage infrastructure.

To help facilitate CCS deployment, large emitters in hard-to-abate sectors could develop and share their decarbonisation strategies, including the scale and timing of any carbon capture technologies.

This could give some certainty to oil and gas industry players of likely future CCS demand which could be met by offering carbon transport and storage solutions. Further, this coordination could help facilities develop common-use infrastructure to keep costs down.

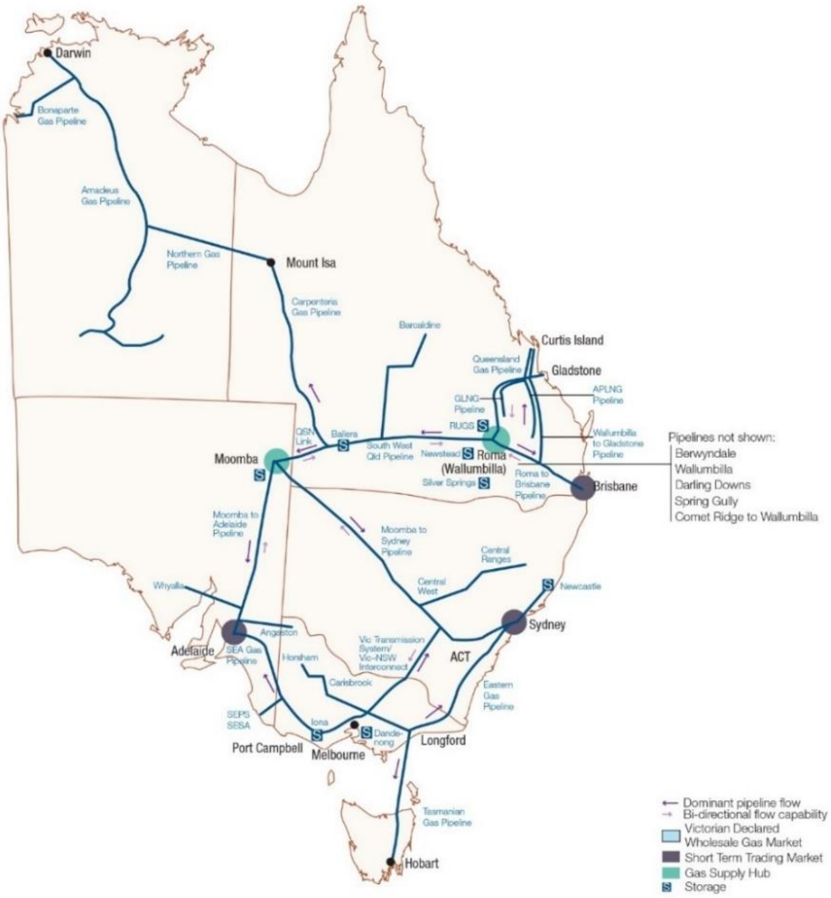
Common-use infrastructure under a hub model offers the greatest opportunity for carbon transport cost reductions

CO_2 can be transported through pipelines, trucks, rail, or sea freight using similar technologies as natural gas transport. There is potential to coordinate industry and investment to enable the development of common-use pipeline infrastructure. This offers the greatest opportunity to reduce carbon transport costs.

Heavy industry is already co-located across Australia's east coast, including in regional hubs such as Gladstone, the Hunter Valley, Illawarra, and the La Trobe Valley. This industrial concentration presents an opportunity to coordinate pipeline infrastructure, in a similar way as the east coast's gas network is interconnected. This common-use infrastructure can reduce the costs of transport for facilities, and help build economies of scale and network benefits. The figure below shows Australia's east coast gas network, the various gas supply hubs, storage locations, and demand centres.

In practice, CCS hubs would look similar to this existing network. In fact, the Moomba gas supply hub, which is connected to Adelaide, Sydney, and Brisbane, is already positioning itself as a major carbon storage hub.

Figure 16: Australia's east coast gas network



Source: Australian Energy Regulator

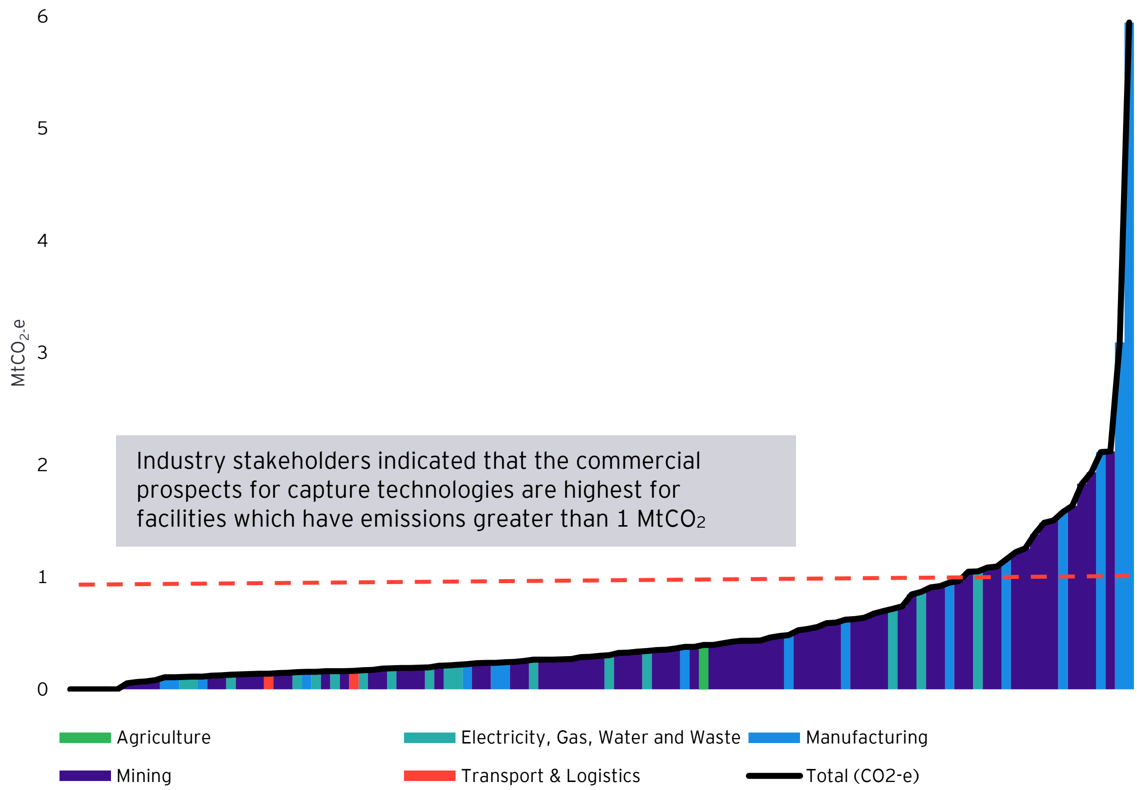
Without coordination, some smaller facilities may struggle to justify investments into capture technologies

Several large emitters covered by the Safeguard Mechanism are considered as emissions-intensive and trade-exposed, which includes cement manufacturing, metal refining, and others. These facilities have concessions carved out for them under the Safeguard Mechanism that acknowledges the pressures facing these industries from global competition.

Some of these industries are relatively low-margin, with ageing capital stocks and major energy requirements, and may struggle to justify large-scale capital investments into capture technologies. Consultations with CCS experts and heavy industry suggested that investments into carbon capture technologies are currently suitable only for facilities which produce over 1 $MtCO_2$ per year.

A hub model could provide a major opportunity to bring down costs for heavy emitters, and potentially reduce the scale required to overcome carbon capture investment hurdles.

Figure 17: Facility-level emissions produced in eastern states and the scale threshold



Source: EY analysis of NGER data, DCCEEW

What could capture and storage hubs look like on the east coast?

CCS value chains have important geographical factors. High emitting facilities and geological storage resources are rarely co-located, outside of the oil and gas sector. The east coast has four major industry hubs, and three key storage resources:

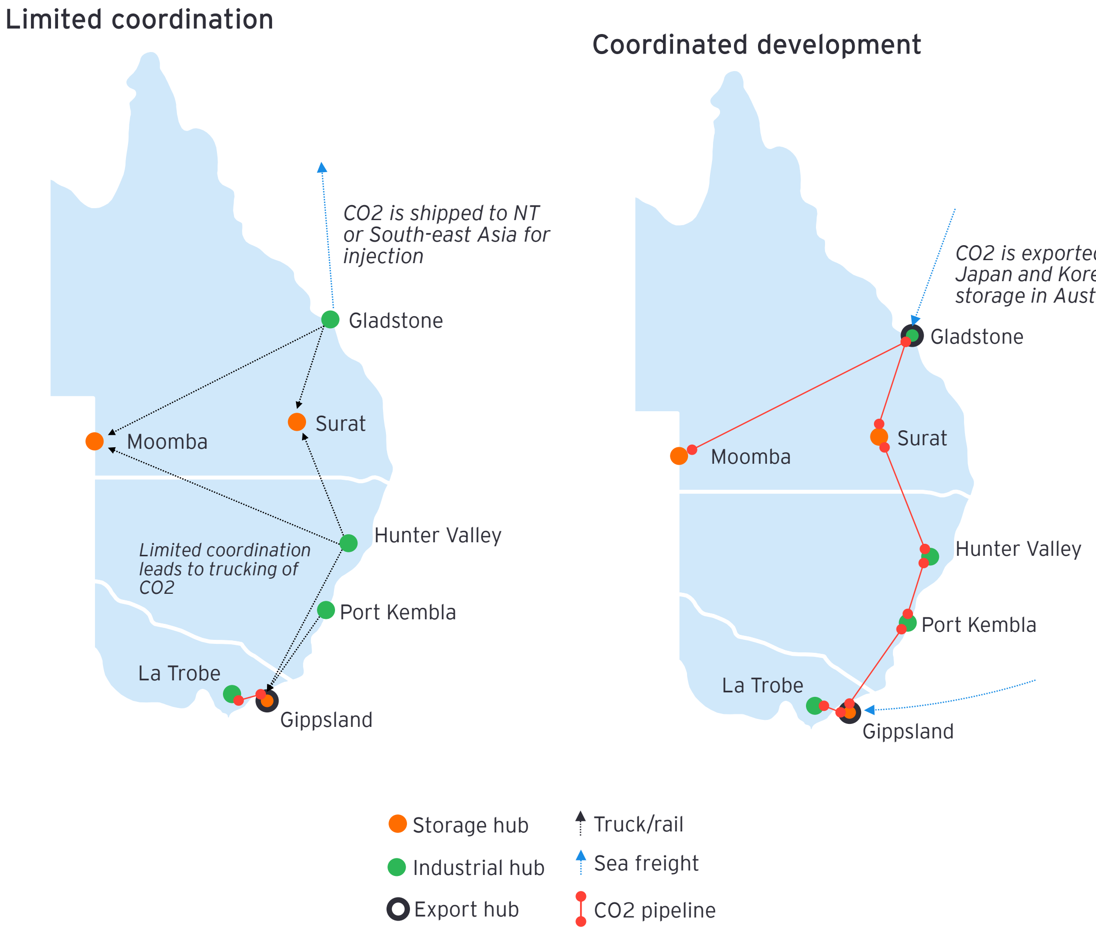
- Gladstone
- Hunter Valley
- Port Kembla
- La Trobe Valley

- Surat Basin, where the former Queensland Government has prohibited CO_2 injection
- Moomba, located in South Australia
- Gippsland Basin, offshore of Victoria

As carbon capture technologies are deployed, there is an opportunity to coordinate the industry's development. The figures below give some insight into how these hubs could shape up. In a scenario where there is limited coordination, industrial hubs could rely more on truck or rail freight to transport CO_2 from capture locations to storage locations. The constraints of truck/rail freight leads to additional costs for large emitters. Further, CO_2 could also be shipped to NT or South-east Asian storage locations for injection.

Under a more coordinated development scenario, common-use pipeline infrastructure linking key industrial and thus carbon capture hubs to storage locations could be developed along the eastern seaboard, similar to existing gas networks. This would lead to reduced transport costs for heavy emitters, and could enable the export of CO_2 from Japan and Korea to be imported for storage in Australia through ports in Queensland or Victoria.

Figure 18: Possible storage locations under a limited coordination of resources verses coordinated development of CCS industrial hubs



Source: EY analysis

4. Future development scenarios for CCS on the east coast

The deployment of CCS on the east coast will be heavily dependent on a range of public policy, technological and commercial factors. These factors, which include issues such as the level of policy coordination across jurisdictions, and which decarbonisation technologies are commercialised, each come with a range of possibilities and uncertainties. How these different factors play out over the short- and long-term will materially impact on the uptake of CCS and other decarbonisation technologies on the east coast.

To help navigate these uncertainties, three potential development scenarios were established and analysed. The scenarios are designed to reflect the considerable uncertainty surrounding the trajectory of global and Australian uptake of CCS and showcase how regulatory and policy support could influence the deployment of CCS on Australia's east coast. They have been designed for the purpose of this study only and aim to explore the development potential of CCS on the east coast.

The following factors were a key focus in the development of the scenarios:

- **The current investment pipeline** – The CarbonNet storage facility in the Gippsland Basin is set to come online by 2030, which can store up to 6 $MtCO_2$ per year.[11] In each scenario presented below, these facilities come online based on their announced operational date.
- **The capital intensity of retrofits and technology deployment** – For large industrial facilities with established machinery, retrofitting a capture plant will require significant capital expenditure, which must be planned in advance to align with the facility's capital expenditure plans.
- **Technology costs and readiness levels –** Each of the scenarios considers how changes in the costs of CCS, including capture, transport and storage, as well as their commercial availability, could impact on CCS adoption.
- **Regulatory conditions and social license –** The scenarios showcase a range of regulatory support measures from Government to highlight how it will impact the deployment of CCS in Australia.

The three potential development scenarios, 'Moderate Growth,' 'Accelerated Deployment,' and 'Sequestration Nation', represent a progressively more favourable environment for CCS adoption, improving with every scenario. As policy support grows, social license improves, and investment accelerates, technology deployment increases. This drives down costs and enhances technology readiness levels. Each scenario builds on the previous one, gradually creating a more advanced and supportive landscape for CCS adoption. These are compared to a 'base case,' where investment, technology, regulations, and social acceptance remain unchanged, with minimal policy support and limited public backing.

[11] Geoscience Australia, 2024, *Carbon Capture and Storage,* https://www.ga.gov.au/aecr2024/carbon-capture-and-storage

Developing three distinctive scenarios for CCS on the east coast

In the transition to net zero by 2050, CCS plays a role in all global and Australian emissions reduction scenarios. As such, all three scenarios include some deployment of CCS on the east coast. They aim to showcase the potential range of demand for east coast CCS under various market and regulatory conditions.

Table 4: Summary of the three scenarios

Base case - Australia's current trajectory	Moderate growth	Accelerated deployment	Sequestration nation
Limited CCS development occurs due to persistent barriers, resulting in minimal adoption and reliance on large-scale facilities in select industries.	There is gradual CCS expansion in industrial clusters with modest improvements in regulatory and technological conditions.	Coordinated efforts and investments enable widespread CCS adoption across industries and regions, lowering barriers for smaller-scale facilities.	CCS becomes a cornerstone of Australia's decarbonisation strategy, supported by strong policy alignment, advanced technologies, and significant public/private investment, positioning Australia as a global leader in CCS.

It is important to note that all scenarios are assumed to reach net zero by 2050 through varying decarbonisation pathways and policy action. The focus here is the level of CCS demand on the east coast which differs, and as such, the overall cost of the net zero transition. Further, nature based solutions have not been modelled here as they are assumed to be constant under all scenarios.

4.1 The underlying drivers of CCS demand

The scenarios are examined over the period to 2050 and cover a range of uncertainties for Australia's transition to net zero. These uncertainties are summarised in the table below.

- The **overarching CCS development trajectory** provides the overall summary for CCS adoption along the east coast in each scenario. From Australia's current trajectory to a pathway where CCS is a central pillar in the transition to net zero, the scenarios cover a comprehensive suite of possibilities for CCS on the east coast.
- **Industrial demand for CCS** describes what could occur within facilities under the Safeguard Mechanism. **The facility-level scale threshold** also describes pathways for these facilities but presents a threshold where capture technologies become commercially viable. Forecasts from Net Zero Australia and CCA were used to determine the potential emissions profiles of the hard-to-abate industries and have informed demand projections for CCS.
- **Direct air capture** and Australia's intake of **CCS exports** from APAC nations is assumed to increase across each scenario as research and development and coordinated action occurs across both government and industry to further adopt and deploy CCS services. The east coast of Australia becomes increasingly important for storing carbon shipped from Korea, Japan and Singapore. Under each scenario, Australia is able to capture some market share of these exports.
- **Low-emissions production** increases across each scenario, taking an increasing proportion of Australia's total blue hydrogen production based off the Global Hydrogen Review 2024.
- As **regulatory conditions** play a significant role in the deployment of CCS technologies, the scenarios showcase three ways in which government support can impact CCS investment and deployment.

It is important to note that while each scenario is plausible, analysis on the probabilistic likelihood was not considered. More details on the assumptions used in each scenario can be found in Appendix A.

Table 5: Summary table of the key parameters in each scenario

Scenario parameter	Base case	Moderate growth	Accelerated deployment	Sequestration nation
Overarching CCS development trajectory	Significant barriers to CCS deployment on the east coast prove persistent. High costs, supply chain constraints and limited government support remain.	Steady adoption in select industrial clusters in Victoria, with minimal expansion into other regions or industries.	Coordinated effort to deploy CCS technologies at scale across states, with an emerging storage as a service and H2-CCS industry.	Strong policy alignment, regulatory certainty, and public/private investment drives rapid advancements in CCS technologies and infrastructure. CCS is a central pillar of Australia's decarbonisation strategy.
Industrial demand for CCS	Hard-to-abate industries de-industrialise as they reach end of life.	Some growth occurs in the demand for CCS in hard-to-abate industries.	Industrial onshoring, decarbonisation of metallurgical coal mining, and development of a domestic hydrogen sector increases the demand for CCS.	
Facility-level scale threshold i.e. the amount of carbon a facility would need to be emitting to commercialise CCS deployment	2 $MtCO_2$ High upfront costs and lack of R&D results in CCS only being used in large-scale gas facilities.	1 $MtCO_2$ A lack of coordination across industries means that commercial barriers can only be overcome by large emitters.	0.5 $MtCO_2$ Technological developments and an improved regulatory environment reduce barriers for smaller-scale facilities.	0.25 $MtCO_2$ Strong coordination, policy alignment, and common-use infrastructure drives down the cost of CCS allowing smaller facilities to invest in the technology.
Direct air capture	A lack of investment into R&D and enabling infrastructure confines the technology to only experimental facilities.	Industries rely mostly on nature based carbon sequestration, with some DAC used by larger players.	Coordinated efforts to deploy DAC as a service to reduce emissions in heavy industry and overseas markets.	Plays a critical role in working towards a well below 2C pathway.
Low-emissions hydrogen	0% of Australia's total hydrogen	20% of Australia's total hydrogen	30% of Australia's total hydrogen	40% of Australia's total hydrogen
CCS exports to Australia from APAC countries (excluding DAC)	0% of APAC market Regulatory and business settings in Australia are not conducive to direct large-scale investment.	5% of APAC market Australia is a small player but is not highly cost competitive.	10% of APAC market Australia attracts some market share, leveraging its existing LNG export strengths.	20% of APAC market Proactive investment and regulatory certainty enables Australia to be a major player in the region.
Regulatory conditions	Constrained	Limited – Few changes from current settings	Supported (carbon storage permitted in Queensland from 2035)	Supported (carbon storage permitted in Queensland from 2030)

4.2 The demand for CCS on the east coast

The development and combination of these scenario parameters has led to a potential overall demand for CCS on the east coast. Largely driven by industrial emissions, bioenergy with carbon capture and storage (BECCS), DAC and exports, the following graphs showcase the developed demand profiles of CCS under each scenario. As all scenarios reach net zero, this is solely the emissions captured and stored by implementing CCS along the east coast of Australia.

The base case represents a future where demand for CCS on the east coast is low, which limits decarbonisation opportunities for hard-to-abate sectors

In this scenario, CCS only becomes commercially available from the early-2040s. Limited decarbonisation options for hard-to-abate sectors would necessitate that Safeguard-covered facilities pay a carbon price for credits, which would help them meet their emissions reduction baselines. This could push up the carbon price as demand outpaces supply. Facilities which cannot absorb these elevated carbon prices could downsize or cease operations, leading to a potential de-industrialisation of Australia's east coast.

In the base case, just over 6 MtCO_2 per annum is assumed to be captured by 2050, largely driven by large facilities in the iron and steel industry, and stored in CarbonNet in the Gippsland. Australia receives no exports of carbon, blue hydrogen deployment or direct air capture, leading to some missed economic opportunity.

CCS demand grows with regulatory support and the investment environment improves

Through each of the additional three scenarios, the demand for CCS on the east coast increases.

- The **moderate growth** scenario showcases increased CCS in key sectors like iron and steel and oil and gas extraction, with total CCS demand projected to reach up to 15 MtCO_2 each year by 2050. From 2035, the introduction of blue hydrogen is likely to create a small level of additional CCS demand.

- The **accelerated deployment** scenario presents a situation where CCS deployment is a coordinated effort across all east coast states with the CCS ban in Queensland lifted in 2035, allowing some storage in the Surat Basin from 2040. Over 26 MtCO_2 per year is reduced by CCS technologies by 2050, largely driven by a significant increase in the amount of carbon imported from neighbouring countries. Hydrogen facilities come online in 2032 while cement, aluminium and chemical facilities are now using CCS as it has become economically viable. Gas businesses are exploring electrification alternatives and while metallurgical coal is also expected to contribute to this demand, fugitive emissions are unlikely to be captured, and mobile fuel emissions remain technically challenging to capture.

- The **sequestration nation** scenario showcases a supportive environment to deploy CCS technologies. The CCS ban in Queensland is lifted, allowing storage in the Surat Basin from 2035. A serious ramp up of demand for CCS from 2034 to 2037 occurs as all east coast Safeguard Mechanism facilities begin utilising CCS. The east coast imports 20% of Korea, Japan and Singapore's exported carbon and the east coast's share of hydrogen jumps to 40%. Direct air capture becomes more economically viable, sequestering carbon from 2037. This scenario also recognises that electrification pathways are being assessed in parallel, and the resulting CCS demand reflects a mix of decarbonisation strategies being pursued by gas and industrial sectors.

Figure 19: Carbon captured through engineered removals in each scenario by industry

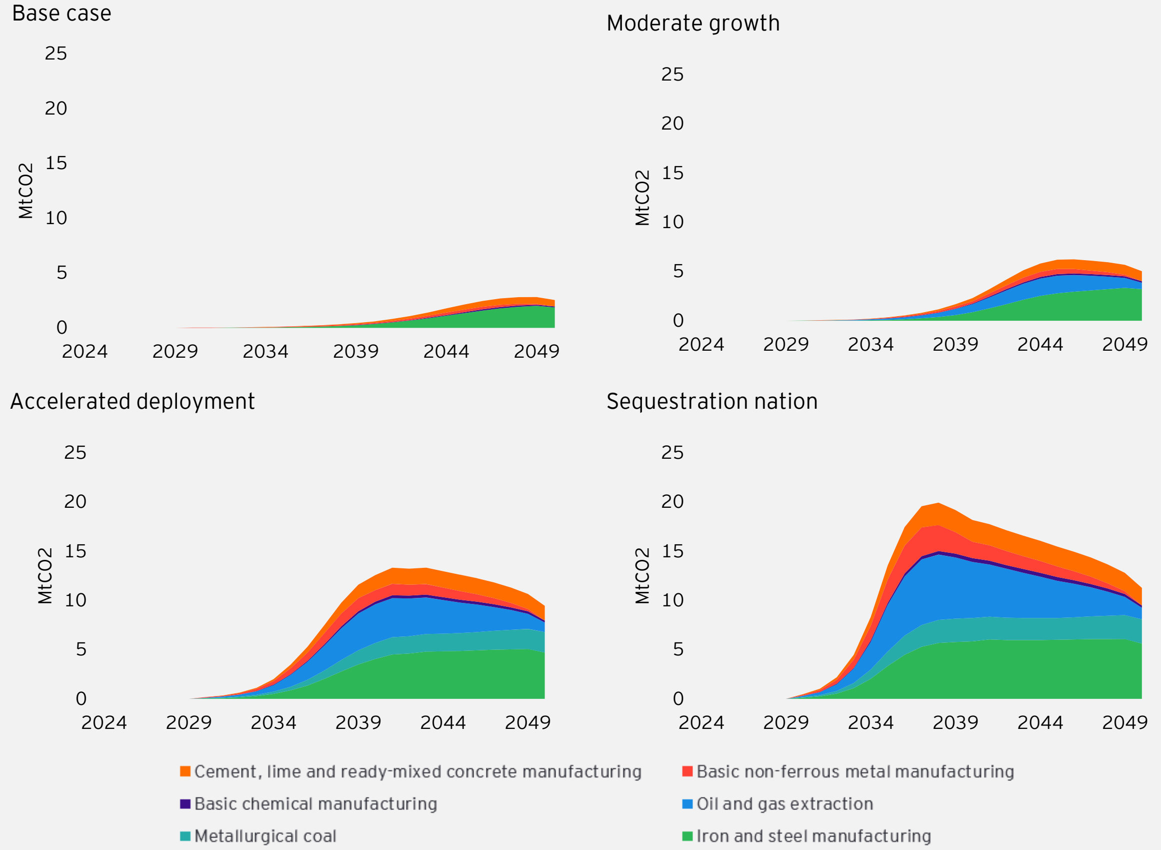
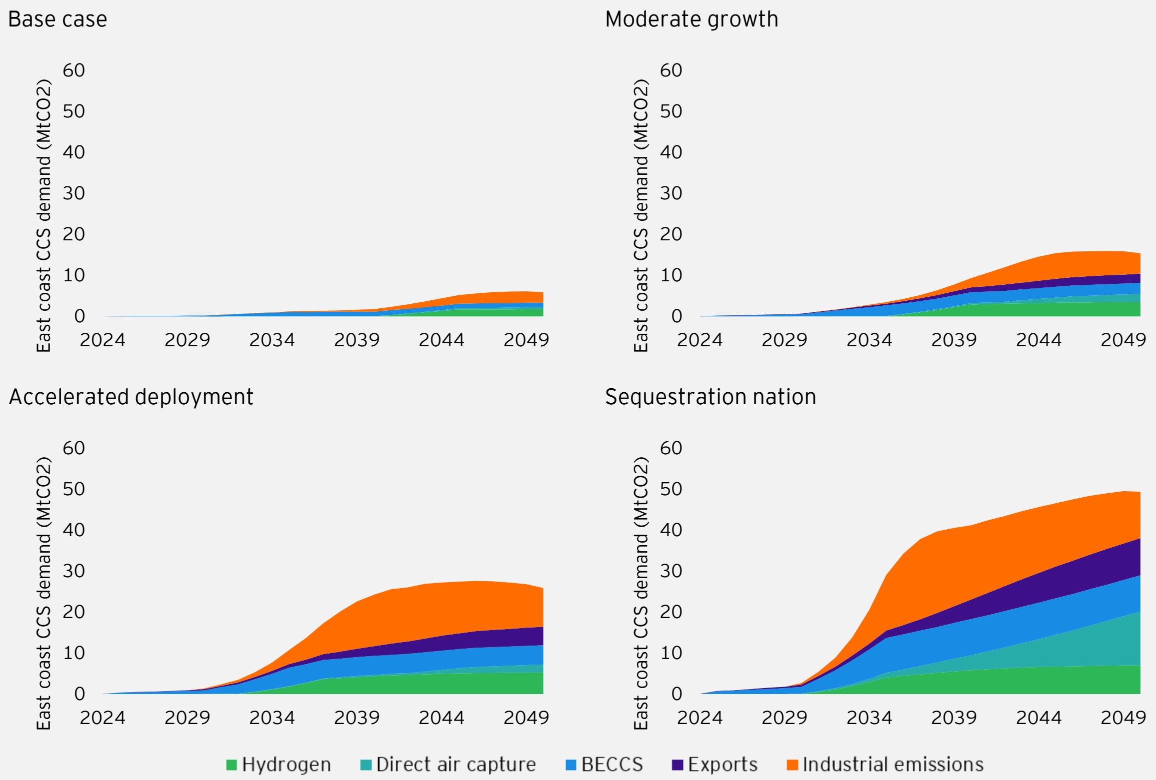


Figure 20: Demand profiles of the industrial emissions by scenario



4.3 The investment required

Realising these demand profiles of CCS along the east coast would require significant investment into the technology. This section sets out tentative estimates (at a high-level) of the cost of installing and operating CCS technologies. It highlights the cost of abatement across industries, and how economies of scale and common-user infrastructure can help improve the profitability of abatement, attract further investment and grow an industry. Importantly, the scenarios show that by reducing the costs of CCS technologies, the cost of abatement is reduced.

Carbon capture and storage capital investments have long lead times and must align with broader business strategies and regulatory requirements

As industrial facilities seek to reduce their carbon emissions to meet regulatory and emissions targets, businesses will look to find the most cost-effective decarbonisation options. This may include a role for CCS, however with the large upfront cost of implementing the technology, it is important that these costs fit into the business's broader capital expenditure renewal cycles. In addition, businesses are likely to undertake analysis comparing upfront capital requirements with long term operating and compliance costs. The development of modular carbon capture technologies, which can be retrofitted at a scalable and cost-effective rate, has the potential to accelerate adoption of CCS.

Carbon storage sites face significant regulatory hurdles, with lead times comparable to mining projects — typically 10 to 15 years from site identification to the injection of CO_2. These timelines are reflected in the scenarios, where capital costs are distributed over the initial construction phase, followed by operating and transport costs during the operational phase.

The installation costs of CCS are high, but can come down with the right mix of policy, technology, and commercial settings

While CCS technologies are available today, their high costs and low technology readiness levels across most industries limit widespread adoption. The scenarios presented reflect current cost estimates based on these readiness levels, with the assumption that costs will decline as the technology matures and approaches commercialisation. Additionally, the scenarios account for the likelihood that industries will delay deploying CCS technologies until costs become competitive with alternative decarbonisation pathways, such as paying a carbon price. Further, in scenarios with greater investment and government support, it is assumed that commercialisation timelines are shortened, accelerating the development and deployment of CCS technologies.

The scenarios also incorporate varying approaches to CCS transport. In the base case, transport relies entirely on trucks and rail, resulting in higher ongoing costs due to inefficiencies and scale limitations. By contrast, the other scenarios include the construction of dedicated CO_2 pipelines, which require significant upfront capital investment but lead to much lower ongoing transport costs. Pipelines are particularly advantageous for industries with large, centralised CO_2 capture points, enabling cost-effective, high-volume transport and the potential for shared infrastructure to reduce costs.

Storage costs mostly occur early in each scenario, as substantial investment is required to identify, assess, and develop suitable storage sites. Regulatory requirements, site assessments, and infrastructure setup all contribute to these initial costs. Once operational, however, storage sites benefit from relatively low ongoing maintenance costs, as the primary expenses involve monitoring and managing the injection process and ensuring compliance with long-term safety and environmental standards.

Capital expenditure, operating capture technologies, transport and storage costs are combined and reflected in the scenarios below. Capital costs are distributed over the initial construction phase; while operating, transport and storage costs occur for the remaining time.

Building up CCS infrastructure as costs of abatement decline

Through each of the scenarios, the cost of abatement on the east coast reduces as technology improves, regulatory barriers ease, and economies of scale are achieved. These costs have been estimated in the graphs on the next page.

- The **base case** showcases storage facility development limited to just the Gippsland Basin, with activity starting in the early 2030s. Capture demand is driven primarily by industrial emissions and some investment in hard-to-abate sectors like steelmaking. In this scenario, limited adoption of CCS and rising abatement costs contribute to some de-industrialisation along the east coast.

- In the **moderate growth** scenario, modest reductions in CCS technology costs enable more industries to overcome capital cost barriers, allowing CCS to penetrate sectors such as cement manufacturing, steelmaking, and an emerging hydrogen industry. Some domestic direct air capture capacity is developed, though high costs limit its contribution to abatement efforts. While costs decline compared to the base case, significant reductions in the cost of abatement remain constrained by technology maturity and scale.

- Deeper cost reductions and technological advancements result in an **accelerated deployment** of CCS technologies. The total cost of abatement under this scenario is comparable to the moderate growth scenario, but the earlier adoption of CCS drives emissions reductions nearly a decade sooner. Improved industry coordination enables the creation of shared pipeline networks in Victoria and New South Wales, connecting industrial capture hubs to storage sites. These shared networks lower transport costs significantly, further reducing the cost of abatement.

- Costs of abatement are anticipated drop sharply due to a more supportive regulatory environment, increased deployability of CCS technologies, and favourable regulatory conditions in the **sequestration nation** scenario. By 2035, a large number of facilities retrofit capture technologies, achieving rapid scaling of CCS infrastructure. With a significant increase in facilities adopting CCS and the associated rise in carbon capture demand, the cost of sequestering carbon decreases substantially due to economies of scale. High pipeline utilisation rates further drive down transport costs, resulting in consistent and lower operating costs across the scenario.

The cost structure of the **sequestration nation** scenario is highlighted on the marginal abatement cost (MAC) curves on the page below the cost graphs, and all other scenarios' MAC curves can be found in Appendix B. The MAC curves show how proving up CCS technologies can bring down total abatement costs – leading to a reduction in volume-weighted abatement costs of almost $40 per tonne of CO_2 in 2050.

These costs and demand profiles for CCS have formed the inputs into the whole-of-economy modelling. This is explored further in the next chapter.

Figure 21: A comparison of CAPEX, OPEX, transport, and storage costs across scenarios

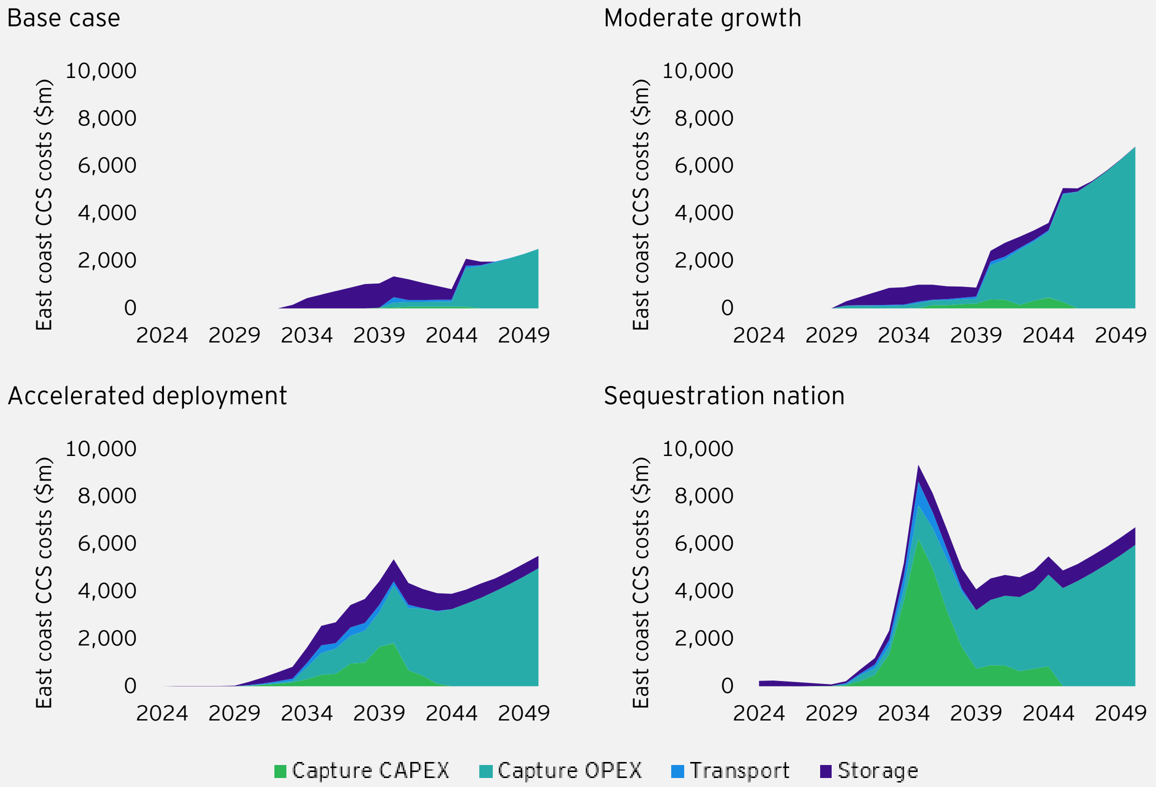
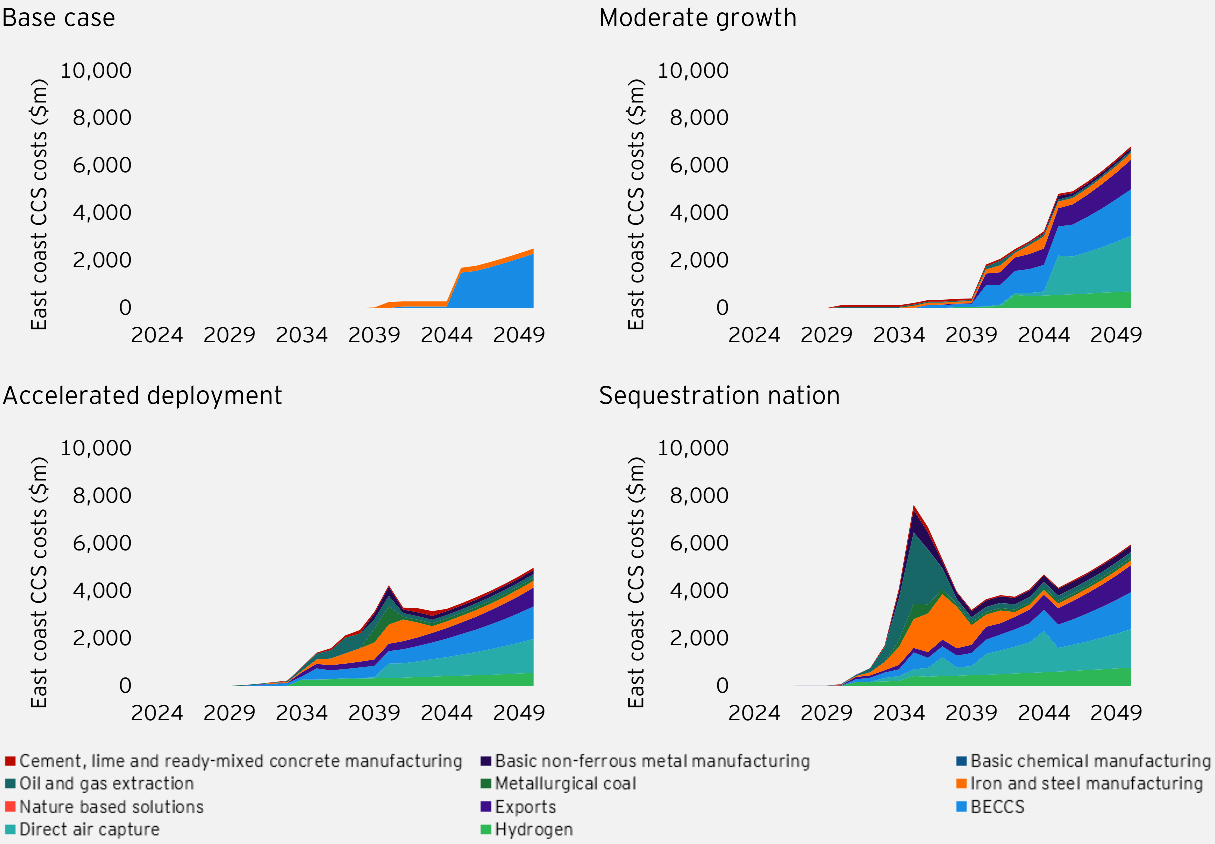
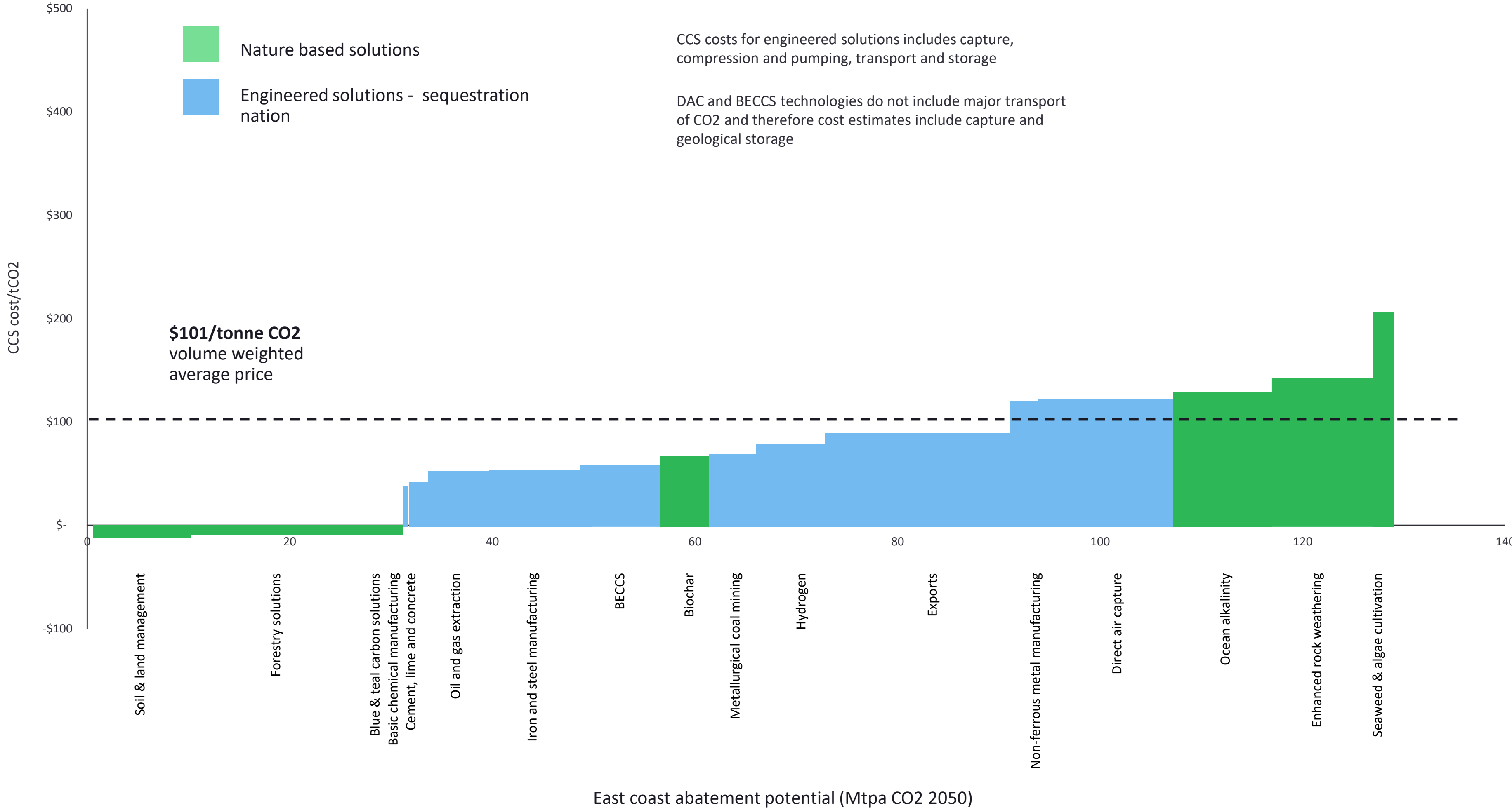


Figure 22: Estimated investment from each industry into CCS technologies



Sequestration nation marginal abatement cost curve



Source: EY analysis

5. The potential economic impact of CCS deployment

The development and deployment of CCS technologies has the potential to reduce the costs of abating emissions for hard-to-abate industries. By lowering these costs, CCS could enhance the profitability of these industries, improving their long-term economic and environmental sustainability along Australia's east coast.

The scenarios described in Chapter 4 outline alternative development pathways for CCS, the capital investment required to deploy the technology, and the associated emissions reduction potential. This section focuses on the macroeconomic benefits that could be realised under each of these pathways. These benefits are driven by three key factors:

- **Capital investments in capture, transport, and storage infrastructure** – To enable CCS deployment, significant investment is required into all parts of the technology's supply chain. The scale and composition of this investment is described further in Chapter 4. This capital expenditure stimulates economic growth by driving construction sector activity and increasing demand for labour and materials. This benefits businesses and employees in related construction and materials industries.

- **Operating costs** – Ongoing costs associated with CCS, such as energy use, pipeline maintenance, and periodic capital renewal, contribute to sustained economic activity in the CCS industry. These costs generate revenue and support employment, ensuring the sector remains an important contributor to the economy.

- **Industry uplift from lower abatement costs** – By reducing the per-tonne cost of abatement for hard-to-abate industries, CCS improves the profitability of these sectors. This enables increased production, which drives economic growth and supports regional development across Australia's east coast.

These factors each contribute to economic benefits to Australia's east coast.

Box 7: The economic benefits of the CCS development scenarios

The acceleration of CCS deployment could lead to:

$6 – $15 per tonne of CO_2 reduction in costs of abatement by 2050

$13.8 billion – $66.2 billion in additional gross domestic product from 2024 to 2050 (NPV)

3,800 – 15,260 jobs added to Australia's workforce on average (FTE) from 2024 to 2050, from a range of industries and occupations

Ranges identify the economic potential from Moderate Growth – Sequestration Nation

Modelling the broader economic impacts

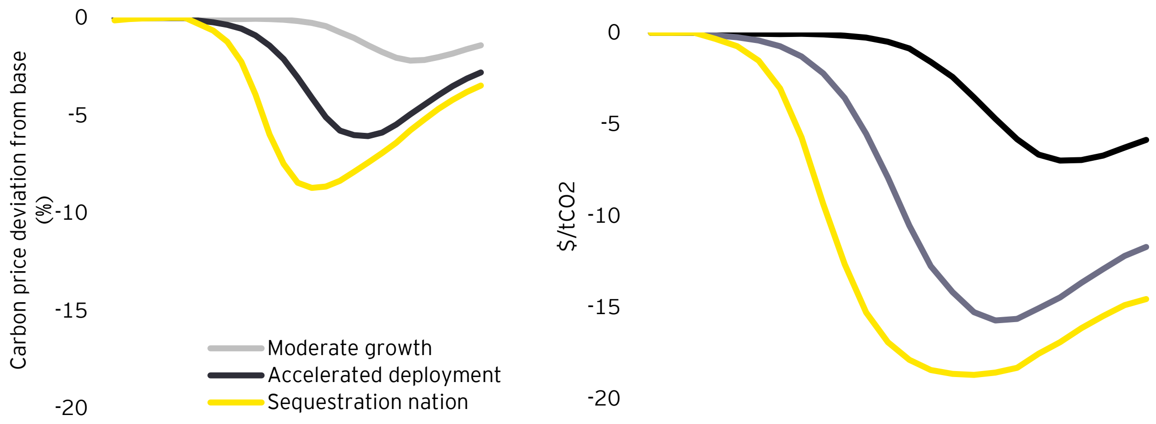
The economic analysis utilises EY's in-house Computable General Equilibrium (CGE) model, EYGEM. This model captures the likely impact of CCS scenarios on the Australian economy through 'economic shocks', representative of CCS cost requirements and emissions reduction capabilities. The CGE model then captures the ripple effects across the economy, beyond only the hard-to-abate sectors of focus. These effects are critical because of the interconnected nature of economic sectors and flows of resources.

Refer to Appendix C for a more detailed description of EYGEM.

CCS could reduce the marginal cost of abatement and improve profitability for heavy industries

By increasing the deployment of CCS, this increases the amount of abatement potential available to industry, reducing demand pressures on other decarbonisation technologies. This leads to a broad-based decrease in abatement costs, which improves both profitability and ease of abatement for businesses. This is represented by the cost of abatement[12] under each CCS scenario relative to the base case as shown below. The cost of abatement is determined by applying the percentage deviation in carbon abatement costs from baseline, as calculated by the model, to the AER's interim value of emissions reduction. Sequestration nation presents the most significant decrease in abatement costs at $15 per tonne of CO_2 below the base case in 2050. This compares to $12 per tonne of CO_2 for accelerated deployment and $6 per tonne of CO_2 for moderate growth.

Figure 23: (a) Percentage deviation in carbon abatement costs from base (b) Reduction in carbon abatement costs from base



Source: EY analysis

As carbon abatement costs decrease, economic activity rises – driven by production in hard-to-abate heavy industries and their supply chains

The reduction in ongoing costs is particularly important for hard-to-abate industries which have fewer decarbonisation technologies available to them, as well as higher emissions intensity. The potential cost savings generates economic benefits across the economy, as seen below.

Table 6: The potential economic impact (deviation from base case, 2024 – 2050)

Economic outcome	Moderate growth	Accelerated deployment	Sequestration nation
GDP (NPV, $m)	13,777	39,822	66,231
Employment (average FTE)	3,799	10,199	15,261
Total industry output (NPV, $m)	20,593	67,857	120,276
Output by sector (NPV, $m)			
Iron and steel manufacturing	182	645	1,035
Metallurgical coal	-	2,061	3,994
Gas extraction	7,655	13,026	18,835
Basic chemical manufacturing	1,403	4,556	6,968
Basic non-ferrous metal manufacturing	4,393	15,125	23,361
Cement manufacturing	198	681	1,241
Other sectors	6,761	31,763	64,843

Source: EY analysis

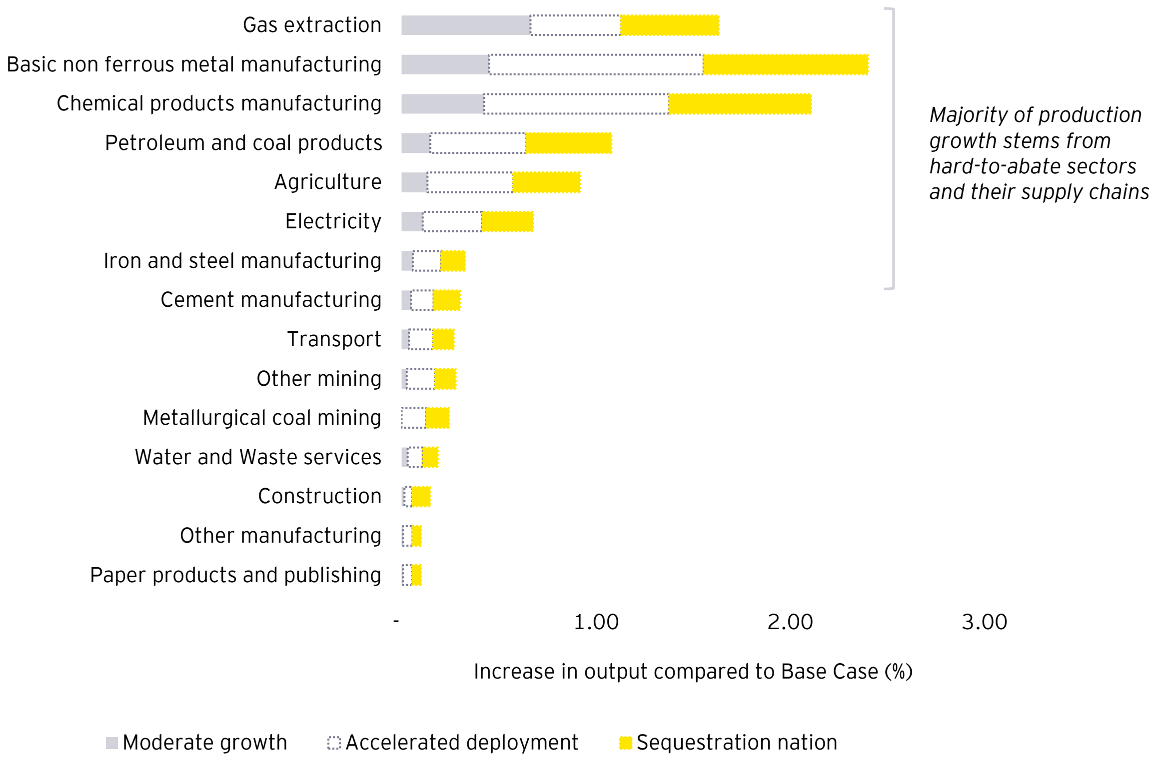
[12] While Australia does not have an economy-wide carbon price, in climate and economic modelling it is common to adopt a 'shadow carbon price', which allows us to estimate the costs of reducing emissions. The carbon prices reported in this analysis reflect the costs of reducing emissions, not a fee charge to producers of carbon emissions.

The accelerated deployment of CCS could potentially lead to an economy-wide fall in carbon abatement costs. This is expected to directly benefit heavy industries using CCS and upstream/downstream sectors, particularly around construction and electricity generation. Lower carbon abatement costs are expected to improve the economic viability and profitability of these heavy industries by shrinking the need to buy ACCUs, attracting investment and uplifting production. Without reduced carbon abatement costs, some facilities in the base case will face financial challenges and may downsize or scale back production.

Importantly, by delivering economy-wide carbon cost savings, there is a broad-based uplift in the economic output and profitability of other emissions-intensive industries, even without installing any CCS technology. This is most clear in the case of agriculture, which is currently responsible for 13% of Australia's emissions.[13] The agriculture industry, particularly cattle-grazing, produces a significant amount of fugitive methane emissions. While CCS is not suitable for eliminating emissions in agricultural processes, it reduces demand pressures on other decarbonisation technologies which the agriculture industry may be dependent on, namely nature based solutions. This ensures that the cost of these solutions remains low, and the agriculture industry can benefit from these lower abatement costs.

Output growth by sector is presented below, where the grey and yellow dotted outlines indicate extended growth from additional CCS integrated in accelerated deployment and sequestration nation respectively.

Figure 24: Potential industry output deviation from base case (NPV 2024 to 2050)



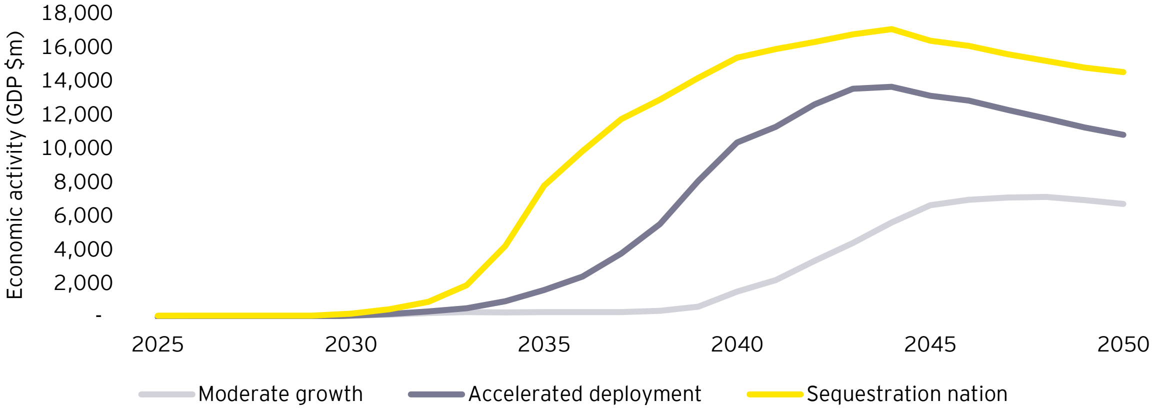
Source: EY analysis

[13] Climate Change Authority, (2021), *Agriculture*, Fact Sheet 7, https://www.climatechangeauthority.gov.au/sites/default/files/2021Factsheet%20-%20Agriculture.pdf

Greater production boosts growth in GDP and employment across Australia's east coast

The following figure showcases Australia's additional GDP from CCS deployment on the east coast, by scenario. In 2050 annual additional GDP is $6.7 billion for moderate growth, $10.8 billion for accelerated deployment, and $14.5 billion for sequestration nation.

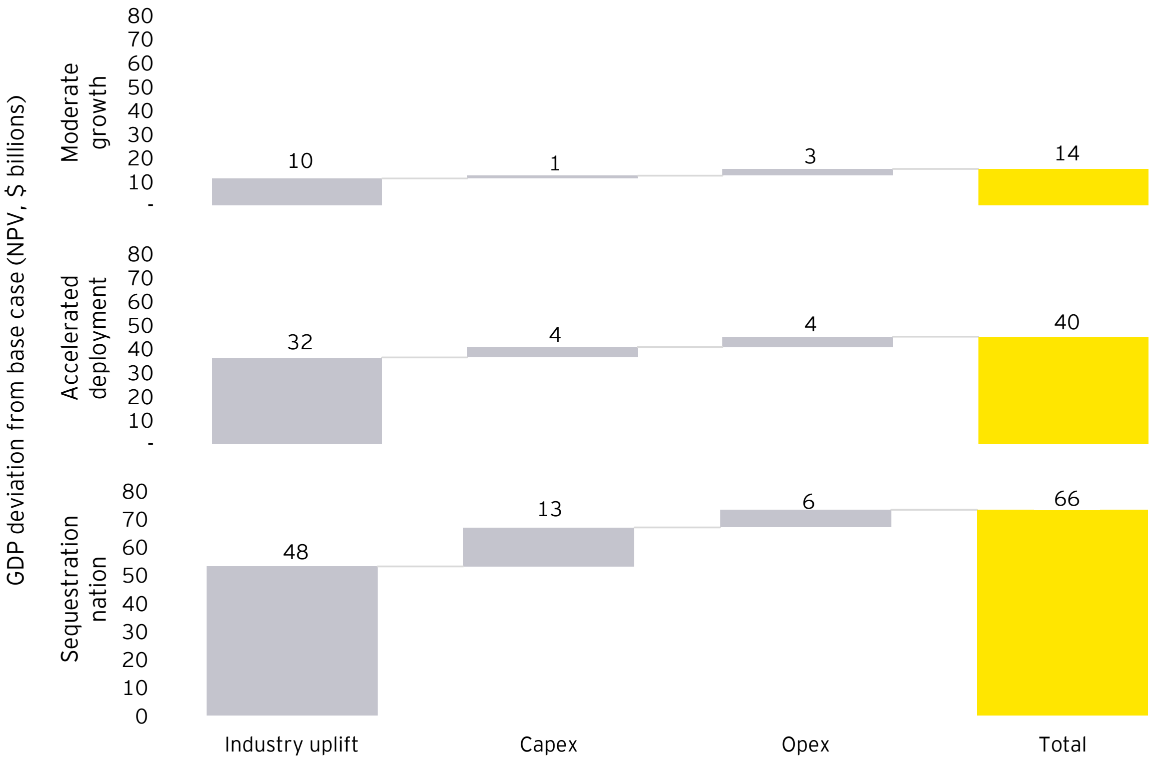
Figure 25: Potential economic output (GDP deviation from base case)



Source: EY analysis

The majority of GDP growth is driven by the emissions reduction capabilities of CCS, which lower the cost of abatement, rather than by capital and operating expenditure. This reflects the productive value of captured emissions, enabling more efficient production of goods and services. In contrast, capital and operating expenditure represent relatively smaller, short-term economic shocks with fewer flow-on effects. The following figure presents this breakdown in NPV terms from 2024 to 2050.

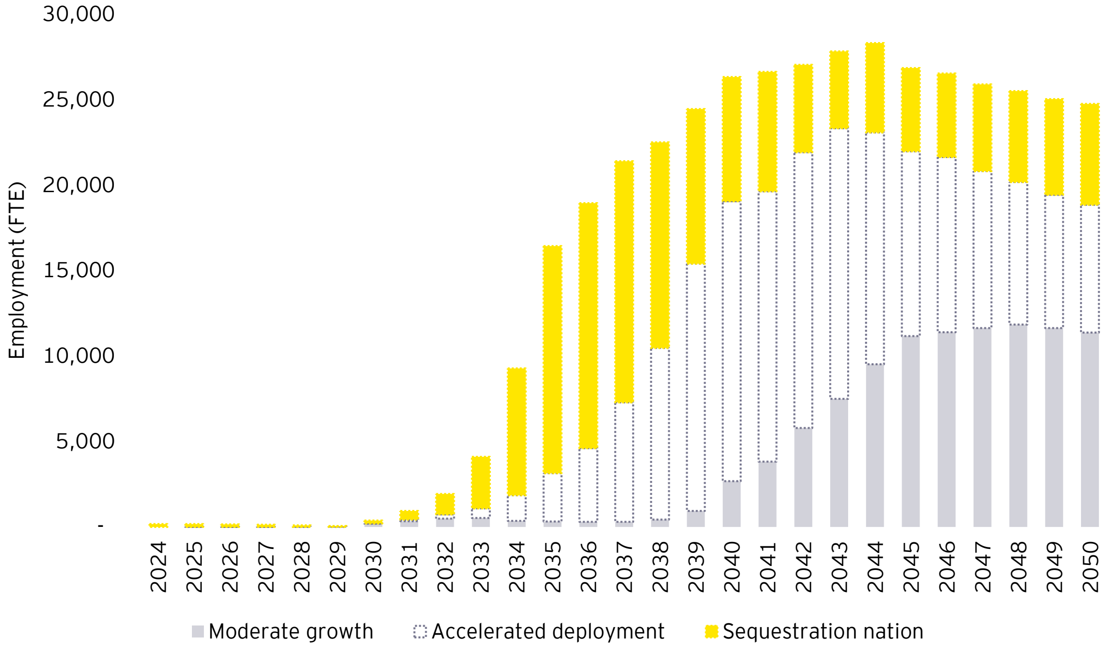
Figure 26: Potential new economic activity (GDP deviation from base case by driver)



Source: EY analysis

Employment growth follows a similar trend to output and GDP growth, as depicted in the figure below. On average from 2024 to 2050 additional jobs growth is estimated at 3,800 FTEs for Moderate growth, 10,200 for Accelerated deployment, and 15,260 for Sequestration nation.

Figure 27: Potential new employment (FTE deviation from base case)



Source: EY analysis

6. Concluding perspectives

This analysis has identified a potential shortfall in Australia's CCS capacity, which could potentially hinder the country's ability to meet its net zero target by 2050. To achieve this goal, scaling up of engineered carbon removal technologies will be required – between 2030 and 2050, engineered removals will need to increase their total carbon captured by tenfold, while nature based solutions will only need to increase the carbon sequestered by 2.7 times. Our economic modelling has demonstrated the broad-based dividends that could materialise through the deployment of CCS across Australia's east coast.

CCS technologies, including those proven in Australia's Gorgon and Moomba projects, provide viable pathways to decarbonise hard-to-abate industries like cement, steelmaking, and fertiliser production. Yet, the east coast remains underdeveloped despite its concentration of industrial emissions. Realising CCS's potential requires overcoming barriers in infrastructure development, regulatory coordination, and investment confidence.

Technology preconditions

Achieving these outcomes requires addressing several technological barriers to CCS deployment:

- Investment in research, development, and pilot programs is needed to enhance the scalability of CCS technologies. Modular designs and cost-efficient retrofits should be prioritised.

- A robust network of pipelines, carbon storage hubs, and transport systems must be established to accommodate the growing demand for CCS.

- Continuous innovation and economies of scale are critical to lowering the capital and operating costs of CCS technologies, making them accessible to a wider range of industries.

- Carbon capture technologies are energy-intensive. To accelerate their deployment, it is crucial to plan for and supply the renewable energy required to meet this demand, including in regular energy market planning by AEMO and AER.

Commercial preconditions

The successful implementation of CCS technologies requires several commercial preconditions to be met. These preconditions ensure that the industry is attractive to investors, profitable, and capable of driving growth.

- Lowering the costs associated with CCS is essential. This includes reducing the cost of abatement to improve the profitability of industries and making CCS a viable option for businesses.

- Creating an environment that attracts foreign investors is crucial. This can be achieved through favourable policies, incentives, and demonstrating the economic potential of CCS.

- Exploring alternative business models such as storage as a service, direct air capture as a service, and CCS exports can provide new revenue streams and enhance the commercial viability of CCS projects.

- Ensuring regulatory certainty and alignment across federal and state governments helps streamline approval processes and reduce barriers to entry for CCS projects.

- Maintaining mechanisms like the Safeguard Mechanism and carbon pricing can provide stability and predictability for businesses investing in CCS technologies.

Key regulatory preconditions

To ensure the successful implementation of CCS technologies, several regulatory preconditions need to be addressed. These preconditions provide a structured framework that facilitates the deployment and scalability of CCS projects.

- Simplifying and speeding up the approval processes for carbon storage projects can significantly reduce the time required to get a project off the ground. This is vital to maintaining momentum and securing early investment, avoiding delays similar to those experienced in the mining sector and accelerating the deployment of CCS technologies.

- Establishing centralised hubs for carbon capture, utilisation, and storage can streamline operations and enhance collaboration among various stakeholders. This model can also facilitate the efficient allocation of resources and infrastructure.

- Providing clear and consistent regulatory guidelines across federal and state governments ensures that CCS projects face fewer bureaucratic obstacles. This alignment helps to mitigate risks and offers a predictable environment for investors.

- Ensuring that regulations are harmonised across different jurisdictions is essential. This involves coordinating efforts between federal and state authorities to create a cohesive regulatory framework that supports the growth of CCS technologies, and could include a national CCS strategy or roadmap.

The deployment of CCS technologies will not only address immediate decarbonisation challenges but also drive broader economic and social benefits. Lower abatement costs make Australian industries more competitive globally, while increased economic activity and job creation strengthen regional economies. Furthermore, establishing Australia as a leader in CCS could open new opportunities for exporting CCS technologies and services, enhancing Australia's role in the global energy transition.

By addressing these challenges, CCS may deliver meaningful emissions reductions but also provide significant economic and employment gains. For industries and regions reliant on heavy manufacturing, the analysis found an expansion of CCS under the Sequestration Nation scenario could add up to $66 billion to GDP and over 15,250 jobs by 2050. This underscores CCS's role as a foundation for industrial growth in Australia's decarbonised economy.

Appendix A Key assumptions

The following tables include a summary of assumptions used across each scenario.

Table 7: East coast industry Safeguard Mechanism emissions

Industry	Total emissions (CO_2 equivalent)	Count of facilities
Non-ferrous metal ore mining	753,208	4
Iron and steel manufacturing	6,167,669	3
Coal mining	29,177,777	60
Waste collection, treatment and disposal services	814,580	4
Glass and glass product manufacturing	107,278	1
Water, pipeline and other transport	165,384	1
Rail transport	138,625	1
Oil and gas extraction	8,720,837	9
Basic chemical manufacturing	2,367,899	8
Gas supply	1,377,704	6
Basic non-ferrous metal manufacturing	8,180,695	6
Pulp, paper and paperboard manufacturing	235,738	1
Petroleum and coal product manufacturing	1,768,207	2
Cement, lime and ready-mixed concrete manufacturing	2,534,310	2

Source: Clean Energy Regulator

Table 8: CCA projected CCS abatement by sector

	2025	2030	2035	2040	2045	2050
Carbon sequestered through CCS by sector ($MtCO_2$)						
Hydrogen	4.932	1.334	2.497	0.069	0.500	1.086
Resources	0.015	0.016	0.024	0.067	2.644	2.302
Manufacturing	0	0.272	0.692	2.486	3.989	5.470
Chemicals	0	0.115	0.259	0.886	1.308	1.794
DAC	0.004	0.005	14.046	21.328	22.962	23.583

Table 9: EY scenarios for east coast CCS abatement by sector

	Base case	Moderate growth	Accelerated deployment	Sequestration nation
Cost to construct a facility ($/tonne CO_2-e)				
Hydrogen	150	117	83	50
Direct air capture	1,000	871	743	614
BECCS	300	233	167	100
Exports	130	123	117	110
Iron and steel manufacturing	222	185	149	112
Metallurgical coal mining	400	300	200	100
Oil and gas extraction	250	200	150	100
Basic chemical manufacturing	200	167	133	100
Basic non-ferrous metal manufacturing	250	187	125	62
Cement, lime and concrete manufacturing	250	187	124	61
Cost to operate a facility ($/tonne CO_2-e)				
Hydrogen	135	110	85	60
Direct air capture	600	433	267	100
BECCS	120	92	64	37
Exports	80	77	73	70
Iron and steel manufacturing	120	92	63	35

	Base case	Moderate growth	Accelerated deployment	Sequestration nation
Metallurgical coal mining	75	67	58	50
Oil and gas extraction	50	45	39	34
Basic chemical manufacturing	70	53	37	20
Basic non-ferrous metal manufacturing	120	113	107	100
Cement, lime and concrete manufacturing	100	74	49	23
Commercialisation timeline				
Hydrogen	N/A	2042	2034	2030
Direct air capture	N/A	2045	2040	2037
BECCS	2045	2040	2035	2035
Exports	2045	2040	2034	2031
Iron and steel manufacturing	2040	2035	2032	2025
Metallurgical coal mining	2040	2035	2035	2030
Oil and gas extraction	2035	2030	2025	2025
Basic chemical manufacturing	N/A	2035	2025	2025
Basic non-ferrous metal manufacturing	N/A	2045	2040	2035
Cement, lime and concrete manufacturing	N/A	2030	2033	2025
Size of facility that is economically viable (Mtpa)				
Hydrogen	2.00	2.00	2.00	2.00
Direct air capture	0.50	0.50	0.50	0.50
BECCS	2.00	2.00	2.00	2.00
Exports	2.00	1.50	1.00	0.50
Iron and steel manufacturing	2.00	1.00	0.50	0.25
Metallurgical coal mining	2.00	1.00	0.50	0.25
Oil and gas extraction	2.00	1.00	0.50	0.25
Basic chemical manufacturing	2.00	1.00	0.50	0.25
Basic non-ferrous metal manufacturing	2.00	1.00	0.50	0.25
Cement, lime and concrete manufacturing	2.00	1.00	0.50	0.25
Pipeline needed (km)				
Gladstone - Moomba	1,553	1,553	1,553	1,553
La Trobe - Gippsland	181	181	181	181
HV - Gippsland	951	951	951	951
PK - Gippsland	739	739	739	739
PK - Moomba	1,742	1,742	1,742	1,742
Gladstone -Gippsland	0	2,045	2,045	2,045
La Trobe - Moomba	0	0	1,725	1,725
HV - Moomba	0	0	1,672	1,672
Gladstone - Surat	0	0	0	540
La Trobe - Surat	0	0	0	1,671
HV - Surat	0	0	0	822
PK - Surat	0	0	0	1,059
Other scenario parameters				
Exports in 2050	0%	5%	25%	40%
East coast share of Aus demand (hydrogen, DAC, BECCS)	10%	20%	30%	40%
Costs reduced once commercialised	20%	10%	10%	10%
Pipeline costs (USD per tCO_2 per 250 km)				
3Mtpa	N/A	12	8	5
10Mtpa	N/A	4	4	2
30Mtpa	N/A	2	2	2

	Base case	Moderate growth	Accelerated deployment	Sequestration nation
Storage (Mtpa)				
Storage demand	10	18	29	42
CAPEX	146	90	50	23
OPEX	30	25	20	15

Table 10: Consistent assumptions for all scenarios

Industry	Time for construction (years)
Hydrogen, DAC, BECCS, exports	5
All industrial facilities	2

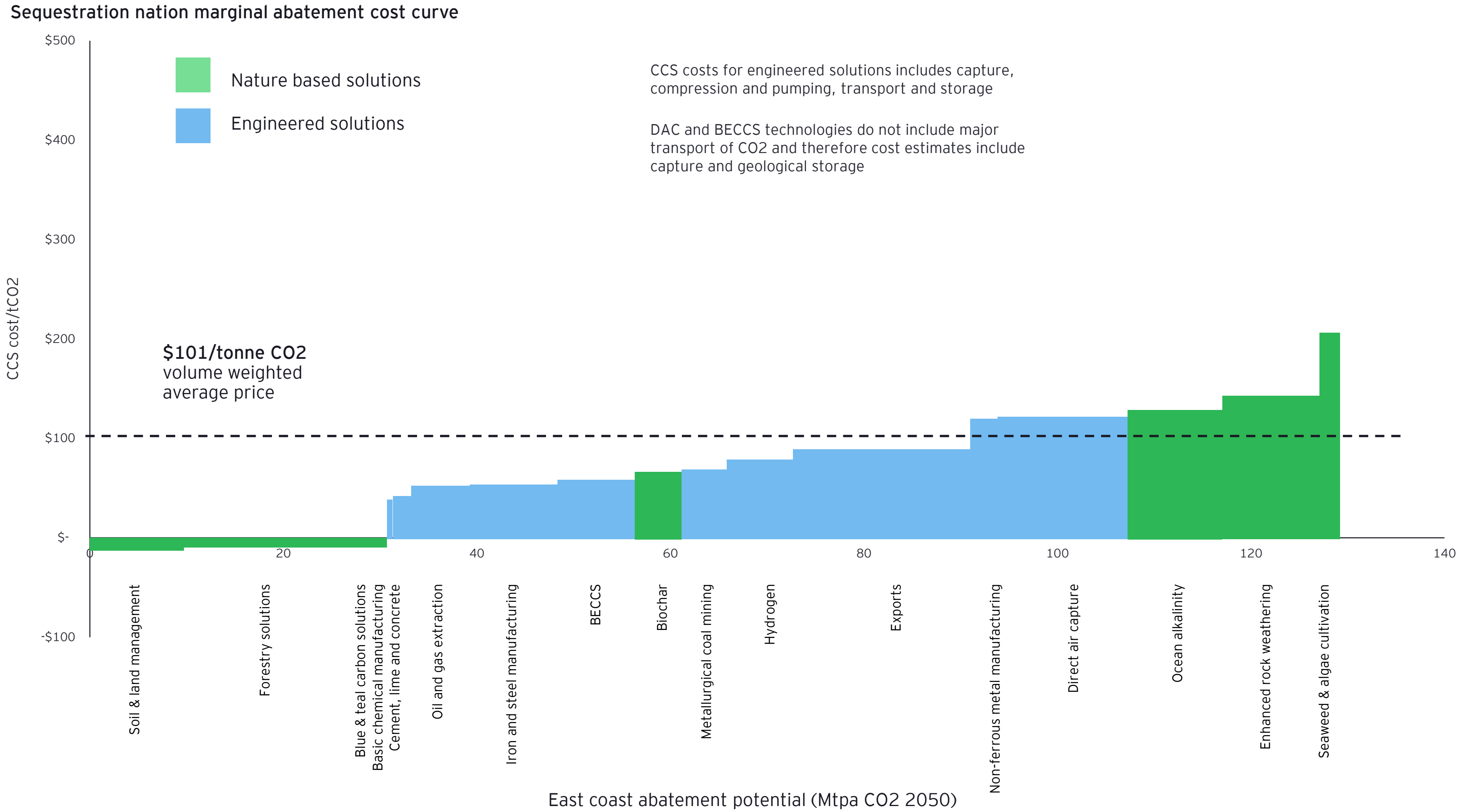
Other scenario parameters		
$MtCO_2$ captured per Mt H2	7.00	$MtCO_2/MtH2$
Natural gas w/ CCS	6.00	CO_2 /t gas
Coal with CCS	19.00	CO_2 /t coal
Metallurgical coal mining emissions	42	% of total coal mining emissions
CH4 to CO_2-e conversion factor	28	CO_2-e per CH4
USD - AUD	1.55	
Trucking cost per tonne per km	0.11	
CO_2 Shipping costs (per tonne per 500km)	24.00	USD/tonne/500km

Table 11: Sources for CCS costs in each industry

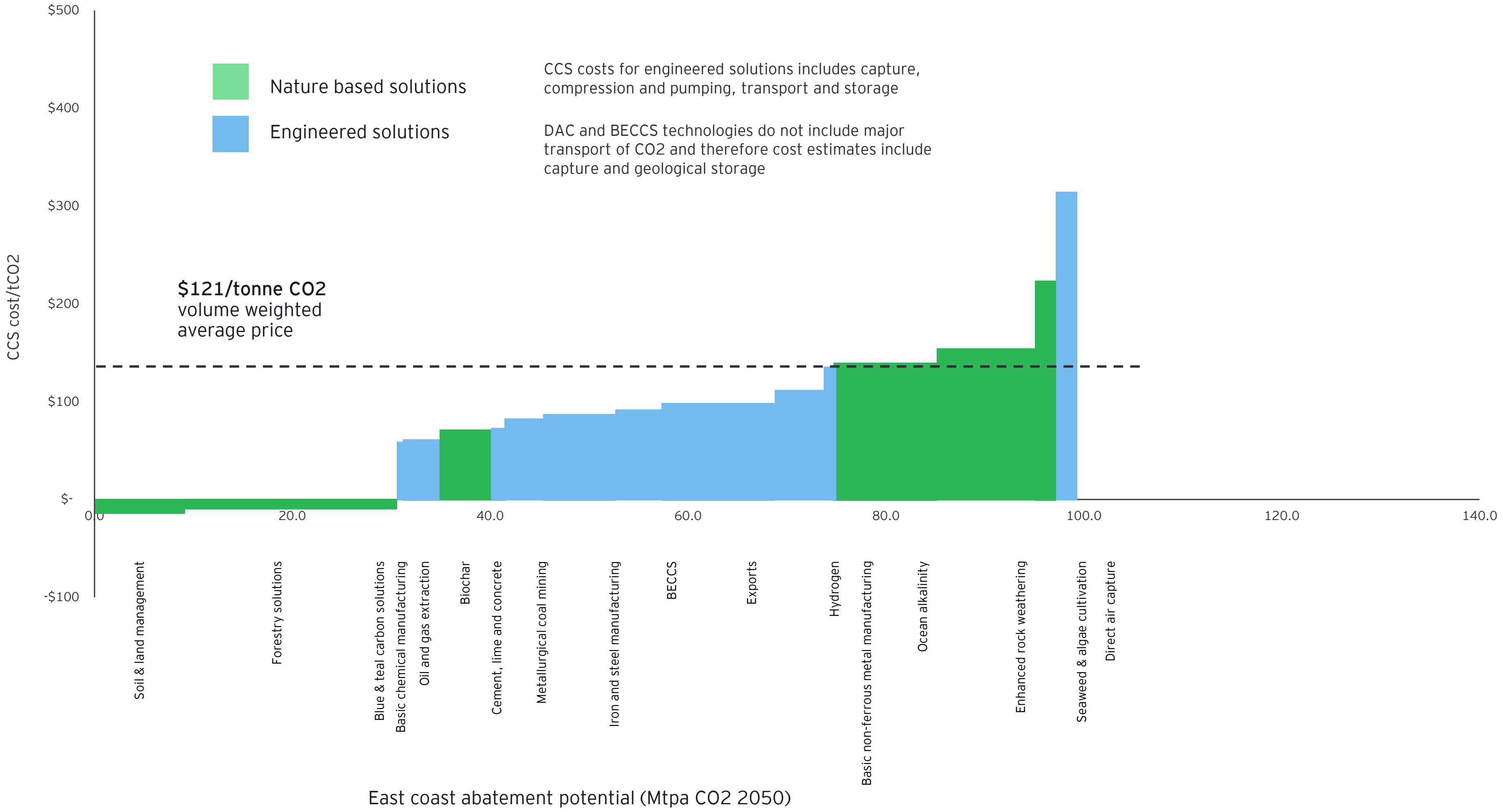
Industry/Technology	Cost (USD/tonne CO_2-e)	Source
Direct Air Capture	500-1000	McKinsey Sustainability, 2023, Carbon Removals: How to scale a new gigaton industry
	681-878	CSIRO, 2023, Sequestration Cost Reduction Workshops Report
	250-600	World Resources Institute, 2022, 6 Things to Know About Direct Air Capture
	100-412	Global CCS Institute, 2022, The Economics of Direct Air Carbon Capture and Storage,
	134-344	International Energy Agency, 2020, Current Cost of CO_2 capture for carbon removal technologies by sector
	100-300	International Panel on Climate Change, 2022, Carbon Dioxide Removal Factsheet
	200	International Energy Agency, 2022, New IEAGHG report: Global Assessment of DACCS Costs, Scale and Potential
BECCS	15-400	The Oxford Institute for Energy Studies, 2024, Carbon Dioxide Removal (CDR): A Key Pillar of Carbon Management and Sustainability
	80-319	Gutsch & Leker, 2024, Co-assessment of costs and environmental impacts for off-grid direct air carbon capture and storage systems
	60-270	McKinsey Sustainability, 2023, Carbon Removals: How to scale a new gigaton industry
	50-200	International Panel on Climate Change, 2022, Carbon Dioxide Removal Factsheet
	62-137	US Department of Energy, 2020, Bioenergy with Carbon Capture and Storage (BECCS)
	59-106	Tanzer et al, 2021, Decarbonising Industry via BECCS: Promising Sectors, Challenges, and Techno-economic Limits of Negative Emissions
	13-85	International Energy Agency, 2020, Current Cost of CO_2 capture for carbon removal technologies by sector
	45-60	CSIRO, 2023, Sequestration Cost Reduction Workshops Report
	50-53	Saharudin et al, 2023, Bioenergy with carbon capture and storage (BECSS): Life cycle environmental and economic assessment of electricity generated from palm oil wastes
Hydrogen	32-150	Udemu & Font-Palma, 2024, Potential cost savings of large-scale blue hydrogen production via sorption-enhanced steam reforming process
	65-136	Belfer Center, 2022, Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context

Industry/Technology	Cost (USD/tonne CO_2-e)	Source
	50-80	International Energy Agency, 2021, Is carbon capture too expensive?
	52-77	Katebah et al, 2022, Analysis of hydrogen production costs in Steam-Methane Reforming considering integration with electrolysis and CO_2 capture
	57-76	National Energy Technology Laboratory, 2022, Cost of Capturing CO_2 from Industrial Sources
Exports and natural gas processing	49-150	Belfer Center, 2022, Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context
	86-130	Hayat et al, 2024, Strategic Priorities and cost considerations for decarbonising electricity generation using CCS and nuclear energy
	50-115	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	48-111	Rubin et al, The cost of CO_2 capture and storage, 2015
	80-90	Schemlz et al, 2020, Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States
	40-90	International Panel on Climate Change, 2005, Carbon Dioxide Capture and Storage
	79-88	S&P Global, 2022, Natural gas plants with carbon capture could save industry billions – think tank
	62	Economic Research Institute for ASEAN and East Asia, A Model Case Study: CCUS Cost Estimation
Oil and gas extraction and processing	0-90	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	20-45	Belfer Center, 2022, Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context
	15-25	International Energy Agency, 2021, Is carbon capture too expensive?
	17	National Energy Technology Laboratory, 2022, Cost of Capturing CO_2 from Industrial Sources
Metallurgical coal mining and energy production	20-132	Belfer Center, 2022, Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context
	50-65	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	52-60	Schemlz et al, 2020, Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States
	30-60	Economic Research Institute for ASEAN and East Asia, A Model Case Study: CCUS Cost Estimation
	36-53	Rubin et al, The cost of CO_2 capture and storage, 2015
Iron and steel manufacturing	45-125	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	65-108	National Energy Technology Laboratory, 2022, Cost of Capturing CO2 from Industrial Sources
	40-100	International Energy Agency, 2021, Is carbon capture too expensive?
	48-71	Fan & Friedmann, 2021, Low-carbon production of iron and steel: Technology options, economic assessment, and policy
	30-60	Economic Research Institute for ASEAN and East Asia, A Model Case Study: CCUS Cost Estimation
	30-40	Ho, 2007, Techno-economic modelling of CO_2 capture systems for Australian industrial sources
Cement, lime and concrete	46-333	Hills et al, 2015, Carbon Capture in the Cement Industry: Technologies, Progress, and Retrofitting
	19-205	Belfer Center, 2022, Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context
	40-120	International Energy Agency, 2021, Is carbon capture too expensive?
	60-78	National Energy Technology Laboratory, 2022, Cost of Capturing CO_2 from Industrial Sources
	45-70	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	30-61	Hanifa et al, 2023, A review on CO2 capture and sequestration in the construction industry: Emerging approaches and commercialised technologies
	21-37	Greco-Coppi et al, 2024, Efficient CO_2 capture from lime plants: Techno-economic assessment of integrated concepts using indirectly heated carbonate looping technology
Basic non-ferrous metal manufacturing	180-300	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	115	Mathisen et al, Cost Optimised CO_2 Capture from Aluminium Production, 2014
Basic chemical manufacturing	22-32	Belfer Center, 2022, Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context
	0-10	Global CCS Institute, 2021, Technology Readiness and Costs of CCS
	19	National Energy Technology Laboratory, 2022, Cost of Capturing CO_2 from Industrial Sources

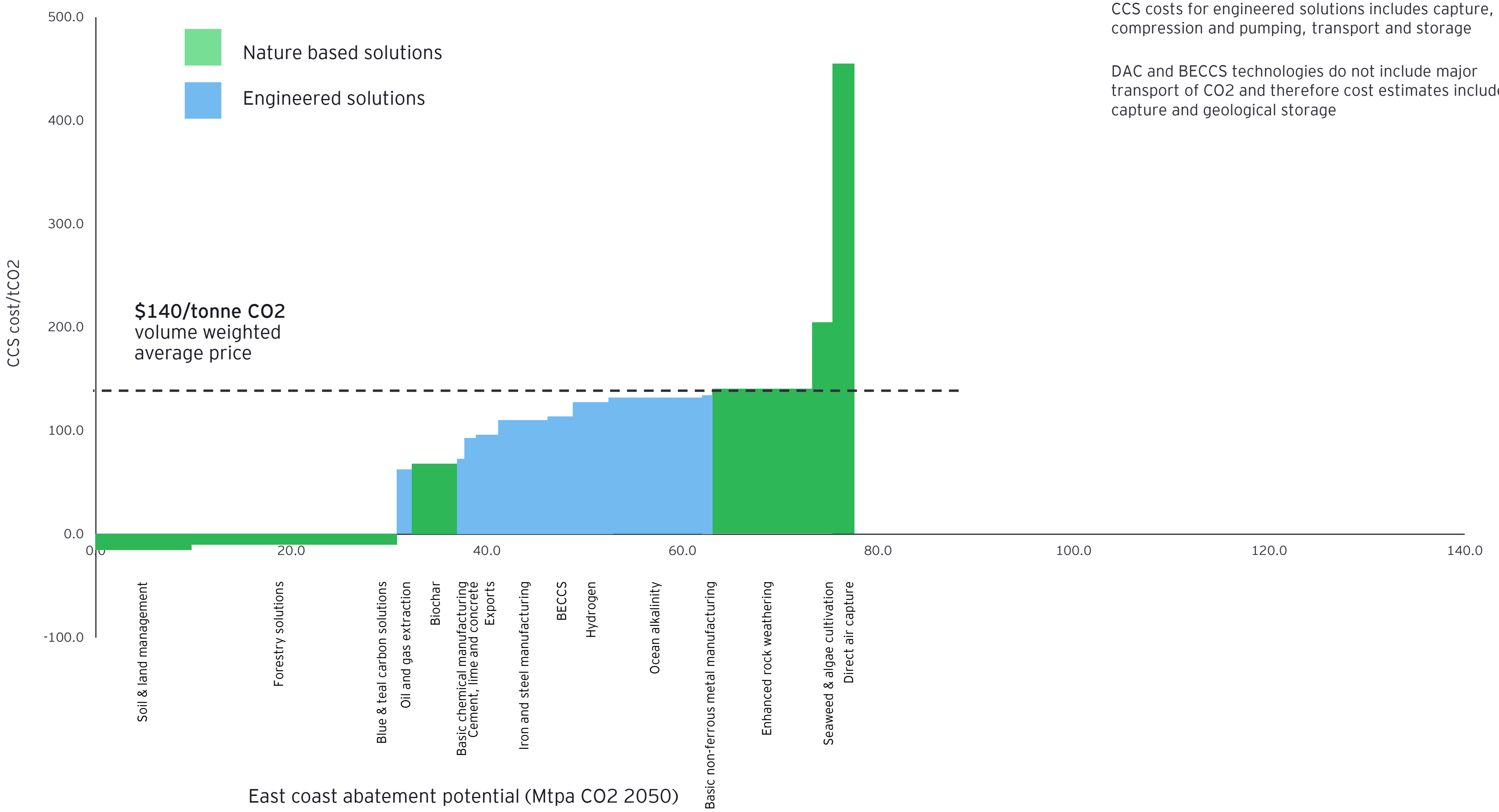
Appendix B Marginal abatement costs by scenario



Accelerated deployment marginal abatement cost curve



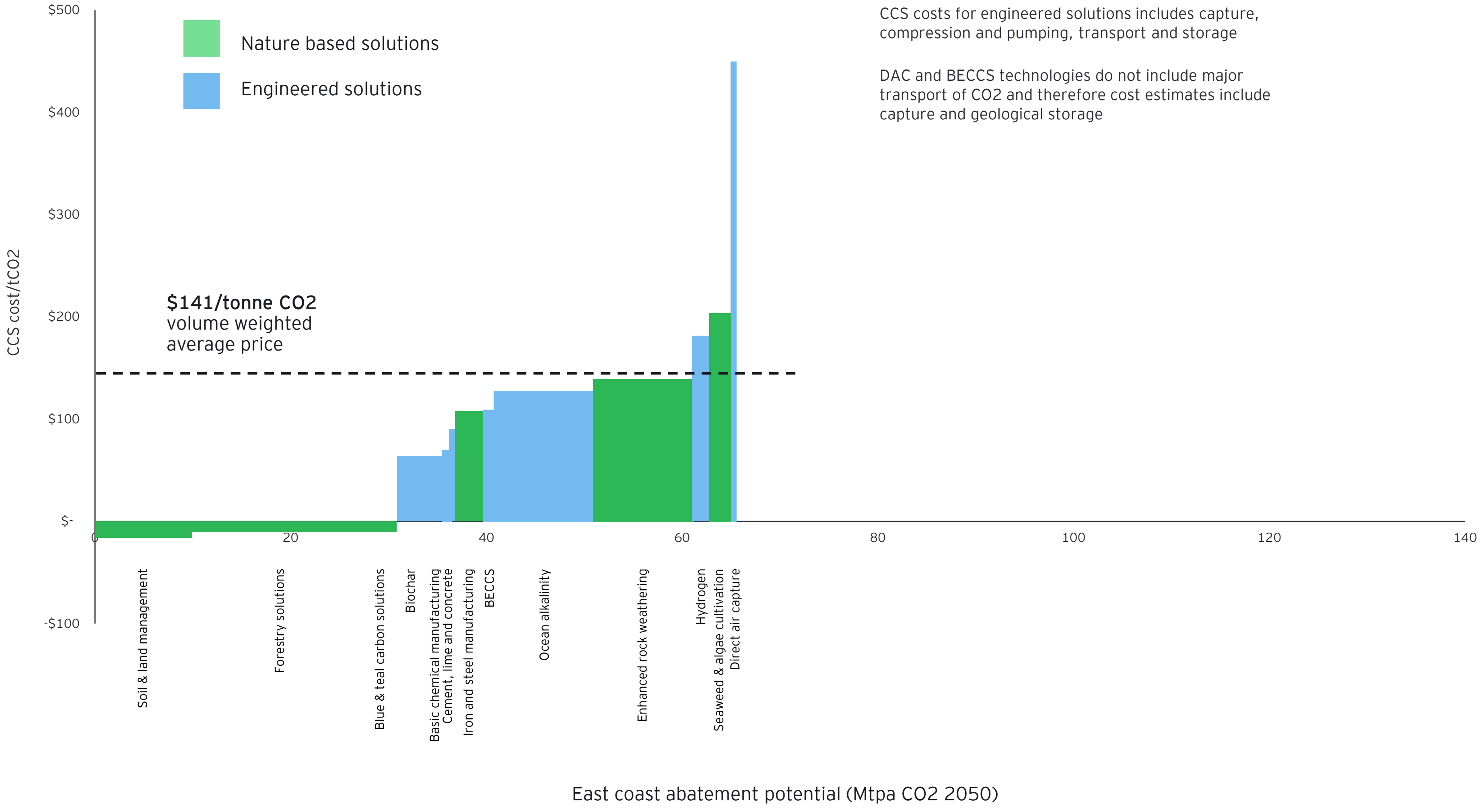
Moderate growth marginal abatement cost curve



CCS costs for engineered solutions includes capture, compression and pumping, transport and storage

DAC and BECCS technologies do not include major transport of CO2 and therefore cost estimates include capture and geological storage

Base case marginal abatement cost curve



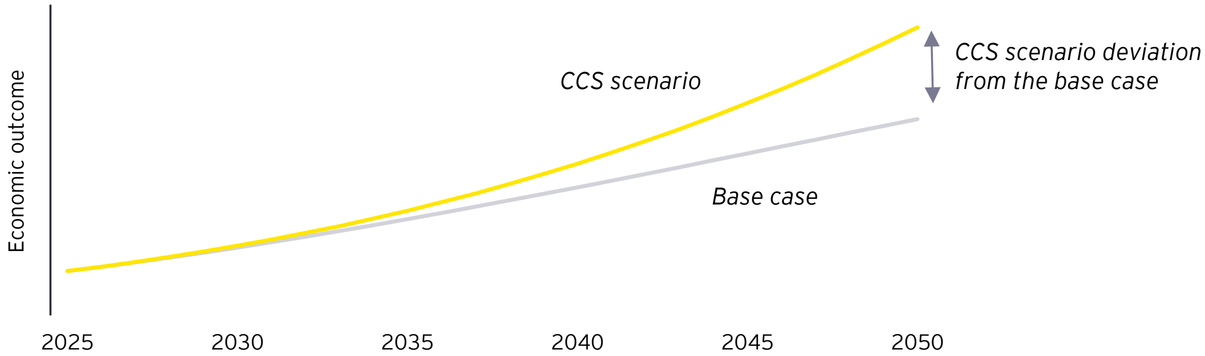
CCS costs for engineered solutions includes capture, compression and pumping, transport and storage

DAC and BECCS technologies do not include major transport of CO2 and therefore cost estimates include capture and geological storage

Appendix C The EYGEM model

Economic impacts, such as production and employment, are reported in relation to the base case described in Chapter 4. The additional economic value (depicted in the figure below) allows for comparison across like-for-like scenarios.

Figure 28: Illustrative representation of CGE modelling outcomes



The scenario deviations from the base case are attributed to faster and greater adoption of CCS, modelled through the three key economic drivers described above: capital investment, operating costs, and lower costs of abatement.

Economic outcomes are quantified against the following three macroeconomic indicators:

- **Gross Domestic Product** (GDP) measures the total value of goods and services produced in the economy, representing an aggregate of the value-add components of each sector's production. GDP is a key metric in tracking the overall progress of an economy, estimated as the sum of consumption, investment government expenditure and net exports in real terms.

- **Industry output** measures the value of goods and services produced by all economic sectors. Unlike GDP, this measure considers both the value-add and non-value-add components of production for each sector, providing an estimate of total intermediate and final production.

- **Employment** measures the full time equivalent (FTE) jobs supported in the economy, where each FTE is equal to one employee working full time for one year. Employment estimations vary each year depending on the start and end dates of employment contracts; some jobs span the entire period while others may only span one year. As such, employment outcomes are averaged across the modelling period to estimate the additional jobs supported by each scenario.

Modelling CCS scenarios in EYGEM

Three shocks form the three CCS scenarios. The sectoral specification of the CGE model does not inherently contain a CCS sector, yet CCS has a similar production function to the gas sector; therefore, greater CCS demand is modelled through increased gas production.

Table 12: CCS CGE scenario shocks

Shock	Shock
Capital expenditure	Construction output
Operating expenditure	Gas output
Industry uplift	Reduction in emissions (achieved through productivity of emissions)

More details on EY's CGE model

Computable General Equilibrium (CGE) models are a class of economic model developed originally out of Input Output (IO) models providing a causal, full system and theory driven framework for the assessment of a wide range of policy, project and economic condition assessments. As suggested in the name, CGE models provide an equilibrium representation of international and national economies in a chosen base year, including explicit treatment of (for example) primary factor markets, inter-industry purchases, and international trade flows. It is this initial equilibrium position which forms the starting point for a sequence of future projections of possible economic states, and it is by comparing these future pathways against each other that we can assess the impact of different policy choices on macroeconomic indicators such as GDP and employment.

As noted by Dixon in the Handbook of Computable General Equilibrium Modelling:

> *"CGE models are used in almost every part of the world to generate insights into the effects of policies and other shocks in the areas of trade, taxation, public expenditure, social security, demography, immigration, technology, labour markets, environment, resources, infrastructure and major-project expenditures, natural and man-made disasters, and financial crises. CGE modelling is the only practical way of quantifying these effects on industries, occupations, regions and socioeconomic groups."*

The primary data source for EYGEM model is the GTAP database, produced by Purdue University. The GTAP database is the most detailed, comprehensive and widely used database of its type in the world, used by over 700 researchers worldwide. The database contains information on inter-industry flows, trade, taxes and behavioural variables.

This section describes the key features and structural underpinnings of the EY version of a global CGE model, the EY General Equilibrium Model (EYGEM), including a description of the economic foundations of the EYGEM model, the national accounting framework and behavioural assumptions.

Overview of the EYGEM model

The EYGEM model is a member of the Global Trade Analysis Project (GTAP)/Global Trade and Environmental Model (GTEM) family of CGE models which have a long history in the public and private sectors to assess the economic impact of projects and policies. As with most modelling frameworks it is natural to think about the model in terms of the data and structural components.

As with all CGE models, EYGEM is based on an underlying input-output or social accounting matrix, which is a standard representation of the national accounting frameworks applied by central statistical agencies globally and forms the basis for calculating well known macroeconomic variables such as gross domestic product. This foundational data describes how economies are linked through production, consumption, trade and investment flows.

Overlaying this system of national accounts are a set of standard behavioural structures that simulate real world decision making and are validated by established academic literature, providing the basis for forecasting responses to policy changes. For policy analysis, this incorporation of behavioural structures provides an advantage over traditional econometric approaches, particularly where historical examples or analogues of the policy being evaluated is not well represented in historical data (for example climate change policy).

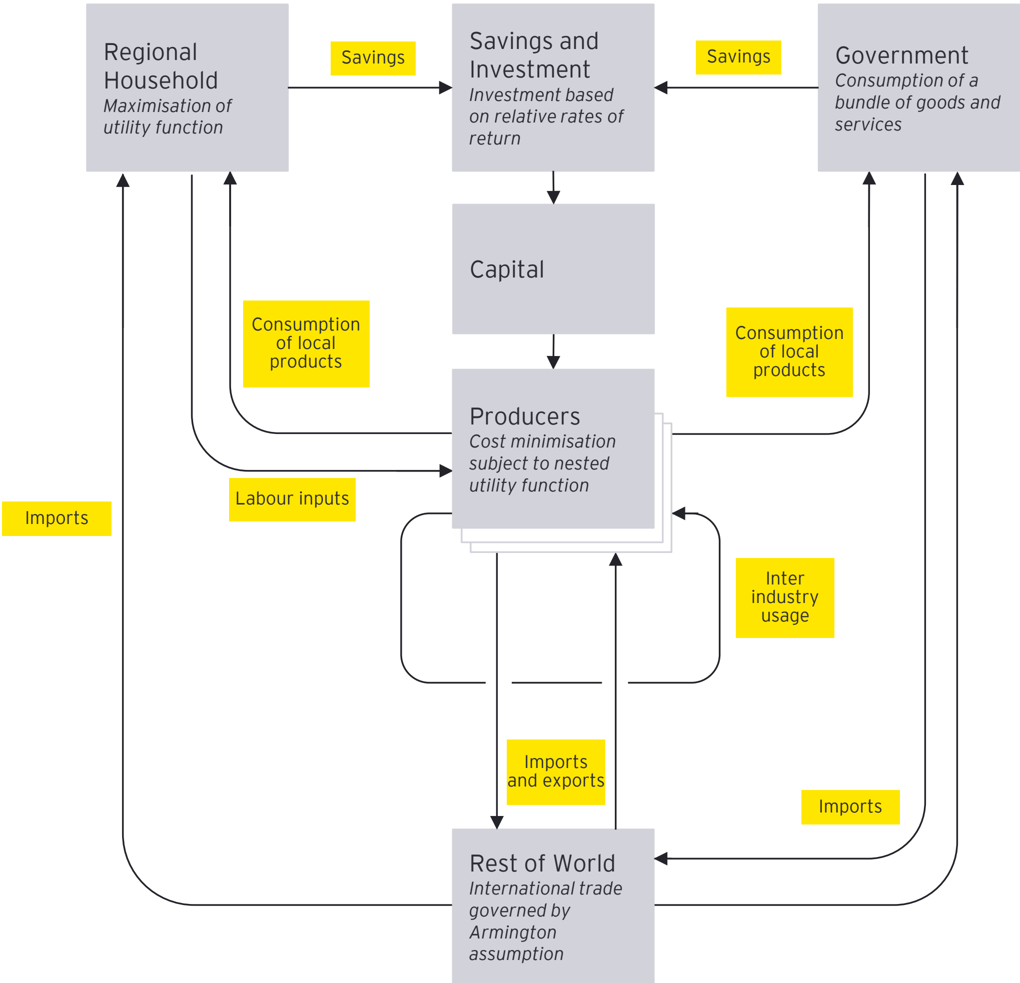
The below points highlight some of the key features of the EYGEM model:

- Direct linkages between industries and countries through purchases and sales of each other's goods and services.
- Inter-industry linkages through purchases and sales of each other's goods and services.

- International linkages through the imports and exports of goods and services.
- Capacity constraints in primary factor markets, representing the finite availability of capital, labour, land and the natural resource (This is not accounted for in IO models).
- Behavioural mechanisms such as the responses to price changes.

An overview of the representative agents and economic flows incorporated in the EYGEM model is shown in Figure 29.

Figure 29: Economic flows in EYGEM



The below summaries highlight the microeconomic theory which the model is founded upon.

Income

- The model contains a 'regional consumer' that receives all income from factor payments (labour, capital, land, and natural resources), taxes and net foreign income from borrowing (lending).
- Income is allocated across household consumption, government consumption and savings so as to maximise a Cobb-Douglas utility function. The Cobb-Douglas utility function represents the relationship between prices and income and provides the framework for maximising utility on the basis of the interplay between spending and saving.

Consumption

- Household consumption for composite goods is determined by minimising expenditure via a CDE (Constant Differences of Elasticities) expenditure function. The CDE expenditure function determines the effect that income has on demand for goods and services (and the substitution between goods and services therein). For most regions, households can source consumption goods only from domestic and imported sources. In all cases, the choice of commodities by source is determined by a CRESH (Constant Ratios of Elasticities Substitution, Homothetic) utility function.

- Government consumption for composite goods, and goods from different sources (domestic, imported and interstate), is determined by maximising utility via a Cobb-Douglas utility function.

Production

- Producers supply goods by combining aggregate intermediate inputs and primary factors in fixed proportions (the Leontief assumption). Composite intermediate inputs are also combined in fixed proportions, whereas individual primary factors are combined using a CES production function. The CES production function is a neoclassical production function that displays constant elasticity of substitution between inputs such as capita and labour.
- Producers are cost minimisers, and in doing so choose between domestic, imported and interstate intermediate inputs via a CRESH production function.
- The supply of labour is positively influenced by movements in the real wage rate governed by an elasticity of supply. A labour supply elasticity of 0.3 is uniformly adopted for this analysis.

Investment

- All savings generated in each region are used to purchase bonds whose price movements reflect movements in the price of creating capital.
- Investment takes place in a global market and allows for different regions to have different rates of return that reflect different risk profiles and policy impediments to investment. A global investor ranks countries as investment destinations based on two factors: global investment and rates of return in a given region compared with global rates of return.
- Once aggregate investment is determined in each region, the regional investor constructs capital goods by combining composite investment goods in fixed proportions and minimises costs by choosing between domestic and imported sources for these goods via a CRESH production function.

Prices

- Prices are determined via market-clearing conditions that require sectoral output (supply) to equal the amount sold (demand) to final users (households and government), intermediate users (firms and investors), foreigners (international exports), and other Australian regions (interstate exports).
- For internationally traded goods (imports and exports), the Armington assumption is applied whereby the same goods produced in different countries are treated as imperfect substitutes. But in relative terms imported goods from different regions are treated as closer substitutes than domestically produced goods and imported composites.

Climate change (accounting for greenhouse gas emissions)

- The model accounts for greenhouse gas emissions from fossil fuel combustion. Taxes can be applied to emissions, which are converted to good-specific sales taxes that impact on demand. Emission quotas can be set by region, and these can be traded at a value equal to the carbon tax avoided, where a region's emissions fall below or exceed their quota.
- The ease of emissions abatement is determined by marginal abatement cost (MAC) curves and fuel switching elasticities. The functional form of the MAC curves and the standard parameters are based on those in Weyant and Chesnaye (2006)[14] and apply only to non-combustion emissions.

[14] Weyant and Chesnaye, 2006, Overview of EMF-21: Multigas Mitigation and Climate Policy, The Energy Journal

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