ACIL ALLEN

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Report to Cooperative Research Australia

Mapping and quantification of CRCs' work on decarbonisation

Final report

About ACIL Allen

ACIL Allen is a leading independent economics, policy and strategy advisory firm, dedicated to helping clients solve complex issues.

Our purpose is to help clients make informed decisions about complex economic and public policy issues.

Our vision is to be Australia's most trusted economics, policy and strategy advisory firm. We are committed and passionate about providing rigorous independent advice that contributes to a better world.

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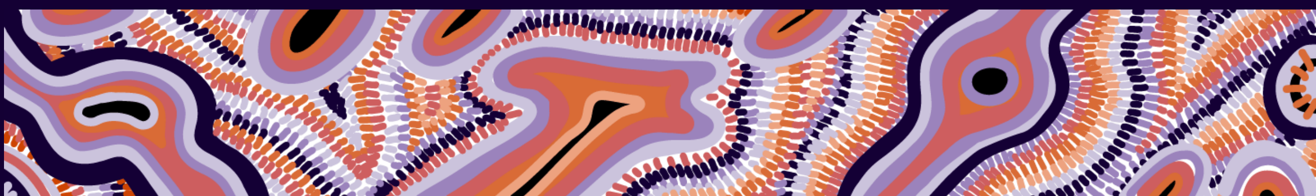
ACIL Allen acknowledges Aboriginal and Torres Strait Islander peoples as the Traditional Custodians of the land and its waters. We pay our respects to Elders, past and present, and to the youth, for the future. We extend this to all Aboriginal and Torres Strait Islander peoples reading this report.



Goomup, by Jarni McGuire

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Introduction

Australia is in a race to meet its emissions reduction target. The Australian Government submitted a new emission target in 2022 under the United Nations Framework Convention on Climate Change (UNFCCC). Australia's decarbonisation goals are outlined in the *Climate Change Act 2022*. The Act sets Australia's greenhouse gas (GHG) emissions reductions targets at a 43% reduction from 2005 levels by 2030 and net zero by 2050.[1] Meeting that target requires significant and rapid innovation across multiple industry sectors.

Australia's Cooperative Research Centres (CRCs) play an important role in developing innovative solutions for industry. They enable and promote domestic and international collaboration between industry, researchers, and government, and their international networks and industry-focused approach accelerate progress on some of society's most complex challenges. The CRC Program also provides long-term investment, with up to 10 years of funding available, enabling the CRCs to evolve their strategy and response to changing national and industry priorities over time.

CRCs – and many entities that began as CRCs – are helping propel Australia towards a sustainable, prosperous, and decarbonised future, where Australia realises its emissions goals. Decarbonisation is a highly complex global issue with a wide array of policy, market, and social considerations at play. CRCs' national and international collaborations and innovative solutions will be key to reducing GHG emissions and mitigating the impact of climate change, while enabling economic opportunities through their cooperative ventures.

This work focuses on the research and development (R&D) being conducted by 12 CRCs and one post CRC (collectively referred to as the 13 CRCs in this report)[2] in support of Australia's efforts to decarbonise its economy. It presents a snapshot of the benefit delivered by the CRC Program (focused on decarbonisation efforts and impacts) and explores the opportunities for Government to better leverage the CRCs and CRC model to realise Australia's emissions targets.

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1 Department of Climate Change, Energy, the Environment and Water (2022). *Australia submits new emissions target to UNFCCC.* Accessed August 2023: https://www.dcceew.gov.au/about/news/australia-submits-new-emissions-target-to-unfccc#:~:text=The%20updated%20NDC%3A,net%20zero%20emissions%20by%202050.

2 iMOVE CRC, Future Fuels CRC, MinEx CRC, Blue Economy CRC, Future Battery Industries (FBI) CRC, CRC for Transformations in Mining Economies (CRC TiME), RACE for 2030 CRC, SmartCrete CRC, Future Energy Exports (FEnEx) CRC, Digital Finance CRC, Heavy Industry Low-carbon Transition (HILT) CRC, One Basin CRC, and Mining3 (originated as a CRC but is now an entirely industry-funded organisation, referred to as a post CRC).

Key findings

The report's key findings are presented below.

Cooperative Research Centres' contribution to Australia's decarbonisation goals

Australia has a suite of decarbonisation-related policies and strategies aimed at supporting Australia's national decarbonisation goals. The work of the CRCs is strongly aligned with these goals, but there is strong potential to further enhance their work programs to better leverage their existing and potential contribution to realising net zero outcomes.

CRC's provide a well-established capability that can be harnessed to accelerated effect and greater impact. As government grows its investment in the decarbonisation transformation, the established capability in CRC's may be an efficient and cost effective way to mobilise capability and scale quickly.

The CRCs demonstrate a diverse range of focuses, aligned with their core objectives, with decarbonisation representing a significant or sole priority for some and a complementary aspect for others. All 13 CRCs see the potential to step up their contribution to the national effort.

The alignment between the CRCs decarbonisation priorities highlights the potential for collaborative efforts between CRCs and government to drive toward these goals and ensure the CRCs are addressing the areas of most need.

Distribution of resources toward decarbonisation priorities

CRCs address a range of priority areas, with approximately 49% or $1.12 billion of the CRC's collective resources are focused on decarbonisation-related activities.

CRCs are performing a positive and important role in raising awareness and capacity among the research, industry, and government sectors about the need to, and opportunities and challenges, relating to decarbonisation. They also connect industry with research expertise, providing a framework for accelerated change.

Decarbonisation outcomes and impacts

CRCs have contributed to Australia's decarbonisation goals by delivering new products and services, developing reports and other publications, contributing to education and capacity building, enhancing Australia's export opportunities, informing decision-making, and engaging with end users.

Seven of the CRCs assessed have quantified anticipated GHG emissions reductions totalling around 62.8 Mt by 2032, which can be directly attributed to their R&D efforts. The net benefits of avoided emissions are estimated to have a cumulative undiscounted benefit of $1.8 billion, with a net present value of $768 million (7% discount rate). When scaled across the 13 CRCs, the expected CO_2 abatement is valued at $3.3 billion or $1.3 billion in net present value terms (7% discount rate).

CRCs will continue to support decarbonisation efforts regardless of the stage that they are at in their life as their workplans are completed. The abatement outcomes above are merely the tip of the iceberg in terms of what may be realised as industry continues to adopt the work of the CRCs over time. The 2032 single year abatement figure of 11.6 Mt CO_2 (over 18% of the total 16 year assessment period total) indicates how rapidly the abatement is expected to increase in subsequent years. It is likely that these impacts will continue to increase over time as end users continue to take up CRC products, services, insights, and advice.

Economic impacts

Seven of the 13 CRCs included in the analysis are projected to provide significant benefits to the Australian economy. Estimates of the impact that might be attributed to the13 CRCs (by scaling the costs and benefits) are expected to include:

— **Generating substantial economic activity**, For grants awarded between 2017 and 2032, it will boost Australia's economic output (GDP) by $4.8 billion over the lifetime of the benefits. The present value of this impact is $1.9 billion.

— **Raising economic welfare across Australia**. It is projected that the CRC decarbonisation work (for grants awarded 2017-32) will increase the real income of Australians by a cumulative total of $1.7 billion in present value.

— **Generating significant employment opportunities**. For grants awarded between 2017 and 2032, the CRCs will increase total employment, creating around 3,705 research job years to 2032 or an average of 265 FTE jobs years per year across Australia.

— **Providing significant value for money**. For every dollar of investment and in-kind contributions to CRCs decarbonisation work from 2017-2032, generated $5.80 in additional economic output (GDP).

These estimated economic impacts understate the overall benefits of the CRCs as they do not account for the social and environmental impacts associated with research projects funded or future benefits not yet able to be quantified.

Measuring impact

CRCs' measurements of impact are guided by their objectives and workplans. CRCs are not currently resourced or required to collect explicit decarbonisation-related activity and performance data, nor to measure impact toward Australia's decarbonisation goals. This largely relates to the fact that each CRC has been established with industry-defined challenges, some of which relate specifically to decarbonisation, while others may have only recently evolved to include decarbonisation as a focus area.

There is an opportunity to better understand, consistently map, and harness the decarbonisation impacts delivered by the individual and collective CRCs, to understand the contributions made towards meeting Australia's decarbonisation goals.

There is an opportunity for CRCs to better map their pathways to impact and ensure processes are in place to support future impact measurement. This should also consider the impacts that the CRCs will achieve as a collective. While all CRCs have an impact tool, CRCs on the whole do not necessarily or explicitly collect information on decarbonisation-specific impacts.

Collaboration and synergies between the CRCs, and beyond

The CRCs collectively collaborate with a deep and broad network of research and industry partners, both in Australia and internationally. These partners are a feature of the CRC model and enhance and extend their impact. The network is large, complex, diverse, and continually evolving. It demonstrates the collective reach the CRCs have across a wide array of research and industry partners. Many of these partners are complementary, enhancing and extending the impact of the CRCs by contributing to the CRCs' research, providing access to facilities, expertise, and funding, supporting impact translation, and by adopting the innovative products and services developed by (and with) the CRCs.

There is an opportunity for the CRCs and Australian Government to better leverage existing partnerships in the CRC network for decarbonisation-related efforts. These partnerships provide the foundation to leverage expertise across the CRCs and CRCs' partners, share resources, be better informed, have broader credibility and policy influence, and enhance research adoption.

There are formal and informal partnerships between the CRCs focused on sharing information and delivering projects. However, collaborations tend to be based on existing relationships and projects, and there is no strategic or coordinated approach.

Most CRCs want to collaborate more. Greater clarity as to the limitations and opportunities surrounding such collaboration would facilitate further joint work. Furthermore, the acquired knowledge from collaborative efforts should be documented and transformed into best practices for future endeavours.

Leveraging the CRCs to achieve greater impact

Australia's decarbonisation strategic direction has paved the way for improved decarbonisation policies and programs. This provides a unique opportunity to enhance the work of the CRCs, which are well placed to deliver more rapid progress toward Australia's decarbonisation goals.

However, CRCs face barriers to supporting decarbonisation including the lack of system wide coordination, funding constraints and social license issues.

CRCs' perceive that their applications for other government funding sources may not be accepted and considered on merit or may otherwise be 'discounted' given they are already the recipient of government funding. In applying for other Government programs, CRC applications should ideally be considered on their merits, with transparent and equitable funding guidelines and application processes. Any additional funding sourced by the CRCs should pass additionality tests and not duplicate activities already funded by government.

A more coordinated and strategic approach would enable the Australian Government to better leverage the current CRCs network to accelerate progress toward decarbonisation and to potentially fund the CRCs to scale impactful research and existing capabilities. This could be guided by a decarbonisation-specific reference group or Cooperative Research Australia (CRA).

Future opportunities

Realising the full potential that the CRCs can offer in pursuing the nation's decarbonisation goals and net zero targets can be attained through a number of opportunities. Action by Government and the CRCs would support the CRCs to operate more effectively and deliver more impact toward Australia's decarbonisation goals as outlined below.

1. CRCs have the potential to further enhance their collaboration with government, industry, and other CRCs (e.g., through secondments) to support greater information transfer, leverage CRCs' expertise, and drive the expanded adoption of CRC outputs. Enhanced collaboration will create cross-sectoral and industry opportunities and ensure that the CRCs are addressing areas of most need.
2. There would be value in the Government exploring incentive structures to encourage increased collaboration on shared initiatives, to extract greater value from the CRC program. This could include recognising collaboration as a positive in reporting, providing funding that is accessible only where a project is undertaken by 2 or more CRCs, ensuring contracting models do not constrain activity, aligning milestones and reporting with project investment timelines, and supporting CRC responses to changes in the external environment. The CRCs require greater clarity on the CRC-CRC collaboration limitations (funding and contractual) to enable them to collectively expand strategic planning and develop more effective alliances.
3. CRCs are long-term entities and so would benefit from increased flexibility to refresh their priorities as Australia's decarbonisation sector matures, new demands and opportunities

emerge, and the needs of partners evolve. The CRCs should account for these changes by embedding:

a) funding flexibility, with a proportion of funds held in reserve for emerging opportunities and flexible funding agreements with partners so that funding is not 'locked in' at the start of the CRC
b) program flexibility, with changes allowed to program delivery and priorities
c) governance arrangements that support funding and program flexibility.

4. Providing CRCs with access to/eligibility for additional funding opportunities (to enable scaling, collaboration, and development of a critical mass of decarbonisation-related efforts) would better leverage the CRCs' capacity, expertise, and flexibility to drive change and enhance progress toward the national goals. The CRCs require greater clarity as to their eligibility for other Australian Government funding programs. This should seek to create transparency and ensure equity in the application processes, so that CRCs can support more capital-intensive activities such as a pilot or demonstration projects, where projects are not already funded under the CRC.
5. The CRCs contribute substantial value to the Australian economy and people. There is an opportunity to create a pathway for more strategic coordination and planning to identify opportunities and pursue new/expanded research topics or collaborative projects across the CRC network as they emerge. This could be guided through a decarbonisation-specific reference group or Cooperative Research Australia (CRA). This would allow the Government to better leverage the existing capability and capacity within CRCs, as well as their networks, to accelerate decarbonisation and support Australia to reach its net zero goals. A flexible approach would be required so that the CRCs can evolve over time to leverage emerging decarbonisation opportunities.
6. The work of the CRCs typically aligns with more than one Australian Government portfolio, which makes it challenging to communicate the capacity and capability of each CRC and their potential for leverage by the Australian Government. There is a role for coordinated activity led by the Department of Industry, Science and Resources, together with CRA and the CRCs, to ensure that the work of the CRCs is communicated more broadly across the Australian Government, and that CRCs' capacity is further leveraged to deliver more value. This should focus on growing the brand of individual CRCs and the collective CRC network in delivering decarbonisation outcomes for Australia.

Introduction 1

This chapter provides an overview of the context and the evaluation.

1.1 Background and context

The Australian Government submitted a new emission target in 2022 under the United Nations Framework Convention on Climate Change (UNFCCC). Australia's decarbonisation goals are outlined in the *Climate Change Act 2022*. The Act sets Australia's greenhouse gas (GHG) emissions reductions targets at a 43% reduction from 2005 levels by 2030 and net zero by 2050.[3]

Under current projections, Australia is expected to reduce its GHG emissions by 37% below 2005 levels by 2030.[4] Achieving the established targets will require targeted effort and innovative solutions.

Australia's Cooperative Research Centres (CRCs) play an important role in developing innovative solutions. They enable and promote domestic and international collaboration between industry, researchers, and government, and their international networks and industry-focused approach accelerate progress on some of society's most complex challenges. The CRC Program also provides long-term investment, with up to 10 years of funding available, enabling the CRCs to evolve their strategy and response to complex problems over time.

The CRCs are helping propel Australia towards a sustainable, prosperous, and decarbonised future, where Australia realises its emissions goals. Decarbonisation is a highly complex global issue with a wide array of policy, market, and social considerations at play. The CRCs' national and international collaborations and innovative solutions will be key to reducing GHG emissions and mitigating the impact of climate change, while enabling economic opportunities through their cooperative ventures.

This work focuses on the research and development (R&D) being conducted by 12 CRCs and one post CRC[5] (collectively referred to as the 13 CRCs in this report) in support of Australia's efforts to decarbonise its economy. It also explores the opportunities for Government to better leverage the CRCs and CRC model to realise Australia's emissions targets.

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[3] Department of Climate Change, Energy, the Environment and Water (2022). *Australia submits new emissions target to UNFCCC.* Accessed August 2023: https://www.dcceew.gov.au/about/news/australia-submits-new-emissions-target-to-unfccc#:~:text=The%20updated%20NDC%3A,net%20zero%20emissions%20by%202050.

[4] Department of Climate Change, Energy, the Environment and Water (2023). *Australia's emissions projections 2023*. Accessed August 2023: https://www.dcceew.gov.au/climate-change/publications/australias-emissions-projections-2023.

[5] Mining3 originated as a CRC but is now an entirely industry-funded organisation (referred to as a post CRC).

This report presents a snapshot of the benefit delivered by the CRC Program, which specifically focuses on decarbonisation efforts and impacts. Across the broader CRC Program, ACIL Allen's recent Impact Evaluation[6] shows that the long-term impact of the CRC Program is substantial, returning $5.61 for every dollar invested by the Australian Government, and leveraging $2.30 of private sector investment in R&D on every dollar invested by the Australian Government.

The 13 CRCs are listed in Table 1.1. In addition to a brief description of the aims of each CRC, its funding, and its partners, the table shows each CRC's stage in the funding life. The stage in each CRCs' life has direct implications for the extent to which measurable impacts achieved to date can be assessed, which is considered during the analysis.

Table 1.1 The 13 CRCs

CRC Name	Aims	Funding period	Australian Government funding ($)	Partners and partner funding*
iMOVE CRC	To advance the development and adoption of technologies that improve Australia's transport systems, through high impact R&D collaborations.	June 2017 – March 2027	$55 million	44 industry, government, and research partners. $178.8 million.
Future Fuels CRC	To enable Australia's energy sector to adapt its infrastructure to net zero emissions fuels by providing new knowledge and facilitating its use by industry.	July 2018 – June 2025	$26.25 million	50 government, university, and energy companies. $64 million.
MinEx CRC	To develop more productive, safe and environmentally friendly drilling methods to discover and drill-out mineral deposits.	July 2018 – June 2028	$50 million	42 partners from government, industry, and research. $168 million.
Blue Economy CRC	To undertake industry focussed research and training to support the growth of the Blue Economy with a focus on 2 new, emerging, and transitioning ocean industries for Australia: offshore aquaculture and renewable energy production.	July 2019 – June 2029	$70 million	44 partners from government, industry, and research. $230 million.
Future Battery Industries (FBI) CRC	To capture the significant economic opportunities for Australia from the growing battery industry and address the challenges associated with the energy transition.	July 2019 – June 2025	$25 million	70 participants from research, government, and industry. $110 million.
CRC for Transformations in Mining Economies (CRC TiME)	To bring together diverse stakeholders to reimagine and transform what happens after mining ends for the benefit of people, communities, industry and the environment.	July 2020 – June 2030	$29.5 million	75+ partners from across the minerals industry, governments, research institutions and regional and community organisations. $130 million.
RACE for 2030 CRC	To drive innovation for a secure, affordable, clean energy future	July 2020 – June 2030	$68.5 million	80 partners from industry, government, and research. $281.5 million.
SmartCrete CRC	To accelerate the transition to sustainable concrete through the delivery of breakthrough advancements in the cement and concrete ecosystem.	July 2020 – June 2027	$21 million	Over 50 partners from research, government, and industry. $86.5 million.

[6] ACIL Allen (2021). *Cooperative Research Centres Program Impact Evaluation*. Melbourne: ACIL Allen. https://acilallen.com.au/uploads/projects/658/ACILAllen_CRCImpactEvaluation_2022.pdf.

CRC Name	Aims	Funding period	Australian Government funding ($)	Partners and partner funding*
Future Energy Exports (FEnEx) CRC	To execute cutting-edge, industry-led research, education and training to help sustain Australia's position as a leading LNG exporter and enable it to become the leading global hydrogen exporter.	July 2020 – June 2030	$40 million	36 industry, government and university participants. $162 million.
Digital Finance CRC	To pioneer research and commercialisation for the emerging digital finance sector.	December 2021 – November 2031	$60 million	Fintech, industry, research, and regulation. $121 million.
Heavy Industry Low-carbon Transition (HILT) CRC	To develop technology and de-risk the decarbonisation pathways needed by heavy industry to achieve Net Zero by 2050.	November 2021 – October 2031	$39 million	50+ industry, research and government partners. $160 million.
One Basin CRC	To develop policy, technical and financial solutions to support and reduce exposure to climate, water and environmental threats in the Murray-Darling Basin.	July 2022 – June 2032	$50 million	96 industry, research, and government partners. $106.5 million
Mining3	To develop and deliver transformational technology to improve the productivity, sustainability, and safety of the mining industry.	Concluded as a CRC in 2014	N/A	11 members from mining, manufacturing, and research.

* Note funding amount included refers to the partner funding announced at the awarding of the CRC.

Source: ACIL Allen, various, https://business.gov.au/grants-and-programs/cooperative-research-centres-crc-grants/current-cooperative-research-centres-crcs

The 13 CRCs considered in this project are committed to and working towards helping Australia meet its net-zero emissions target. There is potential to better quantify this contribution and unlock new research and innovation to support Australia's decarbonisation.

1.2 This report

Cooperative Research Australia (CRA) has engaged ACIL Allen to analyse the current work of 13 key CRCs. This includes both the work undertaken by individual CRCs, and any collaborative work related to the Government's decarbonisation goals.

Australia has a suite of decarbonisation-related policies and strategies in place in pursuit of the goal of net zero by 2050. This project showcases the capacity of the CRCs to actively support and accelerate progress towards the realisation of these ambitious goals. The project also identified how these CRCs can work collaboratively to achieve these goals. The terms of reference for the project are provided in Appendix A.

1.2.1 Methodology

This project involved inception processes (including a meeting with CRA and the CRCs, and a project plan), data collection and mapping, targeted consultations, analysis and refinement, economic modelling (see Appendix A for more details), and reporting.

1.2.2 This report

This report presents the key findings and opportunities identified through the project. This includes exploring the CRCs' decarbonisation priorities, activities, outcomes and impacts (chapter 2); detailing the synergies and alignments between the CRCs and how this may lead to accelerated progress in the future (chapter 3); the potential economic opportunity available from enhanced collaboration; and the project conclusions (chapter 4). The appendices provide additional information on *Tasman Global*, ACIL Allen's computable general equilibrium (CGE) model.

Decarbonisation across the CRCs 2

This chapter discusses the decarbonisation activities across the CRCs, how these contribute to Australia's decarbonisation goals and impacts delivered to date.

2.1 The CRCs' contribution to Australia's decarbonisation goals

The *Climate Change Act 2022* sets an emissions reduction target of 43% from 2005 levels by 2030 and net zero emissions by 2050. To drive action to realise these targets, the Government has introduced a broad range of decarbonisation initiatives. Some such as the Net Zero Economy Agency's work program and the Safeguard Mechanism explicitly focus on the goal, while others deliver multiple, complementary goals (i.e. energy market reform, National Hydrogen Strategy).

In the year to June 2023, Australia emitted 465.2 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e), an increase of 0.8% (3.6 Mt CO_2-e) from the previous year.[7] Emissions are primarily generated by the electricity, stationary energy, transport, agriculture, industrial processes and waste industries. The CRCs span these industries, focusing on innovation of water and agricultural systems; developing renewable energy and resource export industries; empowering energy efficiency, transition, network transformation and security; improving transportation; guiding decarbonisation infrastructure planning; and advancing regulation and environmental management.

The CRCs are well positioned to support these industries and the Australian Government to leverage the opportunities that decarbonisation will offer, including sustainable economic growth, improved incomes, and employment opportunities.

The CRCs' focus on Australia's decarbonisation goals varies depending on their core objectives. Some refer to decarbonisation in their strategic priorities, while some embed decarbonisation in work programs. The CRCs' strategies and work programs have also evolved over time to meet Australia's growing decarbonisation needs and contributing partners' priorities. This demonstrates the flexibility of the CRC model, and the drive of contributing partners to these goals. There is a potential for the CRC's individual and collective capability to be leveraged to contribute even more toward these goals (discussed further in section 3.2).

To provide insight as to how the 13 CRCs contribute to Australian Government's net zero targets, the alignment of their work has been assessed against 6 major decarbonisation initiatives (see

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[7] Department of Climate Change, Energy, the Environment and Water (2023). *National Greenhouse Gas Inventory Quarterly Update: June 2023*. Accessed February 2024: https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-update-june-2023.

Table 2.1): Net Zero Economy Agency work program,[8] Safeguard Mechanism[9] National Energy Transformation Partnership,[10] Energy market transformation,[11] Powering the Regions Fund,[12] National Reconstruction Fund (NRF),[13] and Critical Minerals Strategy 2023-2030.[14] The CRCs also contribute to other relevant national, state and regional strategies (which align, and sometimes aspire to higher levels of decarbonisation than the national decarbonisation agenda).

Table 2.1 identifies where the CRCs are, or are intending to, contribute to Australia's national decarbonisation goals, and identifies potential gaps or areas of opportunity that may be explored by the 13 CRCs or future potential CRCs, either individually or in partnership. This shows that all 13 CRCs strongly align with at least one decarbonisation priority and 11 align with at least one decarbonisation priority. At the international level, the CRCs are involved in major partnerships focused on investments and R&D opportunities to decarbonise the Australian industry.

In line with the outcomes of a recent International Energy Agency (IEA) review,[15] most CRCs believe that current efforts will need to increase if Australia is to meet its decarbonisation goals. The IEA review highlighted that while recent policies support decarbonisation, significant changes are needed to reach net zero by 2050, including a national net zero emissions reduction plan, a 60% increase in transport and residential building energy efficiency, a large increase in power sector decarbonisation, and increased supply of critical minerals. The CRCs' existing capability and expertise in these fields can be further leveraged to support these priorities.

> *"Australia can make sufficient progress on emissions reductions by 2030 to align with the goal of net zero by 2050. However, stronger efforts are needed to improve energy efficiency and boost clean energy investment. A whole-of-government approach is needed to end the country's high reliance on fossil fuels. The IEA review calls for an updated net zero emissions reduction plan for 2050 to guide implementation across all parts of government. A national energy and climate information system is also needed to track progress towards reaching these targets."*
>
> *International Energy Agency*

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[8] Department of Prime Minister and Cabinet (n.d.). *Net Zero Authority.* Accessed October 2023: https://www.pmc.gov.au/netzero/net-zero-authority.

[9] Department of Climate Change, Energy, the Environment and Water (n.d.) *Safeguard Mechanism*. Accessed October 2023: https://www.dcceew.gov.au/climate-change/emissions-reporting/national-greenhouse-energy-reporting-scheme/safeguard-mechanism.

[10] Department of Climate Change, Energy, the Environment and Water (2022). *National Energy Transformation Partnership.* Accessed October 2023: https://www.energy.gov.au/government-priorities/australias-energy-strategies-and-frameworks/national-energy-transformation-partnership#:~:text=The%20National%20Energy%20Transformation%20Partnership,achieve%20net%20zero%20by%202050.

[11] AEMO (2022). *2022 Integrated System Plan (ISP).* Accessed October 2023: https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp.

[12] Department of Climate Change, Energy, the Environment and Water (2023). *Powering the Regions Fund.* Accessed October 2023: https://consult.dcceew.gov.au/powering-the-regions-fund.

[13] Department of Industry, Science and Resources (2022). *National Reconstruction Fund: diversifying and transforming Australia's industry and economy.* Accessed October 2023: https://www.industry.gov.au/news/national-reconstruction-fund-diversifying-and-transforming-australias-industry-and-economy.

[14] Department of Industry, Science and Resources (2023). *Critical Minerals Strategy.* Accessed October 2023: https://www.industry.gov.au/publications/critical-minerals-strategy-2023-2030#:~:text=The%20Critical%20Minerals%20Strategy%202023,expertise%20at%20extracting%20minerals.

[15] International Energy Agency (2023). *Australia has raised its climate targets and now needs to accelerate its clean energy transition, says new IEA review*. Accessed October 2023: https://www.iea.org/news/Australia-has-raised-its-climate-targets-and-now-needs-to-accelerate-its-clean-energy-transition-says-new-iea-review.

Table 2.1 Priority alignment of CRCs and initiatives

CRC	Priority areas	Net Zero Economy Agency	Safeguard mechanism	Energy market transformation	Powering Regions Fund	National Reconstruction Fund	Critical Minerals Strategy
iMOVE CRC	iMove CRC is focused on **personal mobility** for individual travellers and how they get around both physically and informatically, supply chains, networks and data intensity, and **transport sustainability**.	◑	◑	◑	◔	●	◔
Future Fuels CRC	Future Fuels CRC aims to **decarbonise Australia's energy networks**, focusing on future fuel technologies, systems and markets, social acceptance, public safety and security of supply, and network life management. This includes work on the future of the Australian energy economy, delivering the full potential of low-carbon fuels in the energy supply mix, and finding safe and reliable solutions to transport future fuels. Other areas of focus include informing **coordinating national policy concerned with low carbon fuels**, as well as protecting the reliability and life of energy infrastructure.	◑	◑	◔	◔	◑	◑
MinEx CRC	MinEx focuses **on improving the productivity, safety of conventional drilling** while reducing the cost and environmental impact. This includes improving the capability of coiled tube drilling, which will lead to lower energy consumption.	○	○	○	◔	●	◕
Blue Economy CRC	**Decarbonising aquaculture** – developing offshore aquaculture that provide viable and sustainable growth opportunities. **Offshore engineering and technology** – developing infrastructure to support offshore systems (e.g. renewable energy and aquaculture operations). **Offshore renewable energy** – building Australia's offshore renewable energy technologies to assist the decarbonisation of offshore industries. Blue Economy is also developing regulatory frameworks to ensure offshore developments operate sustainably and promote ecosystem integrity. **Environments and ecosystems** – managing the environmental footprint of offshore industries.	●	○	●	○	◔	○
FBI CRC	FBI CRC aims to leverage Australia's minerals and mining advantages into battery materials innovation and production, to accelerate the **uptake of battery technologies** in Australia, to advance our research and capability in battery materials and precursor manufacturing, and to facilitate battery industry development.	◑	○	◑	◔	●	◕
CRC TiME	CRC TiME is largely focused on **mine closure** and the subsequent transition to post-mining economies, including regional economic development and diversification, post-mining land use (including for renewable energy) and land rehabilitation and biodiversity conservation.	◑	◑	◔	●	◑	◕
RACE for 2030 CRC	RACE for 2030 CRC is focused on **reducing emissions and costs** from communities of consumers **enabled by smart distribution networks**. This includes **whole of system optimisation** with an emphasis on energy use in homes, businesses and precincts through placed based solutions focused on the role of the end-user. Other synergistic areas include **electrification** of transport and its role in balancing supply and demand of renewable energy including rooftop PV.	◑	○	◕	◔	●	○

CRC	Priority areas	Net Zero Economy Agency	Safeguard mechanism	Energy market transformation	Powering Regions Fund	National Reconstruction Fund	Critical Minerals Strategy
Smart Crete CRC	SmartCrete CRC creates pathways to design, develop and commercialise innovative materials, technologies and processes that **contribute to Australia's transition to net-zero concrete**. This is achieved through research in the areas of **sustainable concrete**, engineered solutions and asset management.	no	moderate	no	weak	very strong	weak
FEnEx CRC	Focuses on **ensuring Australia's position as a leading energy exporter**, including maintaining the LNG industry's competitive position and **developing the hydrogen export industry** by increasing efficiency, lowering costs and reducing emissions. Other areas of focus include unlocking resource value in the production and export of energy through interoperable **digital technologies**.	very strong	strong	weak	strong	very strong	no
Digital Finance CRC	Focuses on dynamic registers for instant exchange, advanced securitisation, distributed trading and commoditisation of marketplaces, and RegTech with algorithmic real-time enforcement. This research has the potential to **revolutionise carbon trading**.	weak	weak	weak	weak	very strong	weak
HILT CRC	Focuses on de-risking **decarbonisation for heavy industry** through research in process technologies, cross-cutting technologies and facilitating transformation. With a foundation in circular economy principles, programs focus on the technology pathways needed to transition the iron/steel, alumina and cement/lime sectors to low-carbon products while remaining internationally competitive.	very strong	very strong	moderate	moderate	weak	weak
One Basin CRC	**Reducing emissions within the water supply system and irrigation system**, with the potential to innovate in the infrastructure and technologies used on farm. **Carbon sequestration** is a potential revenue source in regional areas on the technology side and economic mix in a region. Focused on the **role of renewable energy economically** in the regions (as water availability declines and impacts on the regional economy) rather than technology.	moderate	no	weak	moderate	very strong	no
Mining3	Mining3 is driving **decarbonisation in the mining industry** through delivery of transformational technology, such as engaging the Hydra Consortium to validate a business case for **hydrogen** fuel cell-based powertrain for heavy-duty mobility within the sector, which could displace diesel and decarbonise the sector.	moderate	moderate	no	weak	very strong	moderate

(grey circle) = no alignment of priorities, (quarter circle) = weak alignment of priorities, (half circle) = moderate alignment of priorities, (three-quarter circle) = strong alignment of priorities, (full circle) = very strong alignment of priorities

Source: ACIL Allen, various

Key Finding 1 The CRCs already significantly contribute to Australia's decarbonisation goals

> Australia has a suite of decarbonisation-related policies and strategies aimed at supporting Australia's national decarbonisation goals. The work of the CRCs is strongly aligned with these goals, but there is strong potential to further enhance their work programs to better leverage their existing and potential contribution to realising net zero outcomes.
>
> CRC's provide a well-established capability that can be harnessed to accelerated effect and greater impact. As government grows its investment in the decarbonisation transformation, the established capability in CRC's may be an efficient and cost effective way to mobilise capability and scale quickly.
>
> In line with the outcomes of a recent IEA review, most CRCs believe that that the current investment in research and innovation, economic transformation, skills development, and policy initiatives will need to be increased if Australia is to meet its current decarbonisation goals.
>
> The CRCs demonstrate a diverse range of focuses, aligned with their core objectives, with decarbonisation representing a significant or sole priority for some and a complementary aspect for others. All 13 CRCs see the potential to step up their contribution to the national effort.
>
> The alignment between the CRCs decarbonisation priorities highlights the potential for collaborative efforts between CRCs and government to drive toward these goals and ensure the CRCs are addressing the areas of most need.

2.2 Distribution of resources toward decarbonisation priorities

Some of the CRCs focus solely on decarbonisation with 100% of their funding allocated to this purpose; for others, decarbonisation is one of several priority areas, with only a portion of funding directed towards decarbonisation-related activities. The activities of a CRC may also contribute to addressing decarbonisation opportunities, issues or needs where this is not an explicit goal. For example, this could include diversification of regional economies where decarbonisation is leading to the closure of coal-fired power generation.

Funding of CRC priorities varies over time in line with the changing needs of each sector, emerging opportunities, and the expectations of contributing partners. CRCs have increasingly focused on decarbonisation in recent years, including reallocating funding and resources. This has been in response to their partner's growing decarbonisation and sustainability-related priorities.

The 13 CRCs have collectively spent/plan to spend a total of $2.28 billion toward their priorities. The CRCs have successfully leveraged the total Government grant funding ($534 million) with partner cash and in-kind contributions at an average factor of 3.26. A total of 49% of this funding, $1.12 billion, is allocated to decarbonisation-related activities.[16] The proportion of funding allocated to decarbonisation-related activities varies from 5% to 100% across the CRCs (at the time of writing Digital Finance CRC was still considering its project mix and was unable to apportion its funding).

The outcomes and impacts of each CRC in the decarbonisation space are directly proportional to both the funding allocated to decarbonisation priorities and each CRC's particular life stage (see Table 1.1). Section 2.3 focuses on the outcomes and impacts of the CRCs related to decarbonisation.

[16] Given Digital Finance CRC is still in the early stages of planning and implementing its work program, coupled with the cross-cutting nature of its work, it is not possible to determine the level of disaggregated decarbonisation-related funding and it has not been included in this range.

Key Finding 2 Distribution of resources toward decarbonisation priorities

> CRCs address a range of priority areas, with approximately 49% or $1.12 billion of the CRC's collective resources focused on decarbonisation-related activities.
>
> CRCs are performing a positive and important role in raising awareness and capacity among the research, industry, and government sectors about the need to, and opportunities and challenges, relating to decarbonisation. They also connect industry with research expertise, providing a framework for accelerated change.

2.3 Decarbonisation outcomes and impacts

The activities undertaken by the CRCs have resulted, and will result, in a range of tangible and intangible outcomes and impacts related to Australia's decarbonisation goals. Beyond actions that directly contribute to reduced emissions, these include new products and services, education and training, enhanced export opportunities, informed decision-making, research papers and reports, and engagement with and evidence of adoption by end users.

While most CRCs consider that their progress is on track or ahead of planned goals, many are still in the early stages of their life (see Table 1.1). Accordingly, for many of the CRCs there are only limited outputs, outcomes and impacts visible to date, noting that all CRCs are funded based on their projected impacts. ACIL Allen's impact modelling demonstrates the long-term proven ability for CRCs to deliver impact, with an estimated increase in Australia's GDP of $32.5 billion as a result of the $5.1 billion Australian Government investment in the 29-year CRC Program.[17] ACIL Allen expects that more evidence of impacts will emerge as the CRCs mature.

2.3.1 The assessment period

Decarbonisation outcomes and impact delivered by the 13 CRCs have been assessed over a finite period corresponding to the period over which Commonwealth grant funding underpins the work of these particular CRCs. The earliest CRC, iMOVE CRC, was funded in 2016-17, while the final year of funding for a CRC, One Basin CRC, is 2031-32 (for ease of reference, throughout the report, financial years are referred to according to their end date, that is 2031-32 is referred to as 2032).

This approach aligns with ACIL Allens 2021 CRC Program impact assessment,[18] which is important given the focus on being able to clearly relate outcomes/impact to the periods in which government support underpins R&D activity.

Given the inevitable time lag in translating research outcomes to full-scale deployment and widespread industry uptake, this truncated assessment period only captures early stage impacts. Indeed, a significant portion of the R&D is still at an early stage where it is impossible to point with any certainty to impact and as such the outcomes are very much understated. While the prospectus and related analysis by the CRCs point to significantly greater impact (with a good probability of success), only those impacts where results are now tangible have been included in the analysis. However, the impact of the decarbonisation work of the CRCs will continue to be realised well after 2032. Indeed, the education and training benefits instilled in graduate and postgraduate students will be realised for their work lives, out to the 2060s.

An overview of these outcomes and impacts realised is provided in Figure 2.1 and described below. The modelled economic impacts are detailed in chapter 4.

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[17] ACIL Allen (2021). Op. cit.

[18] Ibid.

Figure 2.1 Overview of decarbonisation outputs and outcomes

Source: Derived from CRC Annual reports, 2021-22

2.3.2 Delivering new products and services

New products and services provide new solutions and value to CRCs and the economy by providing a source of revenue, employment, and an opportunity to develop spin-off companies. Six CRCs have developed new products or services through their research including:

— In 2020, Mining3 launched an online sensor technology capability toolkit to provide free, unbiased information on Proximity Detection System sensors to assist users with decision making processes. This technology can reduce fuel consumption and emissions by enabling operators to optimise their driving behaviour. Mining3 is also developing a new hydrogen fuel cell-battery hybrid system for large mining haul trucks (see Box 2.1).

— MinEx CRC has developed Coiled-Tubing drill rig technology which has been successfully used in field testing. Data from the program has been made available to the public and has triggered significant uptake in the number of tenements by exploration and mining companies (see Box 2.2).[19]

— FBI CRC's Nickel and Cobalt Extraction project has allowed for recovery of metals to battery grade specifications with low impurity levels. This allows for more efficient production of nickel and cobalt, which are both essential minerals needed to make lithium batteries for electric vehicles.[20]

— FEnEx CRC has released 2 tools that enable the prediction of boil-off rates for the storage of liquefied natural gas and liquid hydrogen. These tools will support natural gas and hydrogen storage and export, which is an energy intensive process as gases need to be cooled to cryogenic temperatures to be condensed into liquid form.[21] In addition to these tools, FEnEx CRC has released a Hydrogen Pathways App. This is a hydrogen supply chain tool that is designed to help estimate costs and emissions across the supply chain. The App is underpinned by a training program.[22]

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[19] MinEx CRC (2021). *MinEx CRC Annual Report.*

[20] Future Battery Industries CRC (n.d.). *Nickel/Cobalt extraction*. Accessed October 2023: https://fbicrc.com.au/project/nickel-cobalt-extraction/.

[21] Future Energy Exports CRC (2021). *BoilFAST – new free software tool to model boil-off production*. Accessed October 2023: https://www.fenex.org.au/boilfast-new-free-software-tool-to-model-boil-off-production/.

[22] FEnEx CRC (n.d.). *Hydrogen Pathways App.* Accessed December 2023: https://www.fenex.org.au/hydrogen-pathways-app/

— RACE for 2030 CRC is developing tools to match large energy users' purchase of renewables with their demand. The project, 24/7 TRUZERO (Tracking Renewables Utilisation for Zero Emission Reporting and Operation), will help businesses better track, understand, and enhance the outcomes of their renewables purchasing approaches and on-site energy management activities. This aims to shift 10% of the demand of participating businesses to times of surplus renewable energy and offset 14,500 MWh carbon-based energy with renewables per annum (thus abating 11,000 t CO_2-e emissions per year).[23]

— Digital Finance CRC has piloted the use of carbon credits that can be tokenised and traded to facilitate investment in nature-based assets (see Box 2.3).

Box 2.1 Mining3 – Hydra project

The mining industry is an energy-intensive industry and one of the largest CO_2 emitters. One of the largest sources of emissions from mining operations is from diesel use in haulage trucks. Mining3's Hydra project commenced in 2021 with the aim of replacing the internal combustion engine of large mining haul trucks (>200 tonnes) with a hybrid system of hydrogen fuel cells and batteries. This will enable the replacement of diesel, which would support the decarbonisation of the mining industry.

This project was originally funded by the Chilean Economic Development Agency (CORFO), which awarded the project $460,000 in partnership with CSIRO. The project involves a range of partners, all providing unique expertise, including AMSA, BHP, Thiess, Engie, Mitsui, Ballard, Hexagon Purus, Reborn Electric, and Liebherr.

The benefits from the Hydra project include:

— the potential to displace 100% of the CO_2 emissions from diesel in hauling operations

— hydrogen trucks being deployed on a similar scale to diesel trucks, but without emissions

— there is more autonomy with hydrogen in comparison with other green alternatives.

A study to evaluate the business case for hydrogen mining truck was successfully completed in 2018-19 and pre-feasibility studies and engineering for the hydrogen mining truck were completed in 2021-22.

In 2024, Mining3 expects to be demonstrating the hydrogen mining truck solution at scale, which would involve replacing the diesel engine of a mining truck with a fully electric, hydrogen fuel cell and battery powertrain. The renewable hydrogen used will be produced by a renewable energy plant using electrolysis. This project is expected to scale up over 2026-30, and to involve the complete conversion of a mining site from diesel to hydrogen powered trucks.

Source: ACIL Allen, Mining3 (n.d.*). Hydra.* https://www.mining3.com/research/hydra/

Box 2.2 MinEx CRC – National Drilling Initiative

MinEx's National Drilling Initiative (NDI) oversees and executes drilling initiatives in case study regions identified by partner geological survey organisations in the MinEx CRC consortium. The NDI aims to drill multiple boreholes in a specific area to comprehensively chart the regional geological composition and structure while establishing a 3D representation of potential mineral systems.

This requires the use of a diverse array of drilling techniques, notably, the newly developed and cost-effective Coiled Tubing (CT) drilling technology and its associated sensory capabilities. This aims to maximise the number of boreholes that can be created, and the amount of data that can be gathered. Field testing with Anglo American resulted in the completion of a 12 hole 5,000 meter drilling program and provided high-quality cutting samples.

Overall, this research aims to identify future mineral deposits that are needed to support decarbonisation. It is an early-stage enabler for other organisations seeking to support decarbonisation. This platform can also revolutionise mineral exploration drilling by providing a cheaper, faster, safer, and cleaner alternative for drilling through deep cover rocks.

Source: ACIL Allen, MinEx CRC (n.d.), MinEx CRC 2022 year in review. MinEx CRC (2023). MEDIA RELEASE: MinEx CRC Clean and Green Drilling Tech a Step Closer Following Trial in Collaboration with Anglo American. Accessed October 2023: https://minexcrc.com.au/news/press-release-minex-crc-clean-and-green-drilling-tech-a-step-closer-following-trial-in-collaboration-with-anglo-american/.

[23] RACE for 2030 CRC (2024). *24/7 TRUZERO (Tracking Renewables Utilisation for Zero Emission Reporting and Operation).* Accessed February 2024: https://racefor2030.com.au/project/24-7-renewables-solutions-for-matching-tracking-and-enhancing-corporate-renewables-purchasing/#anchor1.

Box 2.3 Digital Finance CRC – Carbon credits as an enabler for decarbonisation

In August 2023, DFCRC's report on Central Bank Digital Currency (CBDC) was the first in Australia to study an applied use of CBDC with the Reserve Bank of Australia (RBA) and explore its implications.

The concept of a CBDC has been implemented in numerous forms overseas (Cambodia, Bahamas, Nigeria, and India), yet not in Australia. The pilot involved the RBA issuing digital currency valued at over $500,000, which was redeemed at the end of the pilot.

A component of the pilot focused on supporting innovation in other asset markets, including the ability to assign tokens to and trade, NSW biodiversity credits (with Commonwealth Bank), and carbon credits (with ANZ Bank).

The work with ANZ identified the need to evolve "market infrastructure to facilitate efficient trading and investment" in nature-based assets. DFCRC's solution uses the tokenisation of Australian Carbon Credit Units (ACCUs), which allows for instantaneous and simultaneous trading, thus reducing trading, especially in large amounts.

"This is the first time in the world you will have an asset that is backed and secured by the Reserve Bank digital currency, which will settle carbon [trades] in no time. Today, carbon markets are not known for their efficiency – our attempt is to bring this efficiency to the carbon market by providing atomic settlement, which will reduce any kind of counterparty risk for the players."

Anurag Soin, Digital Asset Services, ANZ

The pilot successfully demonstrated the ability to tokenise and transact ACCUs, and allowed the RBA, financial institutions, and holders to understand the strengths and challenges of integrating a digital currency. The pilot paves the way for further testing and potential public release and impact on decarbonisation.

Source: ACIL Allen, DFCRC (2023) Australian CBDC Pilot for Digital Finance Innovation. https://dfcrc.com.au/wp-content/uploads/2023/08/australian-cbdc-pilot-for-digital-finance-innovation-project-report.pdf. DFCRC (n.d.) Nature Based Asset Trading. https://dfcrc.com.au/2023/02/28/nature-based-asset-trading/. RBA (2023) Reserve Bank and Digital Finance CRC Complete CBDC Research Project. https://www.rba.gov.au/media-releases/2023/mr-23-21.html.

2.3.3 Enhancing export opportunities

Export markets provide opportunities to diversify and grow industry revenue sources, diversify risk, create additional value for the Australian economy, and enhance Australia's competitive advantage and reputation in decarbonisation.

The FBI CRC has contributed to Australia's position as a renewable energy exporter. The *Trusted Supply Chain* project is developing tools and platforms to connect customers to the sources of battery minerals, enabling provenance and traceability.[24] The outcomes from the CRC's *Trusted Supply Chain* project will be a key contributor to unlocking the significant value available to Australia in creating a future battery industry (see Box 2.4).

Box 2.4 FBI CRC – *Trusted Supply Chains*

FBI CRC's *Trusted Supply Chain* project will unlock significant value for Australia's future battery industry. The process of securing materials through sustainable and ethical sourcing is an indispensable component of the battery supply chain, and this holds true for both electric vehicle (EV) manufacturers and consumers.

The project is creating tools and platforms to establish a direct link between the source of battery minerals and consumers. This aims to increase transparency on the source and traceability of these materials. This comes at a time of growing sentiment in support of social and environmental responsibility among consumers. As such, the project will create a competitive edge for Australian producers of battery materials when compared to products of uncertain supply chains. This advantage has the potential to unlock considerable additional value for the battery industry.

Furthermore, by the end of 2025, the European Union will implement the Carbon Border Adjustment Mechanism, a levy on all imports to adjust for the direct carbon emissions stemming from the production of imported materials. This highlights the importance and potential value of validating and verifying responsibly sourced Australian materials for European EV manufacturers.

Source: ACIL Allen, Future Battery Industries CRC (n.d.) Trusted Supply Chain, https://fbicrc.com.au/project/trusted-supply-chain/

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[24] Future Battery Industries CRC (n.d.). *Trusted supply chain.* Accessed October 2023: https://fbicrc.com.au/project/trusted-supply-chain/.

HILT CRC is supporting Australia to remain the world's largest supplier of iron ore, as Australia transitions to green steel (see Box 2.5).

Box 2.5 HILT CRC – Material understanding of Pilbara ores for green iron production

HILT CRC aims to de-risk the technology pathways needed by Australian heavy industry (iron/steel, alumna and cement/lime) to be internationally competitive in the transition to low-carbon products.

After 2 years of operation, HILT CRC has completed 16 'quickstart' projects (<1 year in duration), under 3 themes of work: Process technologies; Cross-cutting technologies; and Facilitating transformation.

HILT CRC subsequently approved 19 new projects covering areas such as iron ore beneficiation, the use of hydrogen in the iron and cement sectors, thermal energy storage and energy recovery in alumina production using high-temperature heat pumps. This is expected to increase to 23 projects by the end of April 2024.

For example, in June 2023 HILT CRC commenced a project to better understand materials behaviour of Pilbara and other Australian iron ores for using hydrogen in making direct reduced (green) iron. This research will support Australia to remain the world's largest supplier of iron ore, as Australia transitions to green steel, and ensure Australian industry can leverage the best technology and knowledge available.

Source: ACIL Allen, HILT CRC (2022). Understanding and eliminating adverse materials behaviour during and after direct reduction in shaft and fluidised bed processes. https://hiltcrc.com.au/projects/program01-rp1001/, HILT CRC (2023). Prevention of sticking in H2 fluidised bed DRI production. https://hiltcrc.com.au/projects/prevention-of-sticking-in-h2-fluidised-bed-dri-production/.

FEnEx CRC is also contributing to enhancing Australia's export opportunities by sponsoring the Net Zero Australia project. This aims to better understand how Australia's exports could be decarbonised (see Box 2.6).

Box 2.6 FEnEx CRC – Net Zero Australia project

FEnEx CRC is a key supporter of 'Net Zero Australia'. The project is based upon the approach of the 2021 Net Zero America report by Princeton University, who are also leading the Australian project alongside University of Queensland, University of Melbourne, and Nous Group.

The project establishes a transparent cost benefit analysis of 6 pathways to net zero by 2050. A key output of the project is the mobilisation report, published in July 2023. This provides an evidence base for many of the key decarbonisation decisions that will be made in Australia in the coming years.

The report modelled a reference case against a slower rate of electrification, and more rapid electrification (with 3 sub-scenarios: full renewables rollout, constrained renewables rollout, and onshoring). The report highlights areas where Australia is well positioned, those where Australia is falling behind the milestones required. This includes identifying the necessary actions required by 2030 to transition to net zero.

The report delves into complexities surrounding Carbon Capture, Utilisation and Storage, nuclear power, end use energy efficiency, and zero-carbon fuels and feedstocks. Rather than recommending any one approach, the report presents a series of options and their pros and cons. This aims to inform decision-making on future policy, investment, and innovation decisions on the decarbonisation of Australia.

Source: ACIL Allen, FEnEx CRC (n.d.). Net Zero Australia. https://www.fenex.org.au/project/program-4-net-zero-australia-20-rp4-0052/.

2.3.4 Informing policy decisions

The CRCs have a key role in informing evidence-based decision-making across the government, industry, and research sectors. The CRCs generate data and insights, promote interdisciplinary collaboration, innovation, and problem-solving. As such, they are well placed to support decision-making, which can allow end users to more efficiently allocate resources, deliver better outcomes, and demonstrate improved accountability and trust. Most CRCs engage with multiple levels of government and have cross jurisdictional partner relationships across Australia.

The CRCs have informed policy decisions through their research. For example, the Blue Economy CRC's report titled *Offshore Wind Energy for Australia* was used to inform the Australian Government's *Offshore Electricity Infrastructure Act 2021* (see Box 2.7).[25]

Box 2.7 Blue Economy CRC – *Offshore Wind Energy for Australia*

Plans to develop offshore wind energy infrastructure are becoming increasingly prominent. In looking to accelerating future development and investment in the sector, the Australian Government announced 6 locations for offshore wind project proposals in 2022.

The Blue Economy CRC is researching the conditions needed to optimally develop offshore wind energy infrastructure in Australia. This covers legal and regulatory considerations, as well as the relevant social and logistical challenges.

As a less established energy source (relative to other sources in Australia), research is needed to demonstrate the relative strengths of potential projects and ensure that future decisions maximise the potential of offshore wind energy. This research builds on a 2021 Blue Economy CRC report with CSIRO and civil engineering company Saitec, which focused on the technical and economic feasibility of offshore wind power for Australia.

Blue Economy CRC produced the report titled *Offshore Wind Energy for Australia*, which details the project findings. This was used to inform the Australian Government's *Offshore Electricity Infrastructure Act 2021*, which regulates the offshore electricity industry with the objective of delivering a reliable, secure, and affordable energy system.

The Blue Economy CRC is also collaborating with Carnegie Clean Energy and other partners on pilot-scale research into wave-energy converters, where moored barges convert the kinetic energy in waves into usable energy. This presents an opportunity to reduce the aquaculture industry's reliance on diesel as a fuel source.

Source: ACIL Allen, Blue Economy CRC (2023) Pre-conditions for the development of offshore wind energy in Australia. https://blueeconomycrc.com.au/project/pre-conditions-for-the-development-of-offshore-wind-energy-in-australia/. Blue Economy CRC (2021) Offshore wind potential for Australia https://blueeconomycrc.com.au/project/offshore-wind-potential-for-australia/. Blue Economy CRC (n.d.) Moorpower – Scaled Demonstrator. https://blueeconomycrc.com.au/project/moorpower-scaled-demonstrator/.

A RACE for 2030 CRC report, titled *Business Fleets and EVs: Taxation changes to support home charging from the grid, and affordability*, influenced the changes made to fringe benefits taxes for EVs in 2023 (Box 2.8). The changes have the potential to reduce the cost of eligible EVs, which would likely support EV uptake and subsequently contribute to emissions reductions from transportation.[26]

Box 2.8 RACE for 2030 CRC – Business Fleets and EVs

RACE for 2030 CRC's report, *Business Fleets and EVs: Taxation changes to support home charging from the grid, and affordability*, explored the impact of tax adjustments on the adoption of EVs in corporate fleets through encouraging home charging.

The report proposed 17 short- and long-term tax modifications aimed at expediting the integration of EVs into corporate fleets and fostering home charging. These included:

- changing the formulas for calculating tax for fleet EVs
- instant asset write off, accelerated depreciation and increased GST credit limit for fleet EVs
- subsidies/rebates to fleet employers for installation of home charging infrastructure
- tax deductible reimbursements for home charging arrangements.

These findings and recommendations informed changes to fringe benefits taxes for EVs in 2023.

Source: ACIL Allen, RACE for 2030 CRC (2022), Business Fleets and EVs: Taxation changes to support home charging from the grid, and affordability.

SmartCrete CRC has influenced public and industry perceptions, helped build public acceptance of new low-carbon concrete products, and has facilitated conversations around decarbonisation between different parts of the industry. This includes developing an evidence base on Australia's cement and concrete value chain and identifying opportunities to decarbonise (Box 2.9).

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[25] Australian Government (2021). *Offshore Electricity Infrastructure Bill 2021*. Explanatory Memorandum. Accessed October 2023: https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22legislation%2Fems%2Fr6774_ems_cc98aab2-2ad3-4a63-a200-e17e715e7da5%22.

[26] Australian Government (2022). *Treasury Laws Amendment (Electric Car Discount) Bill 2022.* Accessed October 2023: https://www.aph.gov.au/Parliamentary_Business/Bills_Legislation/bd/bd2223a/23bd009

SmartCrete CRC has worked with the Blue Economy CRC and other partners to inform a strategic plan to advance the creation of floating artificial reefs.

Box 2.9 SmartCrete CRC – Cement and concrete value chain

SmartCrete CRC has informed policy positions through its collaborative research projects.

In 2021, SmartCrete CRC collaborated with the Cement Industry Federation and Cement Concrete and Aggregates Australia to engage German research centre VDZ to evaluate Australia's cement and concrete value chain. This research aimed to identify strategies to support decarbonisation by 2050. This resulted in a decarbonisation roadmap that highlighted 8 pathways for the industry to reach net zero emissions, including through:

— new CO_2 efficient cements, using supplementary cementitious materials in concrete, and further innovation in concrete
— innovation through design and construction
— alternative fuels and green hydrogen
— accounting for concrete to uptake CO_2 (decarbonation) and capturing remaining CO_2.

A second project with Macquarie University and the Blue Economy CRC, involved a feasibility study of floating artificial benthic ecosystems as a foundation for offshore expansion. This included a review of existing concrete augmented reality (AR) initiatives, spatial analysis of potential concrete AR projects within Australia, and cost-effectiveness analysis. This research informed the development of a strategic plan to advance the creation of floating artificial reefs.

Source: ACIL Allen, SmartCrete CRC (n.d.). Decarbonisation Pathways for the Australian Cement and Concrete Sector. https://smartcretecrc.com.au/projects/decarbonisation-pathways-for-the-australian-cement-and-concrete-sector/, SmartCrete CRC (n.d.). Feasibility Study into Floating Artificial Reefs Using Smart Concrete, https://smartcretecrc.com.au/projects/feasibility-study-into-floating-artificial-reefs-using-smart-concrete/

FEnEx has released a report that will inform changes to current methane monitoring methods. 'Improving fugitive emissions management in the Australian LNG industry' has been reviewed by the Department of Climate Change, Energy, the Environment and Water, the Australian Petroleum Production & Exploration Association and FEnEx CRC partners. This work builds upon the National Greenhouse and Energy Reporting (NGER) scheme. The results highlight issues with the designated computation techniques and instances where inconsistencies among different estimation approaches may occur.[27]

2.3.5 Research papers and reports

The CRCs have contributed a total of more than 600 research papers and reports across their portfolios of work (including research not related to decarbonisation). This includes providing journal publications, books and book chapters, conference publications and workshop reports. The CRCs' end user and impact focused model ensures research translation and publication focus on informing and enabling adoption by industry and government. Collectively, these outputs inform industry partners, research organisations, government entities, the academic community and the general public.

CRC TiME's research into Mine Closure Solutions (MCS, see Box 2.10) has produced case studies of the benefits delivered by MCS. These highlight the opportunities available for enhanced decarbonisation during mine closure and transition, with a view to enhancing benefits to the environment and community.

[27] FEnEx CRC (n.d.). *Improving fugitive emissions management in the Australian LNG industry*. Accessed December 2023: https://www.fenex.org.au/report/improving-fugitive-emissions-management-in-the-australian-lng-industry/.

Box 2.10 CRC TiME – Unlocking the potential of mined land for renewable energy generation

A new report by CSIRO for CRC TiME has highlighted the potential for renewable energy generation and storage as a potential post-mining land use.

The report, *'Enabling Mine Closure and Transitions: Opportunities for Australian Industry'*, presents the first comprehensive mapping of the mining equipment, technology and service-based solutions that are required to support positive mine closure and transition outcomes.

One of four categories of mine closure solutions identified relates to land use transitions, and the role of businesses in helping to identify, assess, enable and develop future land uses. It highlights 2 current examples of how mining transitions can support decarbonisation: Green Gravity, a company developing renewable energy projects on closed or abandoned sites, and the Kidston Clean Energy Hub, where solar, wind and pumped hydro technologies are proposed to be developed on a gold mine under transition, in Queensland.

2.3.6 Education and capacity building

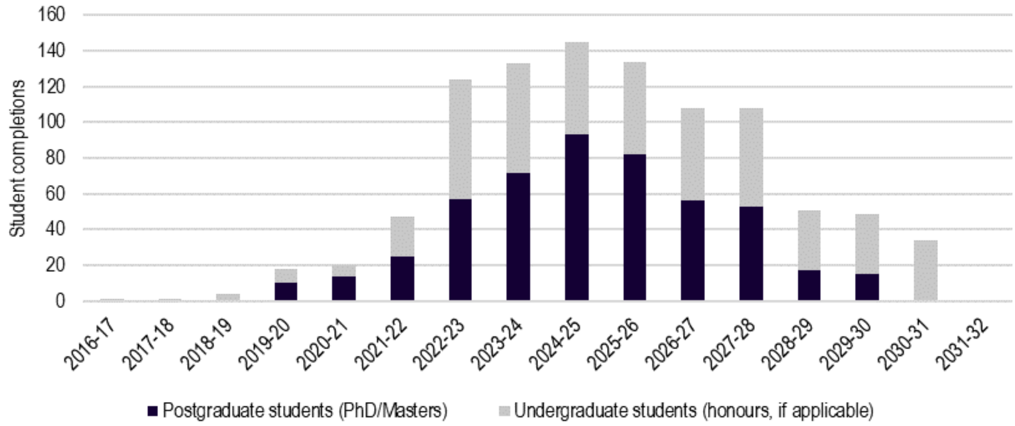
CRCs play an important role in training postgraduate students, building connections between university and industry-based researchers, and enabling industry career opportunities for students. CRC's produce graduates with expertise in working on industry problems and with industry. This has been a strong focus of government in recent years, with the launch of the $296 million National Industry PhD Program. This program specifically aims to facilitate research-industry collaboration by supporting 1,800 industry PhDs over 10 years as part of the Australian Government's Increase Workforce Mobility initiative.[28]

The CRCs directly contribute to education and capacity building in decarbonisation by training postgraduate and undergraduate students. Figure 2.2 shows the number of student completions related to decarbonisation in each year across the CRCs. There were more than 977 PhD, masters and undergraduate students focused on decarbonisation research across 12 CRCs (excludes Digital Finance CRC). The number of students peaks in 2024-25, before decreasing again. This reflects that the students are assumed to complete their studies before the end of the CRC, and that the CRCs have become more mature, and recruited more students, by this time.

While training and developing postgraduate students directly benefits the CRCs through additional human resources and a workforce pipeline, it also has spillover impacts on related sectors through broader workforce development and skill transfers.

[28] Department of Education (2023). *National Industry PhD Program*. Accessed October 2023: https://www.education.gov.au/university-research-commercialisation-package/national-industry-phd-program.

Figure 2.2 Postgraduate student completions at CRCs related to decarbonisation, 2016-17 to 2030-32



NOTE: Student data was not available from Digital Finance CRC.
Source: ACIL Allen, CRCs

2.3.7 Engagement with and adoption by end users

The CRCs collaborate with a broad range of partners including industry, researchers, government agencies, not-for-profits, and community organisations (discussed further in chapter 3). These partners guide the direction of research priorities and funding allocation. They are typically the first end users of any new information, products or services that arise from the work of the CRC.

Impact evaluation of the CRC Program by ACIL Allen demonstrated consistent delivery and high levels of adoption of research, with a net GDP increase of $32.5 billion over 29 years attributed to CRCs. The central role of end users is also evidenced through CRC impact stories throughout the report. This acknowledges that the level of research output delivery and uptake by end users varies with the maturity of a CRC, with an increase in cumulative impact over the life of a CRC and beyond.

Of the 13 CRCs considered in this analysis, the more mature CRCs (e.g., SmartCrete CRC, MinEx CRC, Future Fuels CRC, etc.) are better able to evidence research adoption to date. This includes:

— SmartCrete CRC's research into decarbonisation pathways has influenced the cement and building industries to support the accelerated implementation and adoption of new low-carbon concrete products and alternative ways of capturing CO_2. The CRC has also contributed to stronger coordination in the concrete and building sectors and raised the sector's awareness of, and interest in sustainability.

— MinEx CRC's Coiled-Tubing drilling program has been field tested with leading global mining company Anglo American. This provided proof of concept, as well as high-quality samples (see Box 2.2).

— Future Fuels CRC has set up a 'hydrogen testing laboratory' in partnership with the University of Wollongong, APA, GPA, GHD, Jemena, AGIG and Advisian (Box 2.12). The lab enables industry testing via fee for service contract work. The lab can characterise material performance in line with the testing demand currently required by the industry.[29] Future Fuels

[29] Future Fuels CRC (n.d.). *RP3.1-12: Characterising Representative Australian Transmission Pipelines in High-Pressure Hydrogen Gas*. Accessed October 2023: https://www.futurefuelscrc.com/project/rp3-1-12-characterising-representative-australian-transmission-pipelines-in-high-pressure-hydrogen-gas/

CRC is currently in discussion with commercial operators from Australia and overseas who want to partner with the lab.

— FEnEx CRC's Hydrogen Pathways App is publicly available and has been adopted by one partner.[30] Its research into enabling large-scale hydrogen storage in porous media has been adopted by a partner to assess other storage sites,[31] and the early results of its open specification for analytics interoperability project has been adopted by a partner.[32]

— iMOVE CRC is exploring consumer behaviour around uptake of net zero emissions technologies (see Box 2.11) and encouraging the use of public transport over private vehicles by piloting new technologies and approaches to transport.

— More than 300 participants enrolled in the first intake of the Foundations of Mine Closure and Sustainable Transitions Mass Open Online Course funded through CRC TiME.[33] The free or low cost (for an assessed version) course provides practical knowledge to help regional and First Nations communities as well as industry in planning before and during mine life for the end of production. This is especially important given the scale of minerals development required for decarbonisation technologies and planned closure of a number of coal-fired power stations.

These examples demonstrate the breadth of end users and the potential impact that can be delivered by these CRCs.

Box 2.11 iMOVE CRC – Net zero emissions technology consumer behaviour research

Consumer adoption is essential for accelerating decarbonisation. This includes adoption of EVs, home battery storage, and the electrification of gas appliances. Consumers will need to adopt these technologies quickly if Australia is to meet its decarbonisation goals. This also has implications for the National Electricity Market (NEM), which will need to manage significantly altered energy use profiles.

iMOVE CRC is partnering with Australian Energy Market Operator (AEMO) to explore barriers to consumer uptake of net zero emissions technologies, and opportunities to accelerate adoption. This will:

— identify and test scenarios for accelerating technology adoption

— examine responses to potential technology-NEM integration solutions (i.e. policy and regulatory incentives)

— determine whether consumer perceptions vary by consumer demographics.

This will ultimately inform future iterations of AEMO's Victorian Integrated System Plan, as well as a range of other potential policy and government initiatives on technology adoption.

Source: ACIL Allen, iMOVE CRC (2023). Consumer adoption of technologies for Net Zero emissions. https://imoveaustralia.com/project/consumer-adoption-of-technologies-for-net-zero-emissions/

[30] Future Energy Exports (2023). *Hydrogen Pathways App*. Accessed December 2023: https://www.fenex.org.au/hydrogen-pathways-app/.

[31] Future Energy Exports (2023). *Enabling Large-Scale Hydrogen Underground Storage in Porous Media*. Accessed December 2023: https://www.fenex.org.au/project/program-2-enabling-large-scale-hydrogen-underground-storage-in-porous-media-21-rp2-0091/.

[32] Future Energy Exports (2023). *Open Specification for Analytics Interoperability*. Accessed December 2023: https://www.fenex.org.au/project/program-3-open-specification-for-analytics-interoperability-20-rp3-0048/.

[33] The first course began in October 2023. Details available at https://edge.edx.org/courses/course-v1:UQx+FMCTx1+2T2023/about.

Box 2.12 Future Fuels CRC – Hydrogen testing lab

Future Fuels CRC aims to address barriers to the implementation and growth of alternative energy in Australia and identify solutions to accelerate the transition to low-carbon fuels.

A key example of Future Fuel CRC's research under its Network Lifecycle Management program is the *Characterising Representative Australian Transmission Pipelines in High-Pressure Hydrogen Gas* project.

As a newer energy source, hydrogen transmission is less established, and the material requirements for the infrastructure required (pipelines) are not yet clearly defined. As a result, the costs, durability, and practicalities of this infrastructure must be optimised to maximise industry uptake.

The project tackles industry requirements for assessing pipeline materials in a hydrogen environment, with the aim of understanding how material properties evolve under these conditions.

Testing is conducted through the hydrogen testing lab (H2SAFE(TI) Lab^), established in partnership with the University of Wollongong. The lab is capable of characterising material performance. The lab is currently in discussion with commercial operators from Australia and overseas who want to partner with the lab. Current partners are APA, GPA, GHD, Jemena, AGIG and Advisian.

The findings will contribute to a comprehensive material database containing information on the performance of Australian pipeline materials when exposed to hydrogen. Ultimately, this will significantly reduce uncertainty, and inform decisions to create new hydrogen pipelines and repurpose existing pipelines.

Source: ACIL Allen, Future Fuels CRC (n.d.), RP3.1-12: Characterising Representative Australian Transmission Pipelines in High-Pressure Hydrogen Gas. Future Fuels CRC (n.d.). RP3.1-12: Characterising Representative Australian Transmission Pipelines in High-Pressure Hydrogen Gas. Accessed October 2023: https://www.futurefuelscrc.com/project/rp3-1-12-characterising-representative-australian-transmission-pipelines-in-high-pressure-hydrogen-gas/

^Note: H2SAFE(TI) Lab is an abbreviation of Structural Assessment of Future Energy Transport Infrastructure Lab

2.3.8 GHG emissions reduction impacts

The CRCs have and will continue to generate GHG emissions reductions with potential effects beyond the period given it will take time for industry to adopt/apply the technology and realise the reduction of GHG emissions. For instance, the impact of the work by the MinEx CRC is only expected to be first realised in 2032. In other cases, it is too early to quantify the impact of the research, such as the impact of reduced congestion on emissions being undertaken by the iMOVE CRC.

As outlined in Table 2.2, 7 of the CRCs assessed have quantified anticipated GHG emissions reductions totalling around 62.8 Mt over the period, which can be directly attributed to their R&D efforts. These abatement outcomes need to be considered in the context of the timeframes required to develop and deploy the technology changes being pursued and for their wide-scale adoption on a whole of industry basis.

As such these abatement figures, which only reflect very early deployment impacts, are merely the tip of the iceberg in terms of what may be realised. The 2032 single year abatement figure of 11.6 Mt CO_2 (over 18% of the total 16 year assessment period total) indicates how rapidly the abatement is expected to increase in subsequent years. In fact, many of the projects currently being undertaken by the CRCs will not deliver impacts before the end of this decade. However, the potential is many orders of magnitude higher. For instance, work by HILT suggests its programs alone may reduce total (global) CO_2 emissions by up to 58 Mt per year over the 2030-2040 period, One Basin CRC will avoid a total of 13.5 Mt CO_2 by 2036, and Race for 2030 CRC expects to exceed its emissions reductions target of 20 Mt CO_2 by 2034.

Of the CRCs included in the economic analysis at chapter 4, a total of 58.4 Mt is expected to be abated by 2032.

The economic value of these GHG emissions reductions is examined in section 4.5.1.

Table 2.2 CRCs reported GHG emissions reductions impacts (to 2032)

CRC	Details	GHG emissions reduction impact
iMOVE CRC	Reduced GHG emissions	iMOVE CRC's initiatives contributes to reduced GHG emissions through reduced car use, the introduction of more efficient transport options, and the increased use of other modes of transport. Studies suggest that congestion may be responsible for up to 2.5% of road transport emissions.
Future Fuels CRC	Reduced environmental costs, GHG emissions; area of environment protected	The transfer to renewable energy over time facilitated by the Future Fuels CRC will result in significant reductions in GHGs emitted (estimated to be in the order of 24.9 Mt CO_2 over the period) and therefore significant improvements to the environment. The move to renewable energy is also expected to reduce contamination of natural resources.
MinEx CRC	Reduced GHG emissions	MinEx CRC's research has led to the development of increased energy efficiency in coiled tubing rigs. The additional electronic and reduced hydraulic usage in these rigs has reduced fuel consumption. The smaller footprint of the drill rigs and compression of water (rather than air) leads to significant efficiency gains. MinEx CRC have estimated that their research will result in total GHG reductions in excess of 0.46 Mt CO_2 between 2023 and 2032.
Blue Economy CRC	Reducing GHG emissions and capturing GHG gases	The Blue Economy CRC is working with the Tasmanian Atlantic Salmon industry to develop options to decarbonise operations (currently reliant on diesel). A shift to hydrogen for the aquaculture sector has the benefit of not only displacing CO_2 emissions but reducing noise (of diesel generators on- and off- shore environments), cost (high and fluctuating diesel costs) and risk of diesel transport in more exposed operating conditions. Detailed energy demand analysis suggests a potential emission reduction of around 0.58 Mt CO_2 per year if adopted across the industry. Blue Economy is also working with the Australian Seaweed Industry to drive industry development. Current Seaweed Industry ocean leases have the potential to capture 0.563 Mt CO_2 (if developed). Current research is on track to deliver a total reduction of around 2.06 Mt CO_2 by 2032.
RACE for 2030 CRC	Enabling energy market transformation and reducing GHG emissions	RACE for 2030 CRC is delivering a range of energy market initiatives to enable true whole of system optimisation with emphasis on energy use in homes, businesses, transport, and precincts through placed based solutions. This includes development of alternative policy, regulatory and business models, enabling consumer choice and actions, and better matching of local supply and demand through flexible operations of energy use including demand response, virtual power plants, vehicle to grid etc. Industrial actions focus on value chain optimization to drive energy productivity through the application of smart technologies including artificial intelligence and machine learning and the development of alternative business models and policy instruments such as white certificate schemes to incentivise adoption of energy saving options. Combined initiatives within the end-use sector are expected to directly deliver a GHG emissions reduction of approximately 7.45 Mt CO_2 by 2032 and enable continual large scale abatement across multiple sectors. RACE for 2030 expects to exceed its target of 20 Mt CO_2 abated by 2034.
SmartCrete CRC	Reduced GHG emissions	The concrete sector produces over 30 Mt CO_2 per year. SmartCrete CRC anticipates that its research will reduce emissions by an estimated 20.75 Mt CO_2 by 2032).
FEnEx CRC	Reduced GHG emissions	The FEnEx CRC's research is expected to reduce CO_2 emissions by 2.1 Mt by 2032
HILT CRC	Reduced GHG emissions	HILT is working to bring forward by 3-5 years the implementation of various net zero technologies in the key industry sectors of alumina, hematite iron ore for green direct reduced iron (DRI) and hot briquetted iron (HBI), magnetite exports to DRI and cement and lime. These changes are assumed to be implemented over the 2030-40 period and may reduce total (global) CO_2 emissions by up to 58 Mt per year by 2040.
One Basin CRC	Reduced GHG emissions	Irrigated agriculture requires large amounts of energy to pump water, both on and off farm and hence produces large quantities of GHG emissions. One Basin CRC expect that agribusinesses, water infrastructure and river operators who implement the CRC's adapted water distribution designs will enable significant reductions in GHG emissions through integrated renewable energy solutions. By 2036, a total of 10,453 GWh of energy will be saved from the use of on-farm integrated renewable energy irrigation systems. This is expected to deliver a GHG emissions reduction of approximately 5 Mt CO_2 by 2032.

CRC	Details	GHG emissions reduction impact
Mining3	Reduced GHG emissions	Mining3 is working with industry to reduce emissions from diesel use in haulage trucks during mining operations by replacing the internal combustion engine of large haul trucks (>200 tonnes) with a hybrid system of hydrogen fuel cells and batteries.

NOTE: Digital Finance CRC was unable to provide details as to potential environmental impacts given it is still in the early stages of planning and implementing its work program, coupled with the cross-cutting nature of its work, it is not possible to determine the level of disaggregated decarbonisation-related funding.

Source: ACIL Allen, CRCs

2.3.9 Broader environmental and social impacts

The CRCs have and will continue to generate a range of broader environmental benefits in addition to those included in Table 2.2. The environmental impacts include lower energy and water consumption, better environmental protection and rehabilitation, and reduced waste production. The CRCs have and will continue to generate a range of social benefits. These include health, safety, education, and community development. These benefits are also challenging to monetise, and as such have not been included in and are additional to the economic impacts (see chapter 4).

Some examples of these impacts from 2016-32 are provided in Table 2.3.

Table 2.3 CRCs reported environmental and social impacts

CRC	Details	Environmental and social impact
iMOVE CRC	Education and training provided	iMOVE estimate that by 2025, 30 PhD students and 360 undergraduate students will receive education and training through their program. This is expected to grow to a total of 40 PhD students and 400 undergraduate students by 2027. The beneficiaries of this include the transport sector, universities, and students nationally.
	Reduced congestion	Congestion reduction is a key objective of the iMOVE CRC. iMOVE is running a suite of projects on how experiences with COVID can be used to create working/transport arrangements that reduce peak and overall traffic, thereby reducing transport time and consumer wellbeing.
Future Fuels CRC	Education and training provided	24 PhD students have completed their education through the Future Fuels CRC between 2019 and 2023. This number is expected to rise to a total of 48 PhD and Masters students by 2025.
	Change in character of local community	Future Fuels CRC is the first to utilise a citizens' assembly approach to community engagement (a citizens' assembly is a group selected from the general population to deliberate on important public questions). This has led to significant improvements to how communities are engaged on the delivery of future fuels energy projects
MinEx CRC	Education and training provided	MinEx has trained 13 postgraduate students to date and have a further 37 currently registered. They also have provided education and training to 180 VET students. The CRC's education and training program is expected to lead to better training outcomes in mineral exploration; more skilled individuals entering a research or industry career; improved training of operators in safety, and newly developed technologies and decision-making capability for large datasets that will be available through new drilling and real-time data analysis.
	International collaborations	MinEx CRC have been involved in 8 international collaborations between 2018 and 2023. They expect at least 2 more collaborations to occur between now and 2027.
	Labour force participation	MinEx CRC has resulted in an additional 35 FTE positions in 2018, and an additional 5 FTE positions in 2019.
	Business diversity and success	MinEx CRC expect that 4 new coiled tubing drilling companies and/or geophysical companies will emerge between 2024 and 2029 as a result of their research. The CRC's research has resulted in spin-out technologies, including LogAR (Augmented Reality Core Logging), Laser-induced Breakdown Spectroscopy (LIBS) and Fluids.
	Improved safety	Coiled tubing drilling, developed by the MinEx CRC, is safer than conventional drilling techniques and is therefore expected to lead to less workplace incidents for operators.
FBI CRC	Reduced environmental costs	FBI CRC has developed traceability technology to assure mineral and supply chain provenance. Its certification commonalities research contrasts various ethical and sustainability certification systems, with a focus on reducing duplication and compliance costs. The CRC has contributed to

CRC	Details	Environmental and social impact
		critical minerals policy to improve Australia's competitiveness in critical minerals supply chains and extract value from environmental, social, and corporate governance at mines and in domestic processing. The value of these benefits is expected to be realised from 2025 onwards.
	Labour force participation	FBI CRC will support a total of 49 HDR students between 2018 and 2026, 32 are expected to take up positions in industry
	International collaborations	In 2023, FBI CRC signed a memorandum of understanding with the National Renewable Energy Laboratory in the US, and separately with Indonesia's National Battery Research Institute to collaborate on battery research activities.
CRC TiME	Collaborative planning for a future beyond coal-fired energy generation	A collaborative planning project is underway focused on consensus building and developing a shared vision for the region in the Latrobe Valley. Stage 1 has brought together mine operators, Traditional Owners, community, government agencies and others with researchers to develop feasible, desirable and viable options for lands zoned, but not used, for mining. Stage 2 will involve an Indigenous Reference Panel, citizens panel and youth engagement.
	Enabling Nature Positive ambitions	Investing in research and innovation to support improved environmental outcomes is a core theme in the work of CRC TiME. The CRC's research supports the development of new or improved ecosystems on the mining estate. Planning tools are focussed on integrating nature positive futures into cumulative and regional planning of post mine futures. Working with the CSIRO and the Department of Climate Change, Energy, the Environment and Water, the CRC is a suite of resources to support adoption of Natural Capital Accounting in the mining industry.
	Education and training	More than 300 participants enrolled in the first intake of the Mass Open Online Course on the Foundations of Mine Closure and Sustainable Transitions. CRC TiME opted to fund a MOOC to make free or low-cost education available beyond industry to regional and Indigenous communities and organisations.
	Education and training	An Indigenous-led project to understand what information, resources and capabilities Indigenous people and organisations need to negotiate land use, make decisions about post-mining transitions and land use and benefit from opportunities is underway. It is expected to inform development of a suite of VET options. Improving access to this information will support First Nations partnerships for critical minerals development as well as planning for completion of mining at some operations.
	Water consumption reduced	MinEx research has resulted in decreased water usage. Water is used as a medium for sample transport and lubrication, and usage has dramatically decreased from the efficiency gains noted above. MinEx CRC have estimated that their research will result in a reduction of 3.59 megalitres of water usage from 2023 to 2032. Landholders and local community benefit from less water use.
	Sharing knowledge between coal regions	CRC TiME hosted a pilot cross-regional knowledge exchange in Moranbah and Mackay in July 2023, with representatives from Latrobe Valley, Collie and the Bowen Basin. While decarbonisation is affecting each region differently, post-event evaluation confirmed delegates benefitted from sharing economic diversification strategies.
RACE for 2030 CRC	Education and training provided	RACE for 2030 CRC expect to provide education and training to 55 students between 2024 and 2030.
	International collaborations	RACE for 2030 CRC have had 7 international collaborations between 2020 and 2023. They are expecting at least an additional 10 international collaborations by 2026, as a minimum target.
	Improved health and well being	The energy upgrades for Australian homes facilitated by the CRC are expected to improve comfort and health outcomes.
	Change in character of local community	The activities of the CRC have led to improved community engagement through place-based energy efficiency solutions, and more energy efficiency options in Australian homes.
SmartCrete CRC	Reductions in environmental costs	The cement and concrete industry in Australia must act to reduce its carbon emissions. SmartCrete CRC co-funded the development of a Decarbonisation Roadmap for the industry which outlines technology options and indicates the quantum of emissions reduction from carbon reduction options. The impacts of the roadmap are expected to be realised from 2021 to 2050.
	Reduction in the amount of waste produced	SmartCrete CRC's research is facilitating the conversion of waste products back into valuable industrial materials, thus diverting the amount of waste going into landfill. The CRC estimate that between 2024 and 2032, 0.325 Mt of waste will be recycled through their activities (this includes recycled concrete aggregates, glass, rubber, and lithium bi-products).

CRC	Details	Environmental and social impact
	Reduction in contamination of natural resources, including soil, water, air etc	Approximately 65 Mt of fly ash are produced per year through coal fire power stations. This is currently stored in fly ash dams. SmartCrete CRC is investigating the rehabilitation of fly ash dams and positive use of fly ash in concrete. The CRC's research could lead to the positive use of 0.325 Mt of fly ash per annum from 2024 onwards.
	Education and training provided	SmartCrete CRC expect to sponsor 21 PhD students between 2023 and 2028.
	International collaborations	SmartCrete CRC has facilitated 2 international collaborations between 2020 and 2023 and expect to be involved in an additional 18 international collaborations by 2027.
	Labour force participation	In 2020 the SmartCrete CRC led to the creation of 4 FTE positions. This has grown to 5 additional FTE positions per annum between 2021 and 2024. The number will reduce to 4 additional FTE positions per annum between 2024 and 2027.
	Business diversity	SmartCrete CRC research is expected to lead to the operation of a new business in 2024.
	Savings on government expenditure	SmartCrete CRC research is expected to lead to infrastructure maintenance budget savings of about $10 million per annum between 2024 and 2026, resulting from a reduction in the cost of maintenance for Australia's sewer systems.
FenEx CRC	Public opinion	FenEx CRC reports wide public acceptance of its hydrogen study - https://www.fenex.org.au/report/public-acceptance-of-hydrogen-workshop-summary-report/.
	Education and training provided	FEnEx has provided education and training with approximately 60 higher degree candidates (PhD and Masters by research); 90 Associate Degree in Applied Technologies students; and to 250 participants in Interoperability Training and hydrogen pathways application training.
	International collaborations	FenEx CRC has facilitated international collaborations with USA, UK, Korea, Japan, China, and Germany.
HILT CRC	Labour force participation	HILT CRC outcomes will unlock: 92,000 new jobs over the next decade and retain 312,000 jobs.
	Economic development	HILT CRC outcomes will unlock: a 3-fold increase in the value of Australia's ore and processed mineral exports progressively to 2050 and up to $4 billion per year in increased export income contributed by 2036.
	Education and training provided	HILT CRC will lead upskilling of the heavy industry's workforce, enabling skilled personnel to transition the sector to a low-carbon sector. It expects to provide education and training to 60 students. Currently 18 higher degree research students have commenced, Industry Internships program has commenced, and 7 Coursework Grants approved.
	International collaborations	HILT CRC is fulfilling Australia's co-leadership role of the Net-Zero Industries Innovation Mission to facilitate the full decarbonisation of heavy industries in multiple regions of the world, by 2050. It is coordinating the knowledge sharing benefits and building further international networks. HILT CRC currently has over 10 international industry and research partners, at all levels of Partnership.
One Basin CRC	Education and training provided	One Basin CRC has provided education and training to 17 postgraduate students in 2022 and 2023. They expect to provide education and training to an additional 33 students by 2028 (for a total of 50 postgraduate students between 2022 and 2028).

Note: Digital Finance CRC was unable to provide details as to potential social impacts given it is still in the early stages of planning and implementing its work program, coupled with the cross-cutting nature of its work, it is not possible to determine the level of disaggregated decarbonisation-related funding.

Source: ACIL Allen, CRCs

Key Finding 3 Decarbonisation outcomes and impacts

CRCs have contributed to Australia's decarbonisation goals by delivering new products and services, developing reports and other publications, contributing to education and capacity building, enhancing Australia's export opportunities, informing decision-making, and engaging with end users.

Seven of the CRCs assessed have quantified anticipated GHG emissions reductions totalling around 62.8 Mt by 2032, which can be directly attributed to their R&D efforts. The net benefits of avoided emissions are estimated to have a cumulative undiscounted benefit of $1.8 billion, with a net present value of $768 million (7% discount rate). When scaled across the 13 CRCs, the expected CO_2 abatement is valued at $3.3 billion or $1.3 billion in net present value terms (7% discount rate).

CRCs will continue to support decarbonisation efforts regardless of the stage that they are at in their life as their workplans are completed. The abatement outcomes above are merely the tip of the iceberg in terms of what may be realised as industry continues to adopt the work of the CRCs over time. The 2032 single year abatement figure of 11.6 Mt CO_2 (over 18% of the total 16 year assessment period total) indicates how rapidly the abatement is expected to increase in subsequent years. It is likely that these impacts will continue to increase over time as end users continue to take up CRC products, services, insights, and advice.

Many of the CRCs are in the early stages of their life and will continue to support decarbonisation efforts as their work plans are completed. It is likely that these impacts will continue to increase over time as end users continue to take up CRC products, services, insights, and advice.

2.4 Measuring impact

While many of the CRCs' impacts have been captured above and in the economic modelling (see chapter 4), reporting is guided by the CRCs' objectives and workplans. As such, reporting on decarbonisation is not an explicit focus, which makes it challenging to capture decarbonisation-specific information. Consequently, there is an opportunity to enhance decarbonisation impact reporting

The CRC Program's eligibility conditions require the CRCs to aim to solve industry identified problems to improve the competitiveness, productivity and sustainability of Australian industries, and the inclusion of an industry-focused education and training program.[34] A CRC must partner with at least one Australian industry entity and one Australian research organisation.[35]

The standard CRC reporting requirements include:

— Quarterly progress reports over the funding term, including reporting on budget and milestone progress, identification of any significant achievements, as well as any real or potential challenges in achieving the proposed outcomes or complying with the Grant Agreement.

— Annual reporting for each financial year, also contain financial and milestone progress reporting, and a case study of overcoming an industry challenge.[36]

[34] Australian Government (2023). *Funding for medium to long-term, industry-led research collaborations.* Accessed January 2024: https://business.gov.au/grants-and-programs/cooperative-research-centres-crc-grants.

[35] Australian Government Department of Industry, Science and Resources (n.d.). *Cooperative Research Centres Grants – Fact Sheet.* Canberra: Australian Government.

[36] Ibid.

— End of CRC reports that provide a whole of life summary of the CRC, including milestone, budget/audit acquittal and transition arrangements towards a post-CRC organisation (including continuation of outcomes and any education and training programs).[37]
— Evaluation report of the program's impact and effectiveness 12 months after the end of their Agreement Period. This includes an assessment of partners' satisfaction with the program's benefits, the extent to which the CRC addressed industry-identified issues, evidence of broader economic and community impacts (e.g., competitiveness and productivity, risk reduction, employment growth, and cost savings), and unexpected benefits. The report should illustrate how competitiveness and productivity were improved, and track collaborations over time, including internships and secondments between the CRC's partners.

The CRCs do not have specific measures in place and resources available to collect decarbonisation-related activity and performance data, or to measure impact toward Australia's decarbonisation goals. The CRA does not collect this information at a 'whole of CRC effort' level. There would be benefit in the CRCs mapping the individual and collective pathways to providing decarbonisation impact in a consistent manner across the 13 CRCs, to provide a better understanding of the contributions they have made and continue to make, toward Australia's decarbonisation goals. Any approach to such a mapping exercise should consider good practice performance measurement principles.

Good practice performance measurement involves practices of ongoing data collection and program monitoring, reporting, and evaluation. Most CRCs do not have well established and functioning measures in place to collect performance data and use that data to measure impact. While all CRCs have an impact tool, CRCs on the whole do not necessarily or explicitly collect information on decarbonisation-specific impacts.

For example, one CRC had commissioned a consultant to co-design an evaluation approach that outlines a clear pathway from research to impact through a rigorous translation process. One CRC reported using LinkedIn surveys to understand their followers' perspectives on the CRC's progress to date and whether they thought the CRC was on track. Another CRC reported that commercialisation pathways are considered as part of their CRC's project development stage, but that this was not currently an effective process. CRC TiME has also developed an Impact Framework to guide its approach to measuring impact over time. While not specifically referencing decarbonisation, it identifies 5 impact objectives, measures of success and the types of activities that can contribute to long-term change. Data collection is underway for future evaluation activities.

Good practice considerations could include developing a decarbonisation-specific program architecture for both individual CRCs and the suite of 13 CRCs. This could include performance and accountability indicators, monitoring and reporting, and evaluation (see Box 2.13). Using good practice performance measurement would enable the CRCs to conduct a more effective assessment of decarbonisation outcomes and determine the extent to which they are contributing individually and collectively to Australia's decarbonisation efforts.

[37] Australian Government Department of Industry, Science and Resources (2023). *Cooperative Research Centres (CRC) Grants Program – Reporting Guidelines 2023.* Accessed October 2023: https://business.gov.au/Grants-and-Programs/Cooperative-Research-Centres-CRC-Grants#overview.

Box 2.13 Good practice performance measurement

Program architecture

Architecture, such as a program logic, provides a shared understanding of the problem a CRC is addressing, the policy context, key assumptions and risks, together with the CRC's goal, objectives, inputs, activities, expected outputs and outcomes including how they will be measured. This should be used to set the parameters of the CRCs' operational, performance and accountability arrangements.

Performance and accountability indicators

Key performance indicators (KPIs) need to measure true outcomes rather than simply activities or outputs. These must be considered early in the CRC's life to guide the design of activities, monitoring and reporting. Good practice[38] design of KPIs aligns with the SMART principles: Specific, Measurable, Achievable, Relevant, and Timely.

KPIs should be monitored over time to ensure that they are clearly defined and appropriate for their purpose, the data collected is useful, and that the costs of collection are reasonable.[39]

Monitoring and reporting

Monitoring ensures that performance aligns with the workplan and accounts for the use of public funds.[40] This informs how the CRC is progressing and the changes required to improve the delivery or performance of individual grants or the broader CRC. Data collected for monitoring purposes is often also used to inform program management and evaluation. This includes the CRCs' annual reporting.

Evaluation

Good practice evaluation embeds a program logic and pathway to impact framework into the investment process. This framework considers the causal relationship between an investment's objectives, inputs (i.e., resources), activities, outputs, outcomes and ultimately, its impacts. Evaluation provides accountability to stakeholders and drives performance. Evaluation should be integrated into core business, evidence based, fit-for-purpose, transparent, independent, and used to inform decisions.

Source: ACIL Allen

Key Finding 4 Measuring impact

CRCs' measurements of impact are guided by their objectives and workplans. CRCs are not currently resourced or required to collect explicit decarbonisation-related activity and performance data, nor to measure impact toward Australia's decarbonisation goals. This largely relates to the fact that each CRC has been established with industry-defined challenges and may have only recently evolved to include decarbonisation as a focus area.

There is an opportunity to better understand, consistently map, and harness the decarbonisation impacts delivered by the individual and collective CRCs, to understand the contributions made towards meeting Australia's decarbonisation goals.

There is an opportunity for CRCs to better map their pathways to impact and ensure processes are in place to support future impact measurement. This should also consider the impacts that the CRCs will achieve as a collective. While all CRCs have an impact tool, CRCs on the whole do not necessarily or explicitly collect information on decarbonisation-specific impacts.

[38] The principles are based on documentation from the Australian Institute of Company Directors, Australian National Audit Office, ASX Corporate Governance Principles, and Uhrig (2003). *Review of the corporate governance of statutory authorities and office holders.* Canberra: Commonwealth of Australia.

[39] The Australian National Audit Office (2011-12). *Audit Report No.5 2011–12. Performance Audit Development and Implementation of Key Performance Indicators to Support the Outcomes and Programs Framework.* Accessed 14 June 2021: https://www.anao.gov.au/sites/default/files/201112%20Audit%20Report%20No%205.pdf.

[40] Ibid.

Synergies and alignments 3

This chapter discusses the synergies and alignments between the CRCs and identifies potential opportunities for future collaborative efforts.

3.1 Collaboration and synergies between the CRCs

The CRC model provides an effective and flexible mechanism for stakeholders from different sectors to work together, leverage their collective expertise and address complex challenges through research and collaboration. This enhances the quality and impact of research, and the development of fit-for-purpose, evidence-based solutions for various industries and sectors.

An overview of the CRC's collective collaboration impact is provided in Figure 3.1.

Figure 3.1 Overview of the CRC's collective collaboration impact

Source: ACIL Allen, various

3.1.1 CRC partners and collaborators

Partnerships between industry and research bodies are a defining element of the CRC model. CRCs are required to partner with at least one Australian industry entity (which can be government and business) and one Australian research organisation.[41]

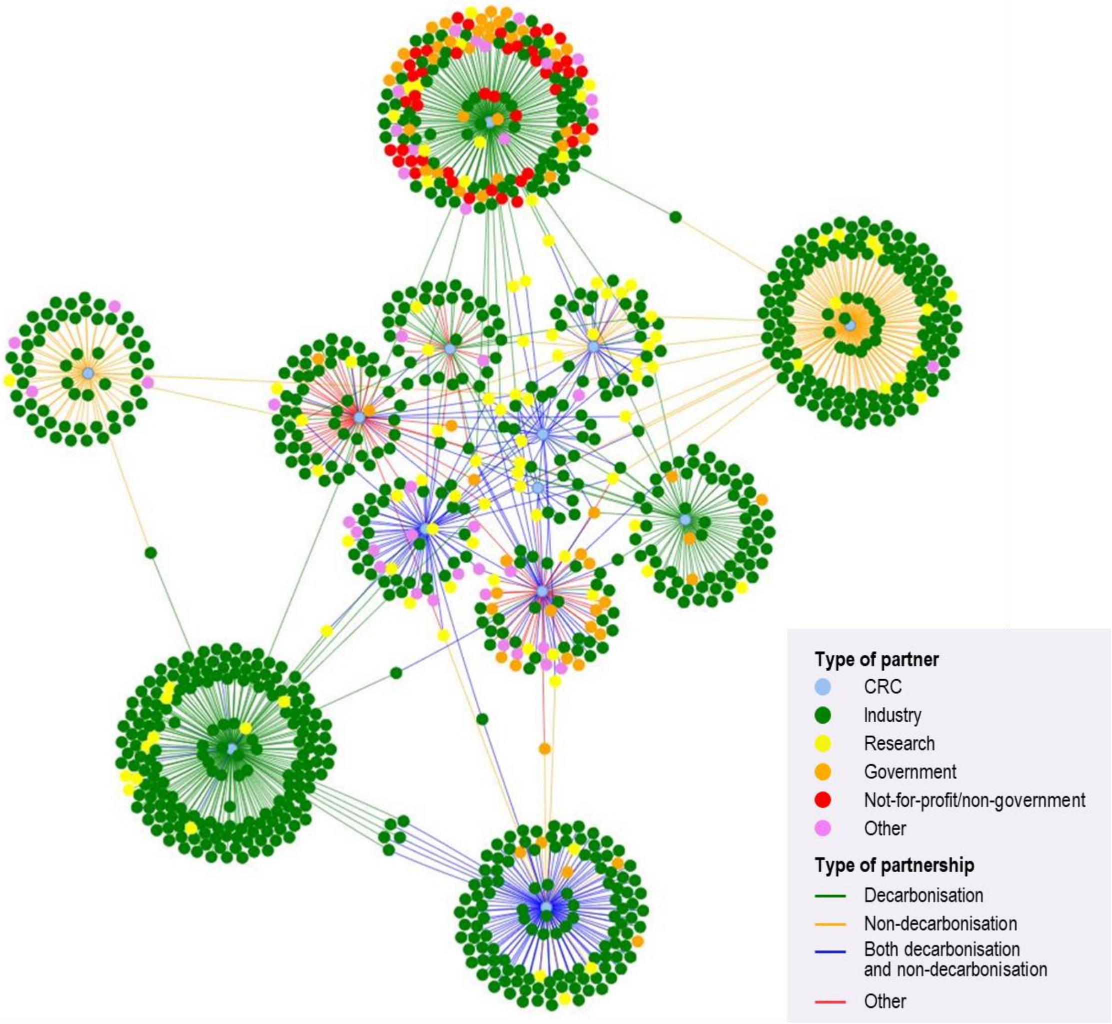
Each of the CRCs' partners were mapped to identify the CRCs' collective network (see Figure 3.2). A total of 1,691 organisations were identified as partners across the 13 CRCs. Industry partners are identified in green, research partners in yellow, government partners in orange, not-for-profit/non-government partners in red, and other partners in pink. Lines between nodes represent the type of

[41] Australian Government Department of Industry, Science and Resources, and AusIndustry Cooperative Research Centres Program (2022). *Cooperative Research Centres (CRC) Program, Frequently Asked Questions*. Canberra: Australian Government.

partnership, with those focused on decarbonisation are represented in green, non-decarbonisation in red, both decarbonisation and non-decarbonisation in blue, and other in orange. Common partnerships are shown through lines connecting multiple CRC nodes. This can be seen most clearly between the 2 bottom CRC nodes and the 5 common industry partners between these.

This network is large, complex, diverse, and continually evolving. It demonstrates the collective reach the CRCs have across a wide array of research and industry partners. Many of these partners are complementary, enhancing and extending the impact of the CRCs by contributing to the CRCs' research, providing access to facilities, expertise, and funding, supporting impact translation, and by adopting the innovative products and services developed by (and with) the CRCs.

Figure 3.2 The 13 CRCs' collective partner network



Source: ACIL Allen, various

An example of collaboration between One Basin CRC research and industry partners on its *Alternative Water Quickstart* project is provided in Box 3.1.

Box 3.1 One Basin CRC – *Alternative Water Quickstart* project

One Basin CRC's *Alternative Water Quickstart* Project is a partnership between Osmoflo, Flinders University, the University of Adelaide and the Loxton Research Hub. The project focuses on understanding the potential expansion and diversification of irrigated water sources using brackish groundwater. It considers the socio-environmental and economic consequences.

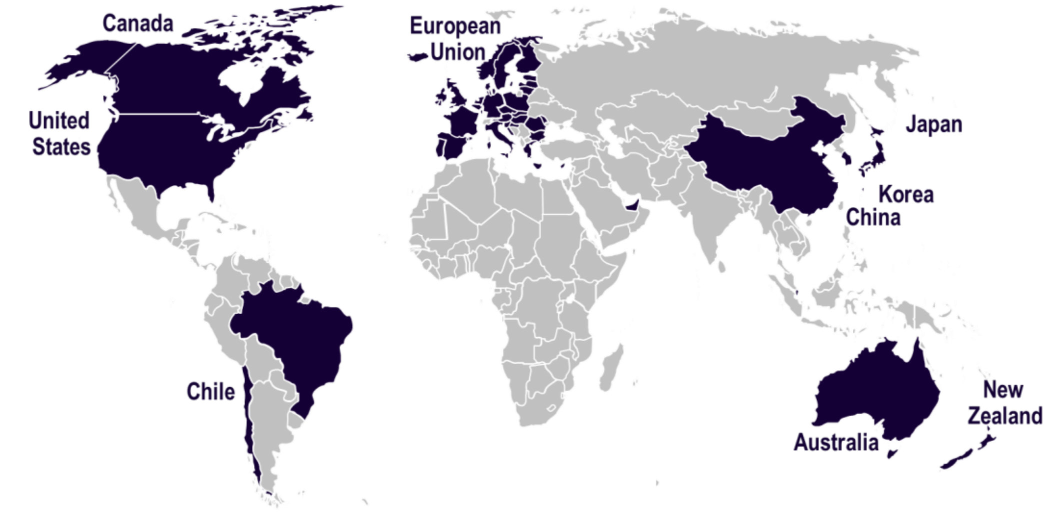
In the next year, the project will identify a location for a desalination demonstration, create an online analytical tool for assessing desalination expenses, and present a report on the basin's prospects.

This project will contribute to One Basin CRC's objectives to improve the sustainability and resilience of the Murray-Darling Basin (including new secure water sources) and reduce emissions within the water supply system and irrigation system. This includes the goal to avoid an estimated 8 Mt CO_2 from off-farm technologies, 5.5 Mt CO_2 from on-farm technologies over 15 years.

Source: ACIL Allen, One Basin CRC (n.d.), Alternative Water Quickstart, https://onebasin.com.au/alternative-water-quickstart-gets-underway

The network includes both domestic and international partners. International partners provide an important avenue for the CRCs to access specialist skills or opportunities not available in domestic organisations. These international partnerships are usually deep and sometimes long connections with an organisation and country. These partnerships also provide an avenue to adopt, test and manufacture new or improved technologies, products, and services. This enables the CRCs to further scale their impact. The 13 CRCs' collective international network (see Figure 3.3) includes Finland, Spain, Singapore, Sweden, Norway, Chile, Belgium, Ireland, United Kingdom, the European Union, Korea, Japan, United States, Canada, New Zealand, Brazil, the United Arab Emirates, and China.

Figure 3.3 The 13 CRCs' collective international network



Source: ACIL Allen, various

The CRCs and Australian Government can further leverage the CRCs' collective network to provide additional resources and direct these resources to take advantage of and enhance the impact of decarbonisation related activities to date, to build broader credibility and policy influence, and to ensure that project outputs are adopted by a broader audience. Enhancing the CRCs' collaboration with government and industry sectors will help ensure that the CRCs are collectively addressing areas of most need.

3.1.2 Collaborations between the CRCs

As well as having common collaborating partners, the CRCs collaborate with each other. This can be informal collaboration to share information or networks, or formal collaboration on projects of mutual interest. Where efforts are formalised, each CRC brings a different value proposition to the project. Existing relationships between CRCs or key personnel have been central to many of these collaborations.

Some CRCs highlighted the stronger potential for cross-cutting CRCs to engage more with other CRCs, while sector-specific CRCs may find it more challenging to easily align their activities with those of other CRCs. The CRCs reported that any collaboration should seek to leverage the unique and diverse capabilities across the CRCs in a strategic manner, rather than duplicate efforts. With the ability to draw on approximately 1,700 partners where the CRCs have existing, active project based relationships, cross CRC collaboration provides additive benefits where they have complimentary partners (e.g. DFCRC and CRC TiME bringing investment and mining partners from each other).

Examples of CRC-CRC collaboration identified during consultations include:

— Informal and strategic linkages between SmartCrete CRC, HILT CRC and Building 4.0 CRC to share updates and information across the same sector of interest.
— Blue Economy CRC has collaborated with Future Fuels CRC on hydrogen and with FBI CRC on battery related projects. They have received co-funding for specific projects with SmartSat CRC and SmartCrete CRC on artificial reefs.
— SmartCrete CRC has collaborated with RACE for 2030 CRC on the 2030 Decarbonisation Roadmap and with Blue Economy on 2 projects.
— FEnEx CRC collaborates with FBI CRC, HILT CRC, Future Fuels CRC, and the CO_2 CRC. FenEx CRC partnered with the CO_2 CRC on the future of underground CO_2 storage.
— iMOVE CRC and RACE for 2030 CRC have partnered on a vehicle-to-grid project, and informally collaborates with other related CRCs.

The CRCs also identified specific opportunities for future collaboration to leverage synergies between the CRCs and better deliver decarbonisation outcomes. This includes:

— Digital Finance CRC identified CRC TiME as a potential collaborator in research related to the integration of securitisation in mine restoration.
— CRC TiME identified Digital Finance CRC as a potential collaborator on developing stronger accountability on financial disclosures, and RACE for 2030 CRC on the use of future technologies in the mining estate. CRC TiME highlighted the importance of working with CRCs in common sectors, such as MinEx CRC, which has a common focus across certain elements of a mine's lifecycle.
— One Basin CRC identified Soil CRC and RACE for 2030 CRC as potential collaborators.

However, some CRCs identified barriers to further collaborating with other CRCs, which could be improved by greater clarity around contractual limitations on collaboration under their grant agreements.

CRCs are required to identify partners and their cash and in-kind contributions during the CRC application stage. Some CRCs have created very structured approaches to allocating funding to each project across the life of the CRC. This was to ensure that partners received an appropriate return on their investment in the CRC, with funding allocated to agreed projects of interest. Further, the need for projects to pass separate CRC governance reviews by each collaborating party was identified as a barrier to CRC-CRC collaboration.

These obligations to partners and the structured approach were reported to limit the CRCs' flexibility to reallocate funding over time and to collaborate with new partners. This was seen to be the case where the new partnerships could deviate the CRCs from their original work plan. This is limiting some CRCs' responsiveness to emerging opportunities and limiting larger-scale projects and capital expenditure.

Some CRCs reported that they would be willing to engage in more collaboration with other CRCs if there was additional funding available or provided by the partnering CRC. Some suggested that collaboration would be more likely to occur for smaller projects, which required lower cash investment. This would also make it easier to secure matching industry funding, a requirement for CRC projects.

In contrast, some of the CRCs considered that there were no contractual barriers to engaging new partners over the life of the CRC. These CRCs considered that new partners provided new funding and enabled the CRCs to pursue emerging opportunities and changing industry needs, in line with partner priorities. Instead of allocating funding to specific projects at the outset of the CRC, funding is allocated iteratively using reference panels of key stakeholders and partners. This was reported to provide sufficient flexibility to adapt and engage new partners over time.

Importantly, there is large diversity across the 13 CRCs in terms of the nature of their collaborations, the scale of research conducted, and the technology readiness level (TRL) being targeted. For example, some CRCs considered that they were unable to progress from benchtop research due to limitations in funding, contractual arrangements or collaborations. In contrast, others are pilot testing large scale facilities, scaling up research translation and launching startup companies. This suggests inherent flexibility in the CRC model that is not fully leveraged across all CRCs and the approaches adopted by some may be self-limiting.

Together, this suggests that while collaboration is underway between the CRCs, there is an opportunity to scale this more broadly across the 13 CRCs. This could be supported by a better understanding of the real funding, program, and governance limitations on CRCs, as well as the opportunities available to CRCs to collaborate. CRCs need to look to opportunities to refocus their priorities and pursue emerging needs over time, to ensure that they are addressing the areas of most need.

Key Finding 5 Collaboration and synergies between the CRCs

The CRCs collectively collaborate with a deep and broad network of research and industry partners, both in Australia and internationally. These partners are a feature of the CRC model and enhance and extend their impact. The network is large, complex, diverse, and continually evolving. It demonstrates the collective reach the CRCs have across a wide array of research and industry partners. Many of these partners are complementary, enhancing and extending the impact of the CRCs by contributing to the CRCs' research, providing access to facilities, expertise, and funding, supporting impact translation, and by adopting the innovative products and services developed by (and with) the CRCs.

There is an opportunity for the CRCs and Australian Government to better leverage existing partnerships in the CRC network for decarbonisation-related efforts. These partnerships provide the foundation to leverage expertise across the CRCs and CRCs' partners, share resources, be better informed, have broader credibility and policy influence, and enhance research adoption.

There are formal and informal partnerships between the CRCs focused on sharing information and delivering projects. However, collaborations tend to be based on existing relationships and projects, and there is no strategic or coordinated approach.

Most CRCs want to collaborate more. Greater clarity as to the limitations and opportunities surrounding such collaboration would facilitate further joint work. Furthermore, the acquired knowledge from collaborative efforts should be documented and transformed into best practices for future endeavours.

3.2 Leveraging the CRCs to achieve more impact

The CRCs considered that the new strategic direction and goals set by the Australian Government had paved the way for improved decarbonisation policies and programs. This also provides opportunity for the CRCs to support Australia's achievement of these goals, which the CRCs are well placed to deliver.

The CRCs identified barriers to decarbonisation, including limited social license, lack of system-wide coordination, strong reliance on existing technology rather generating new knowledge, red tape and a constrained regulatory environment, and an excessive focus on the supply side rather than a system-wide approach.

While the CRCs have and will continue to support Australia to reach these goals (see section 2.3), most CRCs reported that current funding available for decarbonisation was not proportionate to the potential benefits of accelerating decarbonisation and risks of not pursuing it. The funding is also delivered over short time periods (6 to 10 years) that do not reflect the need for persistent, long-term effort to address decarbonisation. The CRCs considered that access to additional sources of funding would enable the acceleration of decarbonisation, support Australia to reach its goals, and incentivise greater business research expenditure. Australia has lower levels of entrepreneur and businesses expenditure on research compared with comparable OECD countries.[42] Larger scale funding was reported to be particularly important for:

— Scaling research findings across industry.

— Progressing research up the TRL scale,[43] noting that CRCs provide one of the few mechanisms where TRL4-6 are actively fostered in Australia's innovation system.

— Conducting large scale demonstration projects, which require significant upfront capital investment, which is a deterrent for industry investment, and challenging for the CRCs to support. This highlights the need to work with funding entities such as Australian Renewable Energy Agency (ARENA), that can provide capital funding.

The CRCs also highlighted the need for more effort to attract further investment and collaboration from domestic industry, as well as incentivising investment from international organisations.

The CRCs highlighted the importance of a more strategic approach to decarbonisation across Australia. They considered that stronger alignment between and across governments, industry and research sectors would enable more collaboration and support acceleration of progress toward Australia's decarbonisation goals. This could include identifying opportunities and pursuing new research topics or collaborative projects across the 13 CRCs as they emerge. This would be further aided by the availability of funding to support cross-CRC, cross-sectoral, transformational, and joint mission partnerships. This would also allow the CRCs to support more secondments between the industry and government sectors, supporting knowledge transfer and enhancing the impact of the CRCs' efforts. This would allow the Australian Government to better leverage the existing capability and capacity within CRCs, and across their extensive collective networks.

> *Anything that builds impact in the industry is important – there are untapped resources across the industry that need to be used.*
>
> *CRC stakeholder*

[42] Organisation for Economic Co-operation and Development (2020). *R&D tax expenditure and direct government funding of BERD*. Accessed October 2023: https://stats.oecd.org/Index.aspx?DataSetCode=RDTAX%20.

[43] Defence, Science and Technology Group (n.d.). *Technology Readiness Levels definitions and descriptions*. Accessed October 2023: https://www.dst.defence.gov.au/sites/default/files/basic_pages/documents/TRL%20Explanations_1.pdf.

The CRCs noted that there are a range of Commonwealth (and other) government programs available that could provide a funding source to effectively extend their decarbonisation work (such as ARENA and the National Collaborative Research Infrastructure Strategy (NCRIS)). Access to additional government funds would provide the opportunity to accelerate current projects, supplement new projects and/or fund projects requiring substantial capital investment to scale, such as a pilot or demonstration projects.

Timeliness is critical for decarbonisation efforts and this need should be reflected in a more agile funding and reporting system that can accommodate shifts in policies and commercial priorities, while enabling sufficient accountability and governance. The current funding system gives rise to specific challenges related to collaboration. Action could address perceptions of duplication, complex reporting on other Commonwealth investments, and the need for flexibility and agility in the grant administration process. CRCs have highlighted issues such as variations in grant agreements, potential barriers related to intellectual property (IP) access, and the challenges of dealing with changes in government priorities within a fixed timeframe.

Despite some limited successes most CRCs have not sought to leverage other government funding sources. In part this reflects a perception that their applications may not be accepted and considered on merit or may otherwise be 'discounted' in the competitive process given they are already the recipient of government funding. While the need to ensure that government funding processes are transparent, and that CRCs are not 'double-dipping' and seeking funding to duplicate existing (government supported) projects are fully appreciated, their applications should be welcomed and considered on equal terms.

That said, it is incumbent on the CRCs to demonstrate their competitiveness and articulate the case for additional support. Applications need to clearly demonstrate the additionality that will be generated through the increased support and how the work will deliver against the decarbonisation goals over and above their current work programs.

There is a collective agreement that there is an opportunity for a decarbonisation-specific reference group or CRA to perform a strategic coordination role across decarbonisation-focused CRCs. This could leverage the decarbonisation steering committee established to oversight this project. The role of the reference group would include supporting more visibility of each CRC's work plans, sector challenges and emerging needs, and the development of stronger and more strategic collaborations. This would ultimately aim to support Australia to accelerate its decarbonisation efforts by better leveraging CRCs, and in turn, leveraging the private sector R&D and investment that they unlock.

Key Finding 6 Leveraging the CRCs to achieve more impact

Australia's decarbonisation strategic direction has paved the way for improved decarbonisation policies and programs. This provides a unique opportunity to enhance the work of the CRCs, which are well placed to deliver more rapid progress toward Australia's decarbonisation goals.

However, CRCs face barriers to supporting decarbonisation including the lack of system wide coordination, funding constraints and social license issues.

CRCs perceive that their applications for other government funding sources may not be accepted and considered on merit or may otherwise be 'discounted' given they are already the recipient of government funding. In applying for other Government programs, CRC applications should ideally be considered on their merits, with transparent and equitable funding guidelines and application processes. Any additional funding sourced by the CRCs should pass additionality tests and not duplicate activities already funded by government.

A more coordinated and strategic approach would enable the Australian Government to better leverage the current CRCs network to accelerate progress toward decarbonisation and to potentially fund the CRCs to scale impactful research and existing capabilities. This could be guided by a decarbonisation-specific reference group or CRA.

Economic impact 4

This Chapter outlines the economic impacts of the CRCs and outlines the estimated economy-wide impacts on GDP, GNP, and employment.

4.1 Economic impacts

The CRCs deliver various impacts (see Figure 4.1) including:

— economic impacts: that can be given a measurable and specific asset value captured by economic actors (e.g., changes in gross domestic product or employment)

— research capacity impacts: on the contribution to knowledge, training, and collaboration

— social impacts: on the wellbeing of the wider community (e.g., changes in resilience)

— environmental impacts: on natural systems, including ecosystems, land, air, and water

— cultural impacts: on cultural understanding, preservation, and creativity.

Importantly, it is not always possible to quantify or monetise all these impacts (e.g., impacts on community resilience as a result of a research project would be challenging to quantify and monetise). Qualitative consideration of impacts is important for recognising that those impacts exist and have value.

In this economy-wide analysis, social, environmental (excluding the value of CO_2 abatement which is quantified separately), and cultural impacts associated with research projects funded by the CRCs have not been monetised. As a result, the economic impacts reported in this chapter understate the overall benefits of the CRCs.

The economic impacts measured includes 2 categories:

— Direct impacts of the CRCs (or in collaboration with others), where the benefit may be either as direct benefits or as costs saved (for example, a cheaper production method).

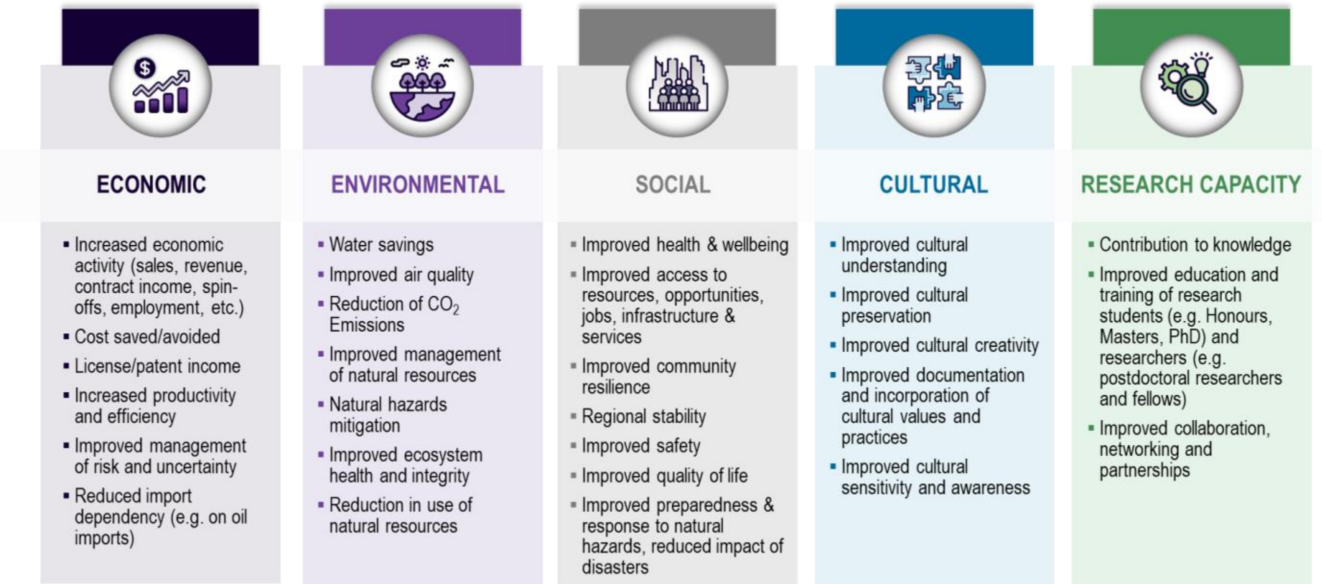
— Economy-wide impacts where the economic benefit is propagated throughout the economy, and the CRC activity stimulates investment, jobs, and further economic growth.

Importantly, the assessment approach and economic impact is viewed solely through a 'CRC perspective' lens. That is, the only costs considered are those related to the conduct of the work of the relevant CRCs (Government grant funds plus partner cash and in kind contributions), while the impact is limited to the CRCs' R&D expenditure plus outcome impacts that can be directly attributed to the work of the CRCs. For the assessed CRCs, only their decarbonisation related funding and impacts are considered.

As such the broader economic impacts generated by industry in adopting the R&D outcomes (which are likely to involve considerable changes in CAPEX and OPEX monetary and employment flows) and moving to a low carbon future, are not captured by the analysis, given these decisions are both uncertain and beyond the reach of the CRCs.

The total economic impacts are reported using the total impact on gross domestic product (GDP), gross national product (GNP) and employment, as well as a cost benefit ratio which compares the impact of the program (such as the impact on GDP) to the amount of government spending.

Figure 4.1 Examples of research project impacts



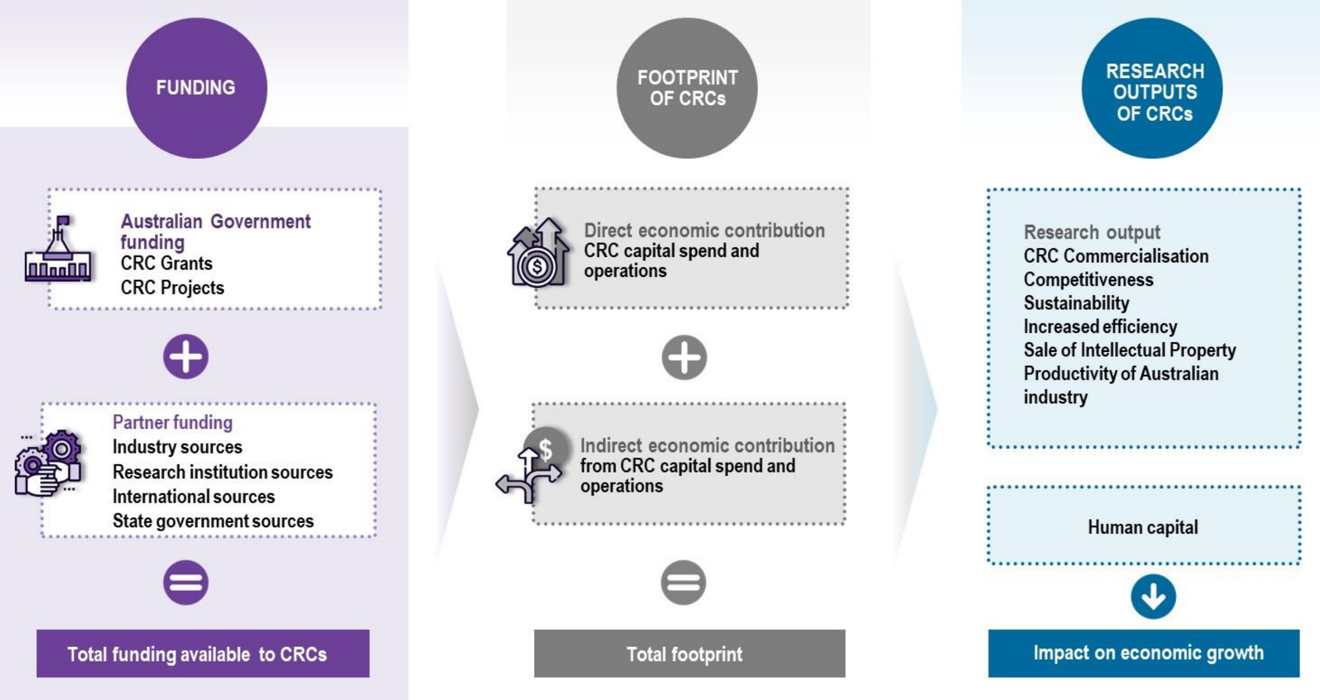
Source: ACIL Allen.

4.2 Analytical framework for economic impact analysis

ACIL Allen has used an analytical framework to assess the impact of CRCs on the Australian economy. This framework is based on previous CRC program evaluations undertaken by ACIL Allen is summarised in Figure 4.2.

This framework shows the main channels through which the CRCs impact the Australian economy. It also provides the context for counterfactual, additionality, and attribution issues in analysing the CRCs' impacts. The total (economy-wide) impacts of the CRCs' impacts were estimated using ACIL Allen's CGE model of the Australian economy, the *Tasman Global* model (detail provided in appendix B).

Figure 4.2 Analytical framework



Source: ACIL Allen.

4.2.1 Key impacts

CRCs receive income from various sources — mainly Australian Government funding, partner contributions, sale of services and IP and consulting income. CRCs spend this income in generating research outputs and attracting researchers who also spend on goods and services. This spending has a direct effect on economic activity, raising demand for goods and services and driving wider economic growth through second (and subsequent) indirect effects.

Goods and services used by the CRCs, as with any other economic activity, contribute to the economy through their day-to-day operations and through their capital expenditure.

ACIL Allen has drawn on data directly from 7 CRCs on 56 economic impacts in the years since 2017. The total economic impacts identified from these 7 CRCs as part of this review totalled $2.6 billion (in nominal terms) for the period from 2017 to 2032.

Specific economic benefits reported by CRCs and included in this analysis comprise:

- benefits derived by partners and the industry sector more broadly through uptake of new products, service and management systems developed by the CRCs
- benefits through the sale of IP, licenses granted, patents sold
- benefits from enhanced skills formation:
  - through the development of highly skilled post-graduates that build a critical mass of skills that either attract private companies to invest or help retain existing business activity levels
  - through the development of highly skilled post-graduates who then work in industry and allow industry to be smart adopters and adapters of CRC generated technology/knowledge
  - through industry and academic researchers interacting and increasing their skills, and hence their future productivity, via this interaction

   – through collaboration across sectors and disciplines encourages researchers to develop an understanding of both research provider and end-user perspectives, maintaining focus on the active planning for and management of pathways to application
- benefits through the increased market value of partner organisations
- benefits through an organisation established to continue the work CRCs
- benefits through the creation of spin-off companies
- benefits through increased revenues from the provision of services and contract income
- benefits of costs saved or avoided.

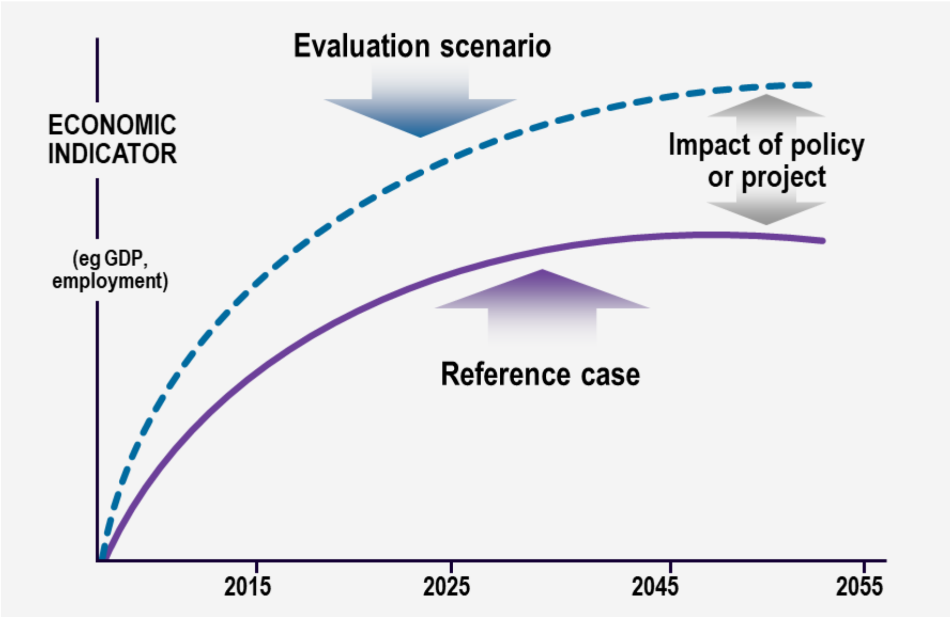
4.3 The model

4.3.1 Tasman Global

Tasman Global is a large-scale, dynamic CGE model of the world economy developed in-house by ACIL Allen and allows for economic analysis to be conducted at the regional, state, national and global levels. CGE models mimic the workings of the economy through a system of interdependent behavioural and accounting equations linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, starting with individual markets, producers and consumers, and building up the system via demand and production from each component. When an economic shock or disturbance is applied to the model, each of the markets adjusts according to the set of behavioural parameters, which are underpinned by economic theory.

In applications of the *Tasman Global* model, a reference case simulation forms a 'business-as-usual' basis with which to compare the results of various simulations (herein referred to as the Base Case). The Base Case provides projections of growth in the absence of the program being analysed (such as GDP, population, labour supply, industry output, etc.) and provides projections of endogenous variables such as productivity changes and consumer preferences. The program case assumes all productivity improvements, tax rates, and consumer preferences change as per the Base Case projections but also includes the program being evaluated (in this case, the CRCs). The 2 scenarios give projections of the economy, and the net impact of the program is then calculated as deviations from the reference case (see Figure 4.3).

Figure 4.3 Illustrative scenario analysis using *Tasman Global*



Note: In reality impacts could be negative, positive, neutral or a mixture.
Source: ACIL Allen.

4.3.2 Simulation design and key inputs used in the economic modelling

The economic modelling conducted in this study estimated the impacts under 2 scenarios: 'with CRCs decarbonisation work' and 'without CRCs decarbonisation work'. Comparison of the 'with CRCs decarbonisation' scenario to the 'without CRCs decarbonisation counterfactual' allows the net economic impact of Australian Government funding for CRCs to be estimated. If the Government had not funded the CRCs decarbonisation work, it is assumed that the associated grant funding would have been allocated across other Government expenditures (potentially having positive impacts elsewhere). This approach is similar to the previous evaluations of the CRC Program.

This report analyses the economic impact of grants awarded (for decarbonisation work) by the CRCs from 2017 to 2032 (i.e., it illustrates the economic impact of the CRCs in Australia over this period). To estimate this impact, the following scenarios were simulated in the *Tasman Global* model:

— *Base Case scenario* 'without CRCs' decarbonisation work' — where it is assumed that the CRCs do no decarbonisation work. This was used as a benchmark with which to compare the results of simulating the with CRC decarbonisation scenario.

— 'with CRCs' decarbonisation work' *scenario* — this scenario refers to a case where the CRCs has been established and grant funding is awarded and directed towards decarbonisation work over the period 2017 to 2032. This scenario includes the decarbonisation funding provided by the government and the co-contributions from different parties.

The key finding from this modelling is that, because of the provision of Australian Government funding for CRCs, over the 2017 to 2032 period, the Australian economy's overall performance has been enhanced when compared to the performance that would have occurred in the absence of funding to the CRCs.

Table 4.1 details the investment made by the 7 CRCs in decarbonisation work. The figures represent both expenditure to date on decarbonisation and future expenditure related to delivering the impacts that have been quantified and feed into the benefits component of the analysis. It does not include future expenditure on decarbonisation projects where it is not yet possible to identify and quantify outcomes with any certainty, nor does it include CRC project expenditure directed to other priority areas (such as enhanced productivity, export opportunities etc).

Table 4.1 CRC expenditure on decarbonisation R&D that has/is realising impact ($ million)

Year	Government funding	Partner cash and in-kind	Total
2017	$-	$-	$-
2018	$-	$-	$-
2019	$1.68m	$5.21m	$6.89m
2020	$6.76m	$13.84m	$20.59m
2021	$13.28m	$24.86m	$38.14m
2022	$13.92m	$52.45m	$66.38m
2023	$13.72m	$64.72m	$78.45m
2024	$9.83m	$42.01m	$51.84m
2025	$6.60m	$34.96m	$41.56m
2026	$4.26m	$14.59m	$18.85m
2027	$3.41m	$8.78m	$12.19m
2028	$2.86m	$6.91m	$9.76m
2029	$1.66m	$2.96m	$4.62m
2030	$2.04m	$2.96m	$5.00m
2031	$2.04m	$2.96m	$5.00m
2032	$0.51m	$2.98m	$3.49m
Total	$82.56m	$280.18m	$362.71m

Source: ACIL Allen based on CRC input.

The 7 CRCs are collectively committed to $617.92 million in R&D decarbonisation expenditure in total over their respective lifetimes. The impacts being assessed are being delivered for $362.71 million – in effect 59% of their intended expenditure.

Furthermore, the decarbonisation expenditure by the 7 CRCs currently expected to realise benefits represents 67% of the expected commitment across all 13 CRCs. A further scaling factor can be applied to represent a proxy of total potential impact of the total work package currently expected to realise benefits across the 13 CRCs. The resulting scaling factors to adjust benefits from the 7 with data to the 13 total CRCs is 1.5 for economic benefit scaling and 1.75 for CO_2 benefit scaling. The difference between the 2 is differences in the size and funding of the CRCs with data in each group. The scaling factors are explored further in section 4.4.

Key shocks

Differences in economic outcomes between the CRC decarbonisation scenario and the Base Case scenario are calculated to determine the economic benefits stemming from the CRCs over their lifetime.

Three sets of shocks were applied to *Tasman Global* in the CRC simulation:

— the direct benefits of the research activity
— the direct benefits of program expenditure
— the improved labour productivity through higher education.

The benefits of CRC-funded research were measured directly using survey data from the CRCs; the direct benefits of program expenditure were estimated within the model using the government funding data together with data collected from CRCs on their monetary and in-kind contributions; and the improved labour productivity was estimated using additional post graduate completions and the expected lifetime increased earnings from higher education.

4.4 Economic impact assessment

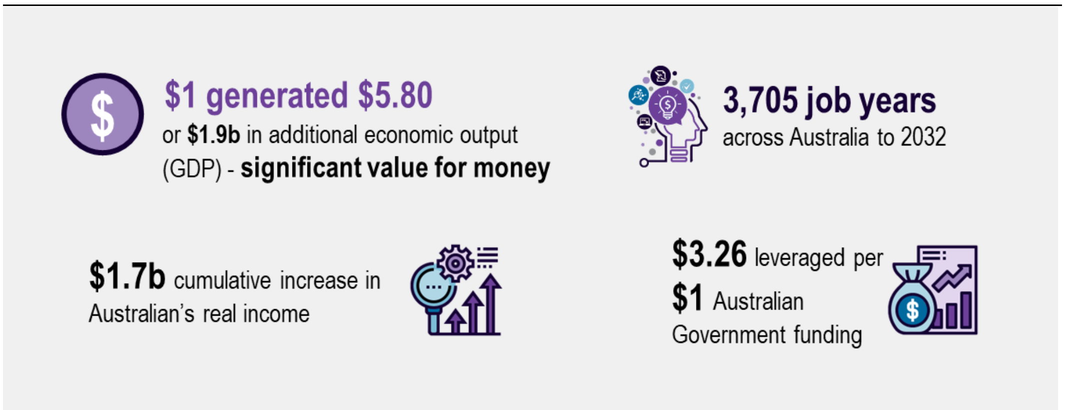
When assessing the impacts of the CRCs activities on the economy, a range of key macroeconomic variables are commonly evaluated (and have been included in other economy-wide studies of research impacts), including the following.[44]

- *GDP* — measures Australia's economic activity (output) and is described as 'economic output'.
- *Real income or GNP* — indicates changes in economic welfare (wellbeing) of the residents of Australia. This indicator measures the ability to purchase goods and services (adjusted by inflation).
- *Employment* — shows how job numbers change across the Australian economy at large.

The sections below discuss the impacts of the CRCs on these key macroeconomic variables for the Australian economy.

All the economic impacts in this section are reported in Australian dollars (in 2023 dollars unless noted) and the net present valuations (NPV) are calculated using a central 7% real discount rate[45] (with sensitivity analysis for a lower 3% rate and higher 10% discount rate presented in tables). Figure 4.4 summaries the key economic outcomes.

Figure 4.4 Modelled economic impacts of the 7 included CRCs



Source: ACIL Allen

[44] Additional explanation about these economic terms is provided in the appendices in Part III.

[45] A 7% real discount rate is based on the Commonwealth Office of Impact Analysis Guidelines on evaluation of projects.

Key Finding 7 Modelled economic impacts of the 7 included CRCs

The 7 CRCs included in the analysis are projected to provide significant benefits to the Australian economy, estimates of the full 13 CRCs by scaling the costs and benefits are expected to include:

— **Generating substantial economic activity**, For grants awarded between 2017 and 2032, it will boost Australia's economic output (GDP) by $4.8 billion over the lifetime of the benefits. The net present value of this impact with a 7% discount rate (NPV7) is $1.9 billion.

— **Raising economic welfare across Australia**. It is projected that the CRC decarbonisation work (for grants awarded 2017-32) will increase the real income of Australians by a cumulative total of $4.3 billion, or $1.7 billion NPV7.

— **Generating significant employment opportunities**. For grants awarded between 2017 and 2032, the CRCs will increase total employment, creating around 3,705 research job years to 2032 or an average of 265 FTE jobs years per year across Australia.

— **Providing significant value for money**. For every dollar of investment and in-kind contributions to CRCs decarbonisation work from 2017-2032, generated $5.80 in additional economic output (GDP, NPV7).

These estimated economic impacts understate the overall benefits of the CRCs as they do not account for the social and environmental impacts associated with research projects funded or future benefits not yet able to be quantified.

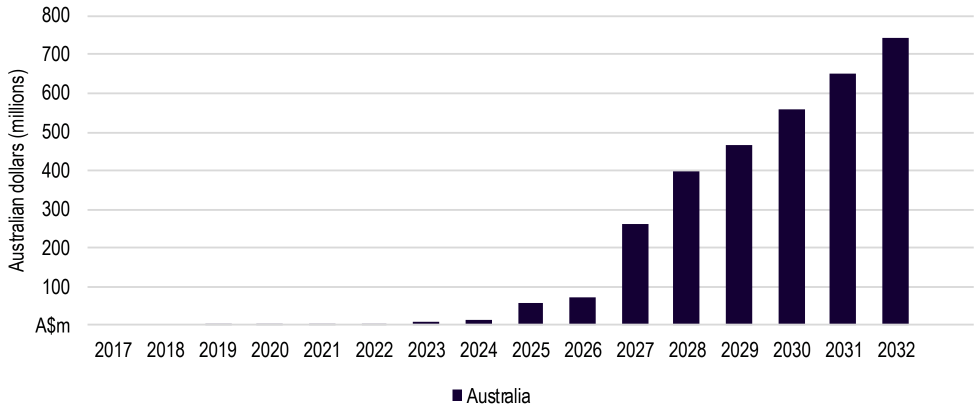
4.4.1 Impact on GDP

Figure 4.5 shows the impact of the CRCs on Australia's real economic output (GDP). This has been measured as the change between actual economic outcomes delivered by the CRCs decarbonisation work compared to the Base Case. Figure 4.5 reflects the economic impacts resulting from CRCs funding and co-contributions for grants awarded between 2017 and 2032. However, if the continuation of CRCs funding were modelled at its current rate into the future, the changes in the economy due to the spending would not decrease, as illustrated in this figure.

As shown in Figure 4.5, the benefits of the CRCs increase over time as the R&D and practical impacts of their work grow and translate into measurable benefits and economic activity through end user adoption. After the initial years of the modelling period, the benefits of the CRCs ramp-up substantially (as these benefits are realised), with the impact on GDP peaking in 2032 at $743 million above that of the Base Case scenario.

Consequentially, GDP begins to increase above that of the Base Case scenario due to the flow of activities and impacts generated by the CRCs. In the long run, the effect of higher productivity in industries is passed on to consumers in the form of lower prices for consumer goods and services, with scarce resources freed up for use elsewhere in the economy, allowing an increase in total production. Lower consumer prices and the increased productive potential of the Australian economy arising from the productivity gains translate into higher real private consumption and higher economic activity.

Figure 4.5 Estimated change in Australian real GDP from 2017–32 associated with CRCs grants awarded between 2017 and 2032 (7 CRCs reporting economic benefits), relative to the Base Case (2023 dollars)



Source: ACIL Allen modelling.

Table 4.2 summarises the estimated change in real economic output because of CRCs decarbonisation work in cumulative and NPV terms. This table also compares the Government investment, and cash and in-kind contributions to the CRCs with the projected increase in economic output. As shown in this table, between 2017 and 2032 CRCs are estimated to increase the real economic output of Australia (i.e., real GDP) by a cumulative total of $3.2 billion relative to the Base Case over the life of the benefits. This is equivalent to a one-off increase of $1.3 billion (in 2023 dollars, using a 7% real discount rate).

The economic modelling also shows that the benefits generated by CRCs are substantially higher than the costs of contributions from the Australian Government and cash and in-kind support between 2017 and 2032.

— CRC investment, that is funding and cash and in-kind contributions, to CRCs between 2017 and 2032 for the 7 included CRCs totalled $365 million in 2023 dollars ($221 million in present value at a 7% discount rate).

— Therefore, it is estimated that for every $1 spent on CRC research investments between 2017 and 2032, GDP is cumulatively $5.80 higher (on a 7% real discounted basis) than it would have been had that $1 instead been allocated to general government expenditure, noting that any return on investment higher than $1 is positive.

Table 4.2 Estimated change in Australian real GDP from 7 CRC reporting economic benefits from 2017–32 associated with CRC grants awarded between 2017 and 2032 (relative to Base Case, 2023 dollars; A$m)

	Annual average	Total (2017-32)	Net Present Value		
			3%	7%	10%
Real GDP	$216m	$3,239m	$2,160m	$1,288m	$889m
CRC decarbonisation R&D investment (including Government funding to the CRCs)	$24m	$365m	$291m	$221m	$182m
Ratio of increase in GDP to funding and contributions	**N/A**	**8.9**	**7.4**	**5.8**	**4.9**

Source: ACIL Allen modelling.

Scaling to all 13 CRCs

Applying the scaling factors detailed in section 4.3.2, the work of all 13 CRCs might deliver a boost to GDP in the order of $4.8 billion or $1.9 billion in PV terms (7% discount rate) (see Table 4.3). This will continue to grow beyond the assessment period as industry continues to deploy the technology options resulting from the R&D in future years post 2032.

Table 4.3 Estimated change in Australian real GDP from all 13 CRCs from 2017–32 associated with CRC grants awarded between 2017 and 2032 (relative to Base Case, 2023 dollars; A$m)

	Total (2017-32)	Net Present Value		
		3%	7%	10%
Real GDP	$4,822m	$3,216m	$1,918m	$1,323m
CRC decarbonisation R&D investment (including Government funding to the CRCs)	$543m	$433m	$329m	$270m
Ratio of increase in GDP to funding and contributions	**8.9**	**7.4**	**5.8**	**4.9**

Source: ACIL Allen modelling.

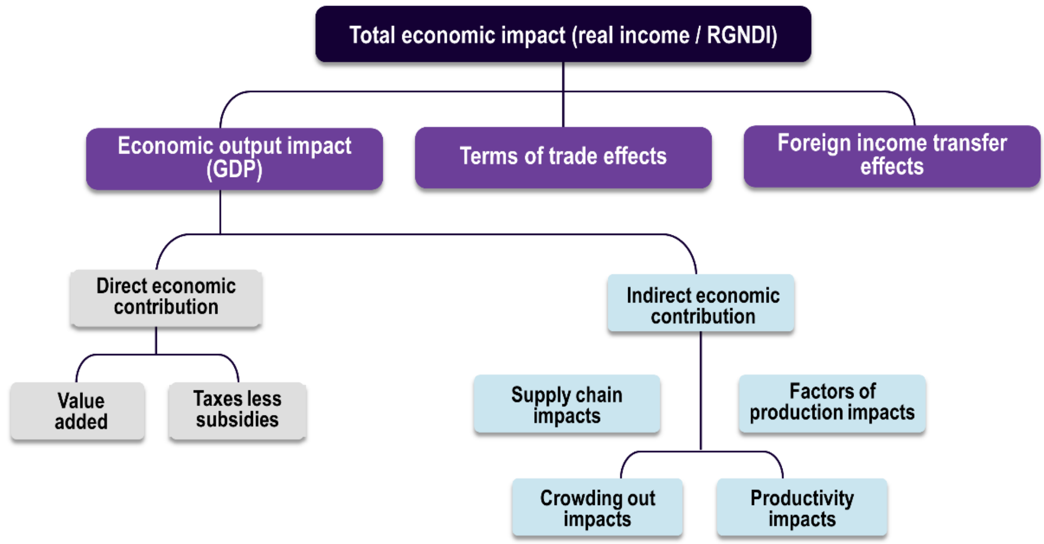
4.4.2 Real income impacts

Measuring the impact of a program using just real economic output (GDP) may disguise investments that are not beneficial in the overall economic welfare sense. This is because it is possible for real economic output to increase (that is, for GDP to rise) while at the same time consumers may be worse off when measured in terms of real income. In such circumstances, people and households would be worse off despite economic growth.

This leads to a preference for considering real income effects. Real income measures the ability to purchase goods and services, adjusted for inflation. A rise in real income indicates a rise in current consumption capacity and an increased ability to accumulate wealth in the form of financial and other assets. The change in real income is equal to the change in real economic output (real GDP) plus the change in international income transfers, plus the change in the nation's terms of trade (which measures the purchasing power of the nation's exports relative to its imports) (see Figure 4.6).

In global CGE models such as *Tasman Global*, the change in real income is equivalent to the change in consumer welfare using the equivalent variation measure of welfare change resulting from exogenous shocks. Hence, it is valid to say that the projected change in real income (from *Tasman Global*) is also the projected change in consumer welfare.

Figure 4.6 Macroeconomic impact of a program or policy



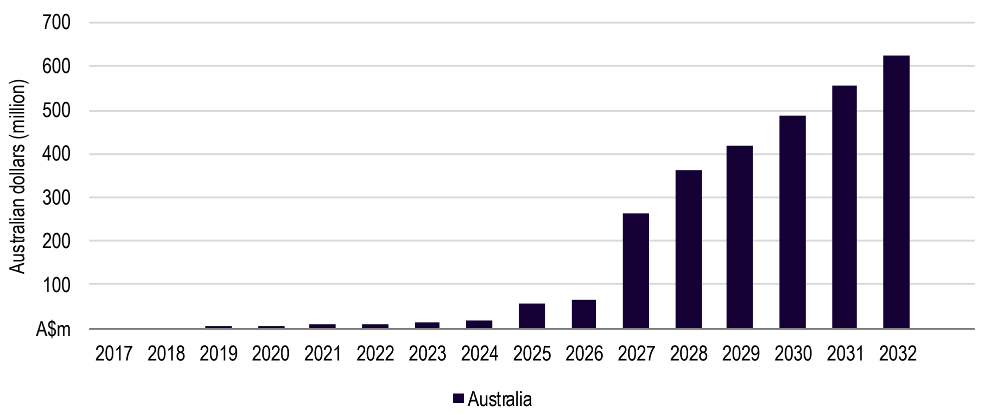
Source: ACIL Allen

The projected changes in real income associated with the CRCs are shown in Figure 4.7 and Table 4.4. Overall, as shown in Figure 4.7, the pattern of changes in income is similar to the pattern of changes in output (with large increases in the short-term due to CRC activity and output), but income gains are slightly lower than the change in economic output.

As shown in Table 4.4, from 2017-2032, the 7 CRCs are projected to increase the real income of Australia as a whole by a cumulative total of $2.9 billion relative to the Base Case. This is equivalent to a one off increase in real income of $1.2 billion (in 2023 dollars, using a 7% real discount rate).

Therefore, it is estimated that for every $1 spent on the CRCs decarbonisation research investments between 2017 and 2032, real income is cumulatively $5.3 higher (on a 7% real discounted basis) than it would have been had that $1 instead been allocated to general government expenditure.

Figure 4.7 Estimated change in Australian real income from 2017–32 associated with CRCs grants awarded between 2017 and 2032 for the 7 CRCs, relative to the Base Case (2023 dollars; A$m)



Source: ACIL Allen modelling.

Table 4.4 Estimated change in Australian real income from 2017–32 associated with CRCs grants awarded between 2017 and 2032 (relative to Base Case, 2023 dollars; A$m)

	Annual average	Total (2017-32)	Net Present Value		
			3%	7%	10%
Real income	$194m	$2,904m	$1,947m	$1,170m	$813m
Funding and cash and in-kind contributions	$24m	$365m	$291m	$221m	$182m
Ratio of increase in real income to funding and contributions	**N/A**	**8.0**	**6.7**	**5.3**	**4.5**

Source: ACIL Allen modelling.

Scaling to all 13 CRCs

Applying the scaling factors detailed in section 4.3.2, the work of all 13 CRCs might deliver a boost to GNI in the order of $4.3 billion or $1.7 billion in PV terms (7% discount rate) (see Table 4.5). This will continue to grow beyond the assessment period as industry continues to deploy the technology options resulting from the R&D in future years post 2032.

Table 4.5 Estimated change in Australian real income from all 13 CRCs from 2017–32 associated with CRC grants awarded between 2017 and 2032 (relative to Base Case, 2023 dollars; A$m)

	Total (2017-32)	Net Present Value		
		3%	7%	10%
Real GNI	$4,322m	$2,898m	$1,742m	$1,210m
CRC decarbonisation R&D investment (including Government funding to the CRCs)	$543m	$433m	$329m	$270m
Ratio of increase in GNI to funding and contributions	**8.0**	**6.7**	**5.3**	**4.5**

Source: ACIL Allen modelling.

4.4.3 Estimated employment impacts

Employment is closely linked with economic activity and investment: as demand for a firm's goods increases, it can expand its operations and increase levels of capital and, in turn, requirements for labour change. Hence, changes in employment mirror changes in economic output.

A key issue when estimating the impact of a program is determining how the labour market will clear.[46] Increases in the demand for labour from the productivity gains enabled by CRCs can be met by 3 mechanisms: increasing migration; increasing participation rates and/or average hours worked; and reducing the unemployment rate. In the model framework, the first 2 mechanisms are driven by changes in the real wages paid to workers while the third is a function of the additional labour demand relative to the Base Case. Given the moderate unemployment rate assumed

[46] As with other CGE models, the standard assumption within *Tasman Global* is that all markets clear (i.e., demand equals supply) at the start and end of each time period, including the labour market. CGE models place explicit limits on the availability of factors and the nature of the constraints can greatly change the magnitude and nature of the results. In contrast, most other tools used to assess economic impacts, including I-O multiplier analysis, do not place constraints on the availability of factors. Consequently, non-CGE methods tend to overestimate the impacts of a project or policy.

throughout the projection period, changes in the real wage rate accounts for the majority of the additional labour supply in the CRC scenario relative to the Base Case.

It should be noted that this analysis does not assume any changes in net foreign migration because of the productivity benefits generated by the CRCs.[47]

4.4.4 Employment creation

The economic modelling projects that the productivity benefits generated by CRCs will result in a net increase in research-related jobs across Australia. These jobs are produced as a direct result of the CRCs.

From 2017 to 2032, it is projected that 2,489 employee years[48] of full-time equivalent employment (FTE) direct and indirect jobs will be created from the 7 included CRCs in Australia under the CRC scenario (equivalent to an annual average of 166 FTE job years a year, see Table 4.6).

This analysis measures the marginal impact of the CRCs on jobs. This considers a largely fixed number of workers who need to do more work or move jobs to increase employment numbers. This does not account for the broader impacts that the CRCs have within their respective industries, nor measure the economic "footprint" of an industry, which estimates the number of workers that are employed in an industry, without accounting for the loss of jobs in other industries.

Table 4.6 Estimated change in Australian employment from 2017–2032 associated with CRC research investments of the 7 CRCs from 2017 to 2032 (relative to the Base Case)

	Annual average	Total (2017-32)
	FTE	Employee years
Australia	166	2,489

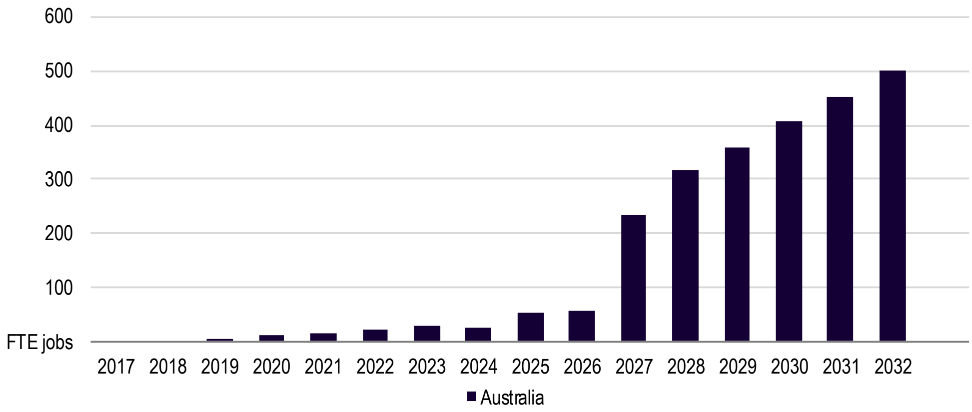
Source: ACIL Allen modelling.

Figure 4.8 illustrates the profile of total additional employment in Australia under the CRCs scenario. As shown in this figure, employment associated with CRC grants awarded between 2017 and 2032 is projected to peak in 2032 at around 500 FTE jobs. The pattern of changes in employment is similar to the pattern of changes in output and income, with large increases in the short-term due to CRC activity and output. The large increase in employment from 2026 to 2027 reflects the data provided by the CRCs, and the CRCs' expectation that there will be a large increase in the CRCs' employment resulting from a strong expected increase in economic impact between those years. This also reflects estimates from several CRCs that are in the early stages of their life cycle that they will have matured further by this stage and will be producing economic impacts from 2027-onwards.

[47] The underlying logic for this assumption is that the CRCs do not have any significant effect on the Australian Government's immigration policy.

[48] An employee year is employment of one full time equivalent (FTE) person for one year or one 0.5 FTE person for 2 years.

Figure 4.8 Projected change in total (direct and indirect) employment from 2017–32 associated with CRC research investments of the 7 CRCs made from 2017 and 2032 (relative to the Base Case, FTE jobs)



Source: ACIL Allen modelling.

These employment impacts only capture those outcomes directly attributable to the CRC R&D efforts (including their support for students in their graduate and post graduate programs). They are also limited to the assessment period. In reality the R&D and graduate/post graduate programs will deliver benefits over the entire working life (and potentially beyond) of the students, well into the 2060's.

CRCs are a net job creator. CRCs are well recognised for their economy-wide and cross-sector impacts and their ability to stimulate investment in jobs and further economic growth. The industry transformation that will potentially result from implementation and wide-scale deployment of decarbonisation-related R&D will generate employment opportunities of a much higher scale. For instance, HILT CRC estimates that adoption of its R&D technologies could generate 92,000 new industry jobs, while a 2023 FBI CRC report highlights how Australia's battery industry opportunity could provide 61,400 new local jobs by 2030.[49]

Scaling to all 13 CRCs

Applying the scaling factors detailed in section 4.3.2, as shown in Table 4.7, the work of all 13 CRCs might deliver a boost to employment of 3,705 researcher employment years from 2017 to 2032.

Table 4.7 Estimated change in Australian employment from 2017–2032 associated with CRC research investments of all CRCs from 2017 to 2032 (relative to the Base Case)

	Annual average	Total (2017-32)
	FTE	Employee years
Australia	247	3,705

Source: ACIL Allen modelling.

4.5 Valuing CO_2 abatement

The above economic impacts do not include consideration of the value associated with a reduction in GHG emissions that can be attributed to the work of the CRCs (as set out in chapter 2). A

[49] Future Battery Industries CRC (23030. *$16.9 billion opportunity awaits.* Accessed January 2024: https://fbicrc.com.au/16-9-billion-opportunity awaits/#:~:text=The%20report%20builds%20on%20important,created%20by%20the%20battery%20industry.

number of approaches can be taken to derive a cost of carbon arising from reduced CO_2 emissions; for instance, through quantifying the reduction in health costs due to lower emissions; the value of carbon abated as indicated by national and international trading schemes; carbon tax values; the cost of purchasing equivalent offsets etc.

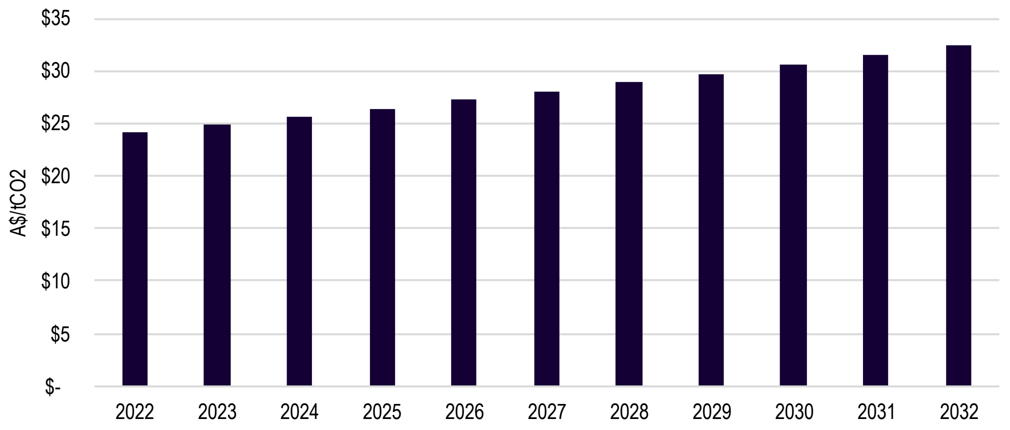
In the absence of a tangible price of GHG emissions, the cost of carbon has been derived based on two Australian pricing mechanisms.

— the latest Emission Reduction Fund (ERF) auction round was held in March 2023. The average auction price for this round was $17.12 per tonne of carbon abatement (with 7.9 million tonnes of carbon abatement contracted for optional delivery).[50] Over the 15 auctions that have taken place since April 2015, the price has ranged from a low of $10.23 to a high of $17.35, with prices over the last 6 auctions since 2020 ranging from $15.74 to $17.35.

— Australian carbon credit units (ACCUs) are traded on the spot market under the auspice of the Government's Clean Energy Regulator. The ACCU Generic Spot Price -at market close on 21 December was 2023 was A$32.75 per tonne.[51]

The average of these two prices, $24.94, is taken as a reasonable start point. It is assumed that the cost of carbon will follow a price path starting at $24.94/t$CO_2$ in 2023 rising by 3% a year in real terms (see Figure 4.9).

Figure 4.9 Assumed cost of carbon, 2024 to 2032 (real 2023 terms)



Source: ACIL Allen

4.5.1 Assessing the economic impact of abatement

In common with the assessment of economic impacts (section 4.4), only those CO_2 abatement outcomes which are tangible are considered over the assessment period. As outlined in section 2.3.8, 7 CRCs reported CO_2 abatement outcomes totalling 62.81 Mt over the period.

Table 4.8 details the quantum of abatement and expenditure required to realise that abatement by the 7 CRCs that reported CO_2 abatement outcomes.

50 From https://www.cleanenergyregulator.gov.au/Infohub/Markets/Pages/qcmr/march-quarter-2023/Australian-Carbon-Credit-Units.aspx

51 https://coremarkets.co/resources/market-prices (accessed 22 December 2023)

Table 4.8 CRC abatement outcomes and expenditure on decarbonisation for the 7 CRCs able to quantify emissions

	CO_2 abated (Mt)	R&D expenditure ($m)
2019	-	$6.89m
2020	-	$19.67m
2021	-	$33.09m
2022	0.11	$53.59m
2023	0.17	$68.76m
2024	0.23	$44.41m
2025	0.47	$24.19m
2026	5.29	$18.83m
2027	6.89	$12.19m
2028	8.56	$9.76m
2029	9.13	$4.62m
2030	9.94	$5.00m
2031	10.46	$5.00m
2032	11.56	$3.49m
Total	**62.81**	**$309.48m**

Note: Only 5 of these 7 are included in the earlier economic analysis (that is 2 of the 7 CRCs included in the economic analysis could not point to tangible CO_2 abatement at this time).

Source: ACIL Allen based on CRC input

In valuing the abatement efforts of the CRCs, both the total reported emissions reductions have been considered along with those related to the sub-set of CRCs included in the earlier economic analysis. The latter ensures consistency across the two economic valuations, that is the assessment of the economic impact of abatement is limited to the same cohort of 7 CRCs that formed the basis of the broader economic analysis.

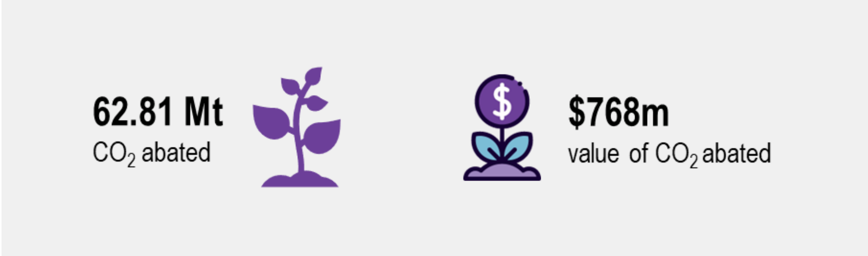
The net benefits of avoided emissions are summarised in Table 4.9 and Figure 4.10, and are estimated to have a cumulative undiscounted benefit of $1.8 billion, with an NPV7 of $768 million.

Table 4.9 Estimated change in CO_2 abatement value from 2017–32 associated with 7 CRCs grants awarded between 2017 and 2032 (relative to the Base Case, 2023 A$m)

	Total (2017-32)	Net Present Value		
		3%	7%	10%
Value of CO_2 abatement	$1,894m	$1,274m	$768m	$534m
Funding and cash and in-kind contributions	$312m	$250m	$188m	$155m
Ratio of increase in value of CO_2 abatement to funding and contributions	**6.1**	**5.1**	**4.1**	**3.4**

Source: ACIL Allen modelling.

Figure 4.10 Modelled CO_2 abatement impacts of the 7 included CRCs



Source: ACIL Allen

Scaling to all 13 CRCs

Applying the scaling factors detailed in section 4.3.2, the work of all 13 CRCs is expected to contribute to CO_2 abatement valuing $3.3 billion or $1.3 billion in PV terms (7% discount rate) (see Table 4.10).

Table 4.10 Estimated CO_2 abatement value from all 13 CRCs from 2017–32 associated with CRC grants awarded between 2017 and 2032 (relative to Base Case, 2023 A$m)

	Total (2017-32)	Net Present Value		
		3%	7%	10%
Value of CO_2 abatement	$3,307m	$2,224m	$1,341m	$932m
CRC decarbonisation R&D investment (including Government funding to the CRCs)	$543m	$433m	$329m	$271m
Ratio of increase in value of CO_2 abatement to funding and contributions	**6.1**	**5.1**	**4.1**	**3.4**

Source: ACIL Allen modelling.

4.6 Overall economic impact

The estimated value of CO_2 abatement for the 13 CRCs has a NPV of $1.3 billion, with impact on GDP totalling $1.9 billion, resulting in a total benefit of $3.3 billion in NPV. When compared to the estimated costs of delivering this value there is an expected $9.9 per dollar invested.

Table 4.11 Estimated GDP and CO_2 abatement value from all 13 CRCs from 2017–32 associated with CRC grants awarded between 2017 and 2032 (relative to Base Case, 2023 A$m)

	Total (2017-32)	Net Present Value		
		3%	7%	10%
Real GDP	$4,822m	$3,216m	$1,918m	$1,323m
Value of CO_2 abatement	$3,307m	$2,224m	$1,341m	$932m
Total benefits	$8,129m	$5,440m	$3,259m	$2,256m
CRC decarbonisation R&D investment (including Government funding to the CRCs)	$543m	$433m	$329m	$270m
Ratio of increase in GDP to funding and contributions	**15.0**	**12.6**	**9.9**	**8.3**

Source: ACIL Allen modelling.

Conclusions 5

This chapter presents the key findings and future opportunities.

5.1 Key findings

The CRCs have a track record in designing and delivering high-impact collaborative programs focused on their specific areas of expertise. They deliver a broad range of decarbonisation-related activities in line with Australia's suite of decarbonisation policies and strategies. The CRCs' focus on decarbonisation varies depending on their core objectives and partner priorities, and these have evolved over time to focus more on decarbonisation.

There is now an opportunity to extract additional benefits from the CRCs to accelerate progress towards Australia's decarbonisation goals and support long-term prosperity and sustainability.

To date, the CRCs participating in this study have delivered new decarbonisation-related products and services, enhanced Australia's export opportunities, informed policy/decision-making, and contributed to improved education and capacity building through training of 977 students. They have raised awareness across research, industry, and government about the need to decarbonise, and supported stronger collaboration, information sharing, and adoption of the CRCs' outputs across the sectors.

These impacts will only increase as the CRCs mature, their work plans are completed, and end users continue to adopt the new products, services, insights, and advice.

The CRCs have an extensive and complex network of industry, government, research and not-for-profit partners and project participants. These partners have a broad national and international reach and contribute to, enhance, and embed the CRCs' decarbonisation efforts. With additional resourcing the CRCs could expand and leverage these partnerships and the collective expertise, resources, and influence they represent to deliver further decarbonisation outcomes and impact. The CRCs are flexible and responsive, which enables them to evolve priorities and partnerships over time to ensure that they are at the forefront of innovation. This is central to Australia meeting its decarbonisation goals.

Economic analysis of the decarbonisation impacts currently being realised by the CRCs indicates (when scaled to include all 13 CRCs) that:

— $1.12 billion or 49%of the CRC's collective funding is focused on decarbonisation

— $5.80 is generated in additional economic output (GDP) for every dollar of investment and in-kind contributions to CRCs decarbonisation work over 2017-2032

— an increase of $4.8 billion in Australia's economic output (GDP) is generated

— an increase of $1.7 billion in the cumulative real income for Australians is generated

— 3,705 job years to 2032 are delivered (an average of 265 FTE jobs years per year)

Further, 7 of the CRCs assessed have quantified anticipated GHG emissions reductions totalling around 62.8 Mt by 2032, which can be directly attributed to their R&D efforts. The net benefits of avoided emissions are estimated to have a cumulative undiscounted benefit of $1.8 billion, with a net present value of $768 million (7% discount rate). When scaled across the 13 CRCs, the expected CO_2 abatement is valued at $3.3 billion or $1.3 billion in net present value terms (7% discount rate). These abatement outcomes are merely the tip of the iceberg in terms of what may be realised as industry continues to adopt the work of the CRCs over time. The 2032 single year abatement figure of 11.6 Mt CO_2 (over 18% of the total 16 year assessment period total) indicates how rapidly the abatement is expected to increase in subsequent years.

5.2 Future opportunities

Realising the full potential that the CRCs can offer in pursuing the nation's decarbonisation goals and net zero targets can be attained through a number of opportunities. Action by Government and the CRCs would support the CRCs to operate more effectively and deliver more impact toward Australia's decarbonisation goals as outlined below.

7. CRCs have the potential to further enhance their collaboration with government, industry, and other CRCs (e.g., through secondments) to support greater information transfer, leverage CRCs' expertise, and drive the expanded adoption of CRC outputs. Enhanced collaboration will create cross-sectoral and industry opportunities and ensure that the CRCs are addressing areas of most need.
8. There would be value in the Government exploring incentive structures to encourage increased collaboration on shared initiatives, to extract greater value from the CRC program. This could include recognising collaboration as a positive in reporting, providing funding that is accessible only where a project is undertaken by 2 or more CRCs, ensuring contracting models do not constrain activity, aligning milestones and reporting with project investment timelines, and supporting CRC responses to changes in the external environment. The CRCs require greater clarity on the CRC-CRC collaboration limitations (funding and contractual) to enable them to collectively expand strategic planning and develop more effective alliances.
9. CRCs are long-term entities and so would benefit from increased flexibility to refresh their priorities as Australia's decarbonisation sector matures, new demands and opportunities emerge, and the needs of partners evolve. The CRCs should account for these changes by embedding:
   a) funding flexibility, with a proportion of funds held in reserve for emerging opportunities and flexible funding agreements with partners so that funding is not 'locked in' at the start of the CRC
   b) program flexibility, with changes allowed to program delivery and priorities
   c) governance arrangements that support funding and program flexibility.
10. Providing CRCs with access to/eligibility for additional funding opportunities (to enable scaling, collaboration, and development of a critical mass of decarbonisation-related efforts) would better leverage the CRCs' capacity, expertise, and flexibility to drive change and enhance progress toward the national goals. The CRCs require greater clarity as to their eligibility for other Australian Government funding programs. This should seek to create transparency and ensure equity in the application processes, so that CRCs can support more capital-intensive activities such as a pilot or demonstration projects, where projects are not already funded under the CRC.
11. The CRCs contribute substantial value to the Australian economy and people. There is an opportunity to create a pathway for more strategic coordination and planning to identify opportunities and pursue new/expanded research topics or collaborative projects across the

CRC network as they emerge. This could be guided through a decarbonisation-specific reference group or Cooperative Research Australia (CRA). This would allow the Government to better leverage the existing capability and capacity within CRCs, as well as their networks, to accelerate decarbonisation and support Australia to reach its net zero goals. A flexible approach would be required so that the CRCs can evolve over time to leverage emerging decarbonisation opportunities.

12. The work of the CRCs typically aligns with more than one Australian Government portfolio, which makes it challenging to communicate the capacity and capability of each CRC and their potential for leverage by the Australian Government. There is a role for coordinated activity led by the Department of Industry, Science and Resources, together with CRA and the CRCs, to ensure that the work of the CRCs is communicated more broadly across the Australian Government, and that CRCs' capacity is further leveraged to deliver more value. This should focus on growing the brand of individual CRCs and the collective CRC network in delivering decarbonisation outcomes for Australia.

Appendices

Terms of reference A

The terms of reference for the project are to:

- Identify the CRC cohort's work that is relevant to Australia's decarbonisation priorities and its contribution to Australia's capacity in meeting its national targets. It showcases the collective capability and capacity offered by the CRCs and the value it has and will continue to deliver in the innovation ecosystem. It also highlights the diversity of the CRC program, and the distributed nature of the program delivery through and across the CRCs.
- Identify areas of synergy and alignment within the CRC and post-CRC cohort with respect to these priorities, including the broad network of sectoral representatives encompassed by the CRCs.
- Quantify (to the extent possible) the current and potential impact the CRC and post-CRC cohort can have on Australia's decarbonisation outcomes.
- Identify opportunities for how the CRC model may be used to deliver complementary innovation programs.
- Identify options, including funding and regulatory, to accelerate and amplify decarbonisation outcomes that the CRC and post-CRC cohort can contribute to as part of the broader innovation system.

Tasman Global B

Tasman Global is a dynamic, global CGE model that has been developed by ACIL Allen for the purpose of undertaking economic impact analysis at the regional, state, national and global level.

A CGE model captures the interlinkages between the markets of all commodities and factors, taking into account resource constraints, to find a simultaneous equilibrium in all markets. A global CGE model extends this interdependence of the markets across world regions and finds simultaneous equilibrium globally. A dynamic model adds onto this the interconnection of equilibrium economies across time periods. For example, investments made today are going to determine the capital stocks of tomorrow and hence future equilibrium outcomes depend on today's equilibrium outcome, and so on.

A dynamic global CGE model, such as *Tasman Global*, has the capability of addressing total, sectoral, spatial and temporal efficiency of resource allocation as it connects markets globally and over time. Being a recursively dynamic model, however, its ability to address temporal issues is limited. In particular, *Tasman Global* cannot typically address issues requiring partial or perfect foresight. However, as documented in Jakeman et al (2001), it is possible to introduce partial or perfect foresight in certain markets using algorithmic approaches.[52] Notwithstanding this, the model does have the capability to project the economic impacts over time of given changes in policies, tastes and technologies in any region of the world economy on all sectors and agents of all regions of the world economy.

Tasman Global was developed from the 2001 version of the Global Trade and Environment Model (GTEM) developed by ABARE (Pant 2007)[53] and has been evolving ever since. In turn, GTEM was developed out of the MEGABARE model,[54] which contained significant advancements over the Global Trade Analysis Project (GTAP) model of that time.[55]

B.1 A dynamic model

Tasman Global is a model that estimates relationships between variables at different points in time. This is in contrast to comparative static models, which compare 2 equilibriums (one before an economic disturbance and one following). A dynamic model such as *Tasman Global* is beneficial

[52] Jakeman, G., Heyhoe, E., Pant, H., Woffenden, K. and Fisher, B.S. (2001). *The Kyoto Protocol: economic impacts under the terms of the Bonn agreement*. ABARE paper presented to the International Petroleum Industry Environmental Conservation Association conference, 'Long Term Carbon and Energy Management - Issues and Approaches', Cambridge, Massachusetts, 15-16 October.

[53] Pant, H.M. (2007), *GTEM: Global Trade and Environment Model*, ABARE Technical Report, Canberra, June.

[54] Hanslow, K. & Hinchy, M. (1996). *The MEGABARE model: interim documentation*. Canberra: ABARE.

[55] Hertel, T. (1997). *Global Trade Analysis: modelling and applications.* Cambridge University Press, Cambridge.

when analysing issues for which both the timing of and the adjustment path that economies follow are relevant in the analysis.

B.2 The database

A key advantage of *Tasman Global* is the level of detail in the database underpinning the model. The database is derived from the GTAP database.[56] This database is a fully documented, publicly available global data base which contains complete bilateral trade information, transport and protection linkages among regions for all GTAP commodities. It is the most detailed database of its type in the world.

Tasman Global builds on the GTAP database by adding the following important features:

— a detailed population and labour market database

— detailed technology representation within key industries (such as electricity generation and iron and steel production)

— disaggregation of a range of major commodities including iron ore, bauxite, alumina, primary aluminium, brown coal, black coal and LNG

— the ability to repatriate labour and capital income

— explicit representation of the states and territories of Australia

— the capacity to represent multiple regions within states and territories of Australia explicitly.

Nominally, version 10.1 of the *Tasman Global* database divides the world economy into 153 regions (145 international regions plus the 8 states and territories of Australia) although in reality the regions are frequently disaggregated further. ACIL Allen regularly models Australian or international projects or policies at the regional level including at the or at the state/territory/provincial level for various countries.

The *Tasman Global* database also contains a wealth of sectoral detail currently identifying up to 76 industries (Table C1). The foundation of this information is the input-output tables that underpin the database. The input-output tables account for the distribution of industry production to satisfy industry and final demands.

Industry demands, so-called intermediate usage, are the demands from each industry for inputs. For example, electricity is an input into the production of communications. In other words, the communications industry uses electricity as an intermediate input.

Final demands are those made by households, governments, investors and foreigners (export demand). These final demands, as the name suggests, represent the demand for finished goods and services. To continue the example, electricity is used by households – their consumption of electricity is a final demand.

Each sector in the economy is typically assumed to produce one commodity, although in *Tasman Global*, the electricity, transport and iron and steel sectors are modelled using a 'technology bundle' approach. With this approach, different known production methods are used to generate a homogeneous output for the 'technology bundle' industry. For example, electricity can be generated using brown coal, black coal, petroleum, base load gas, peak load gas, nuclear, hydro, geothermal, biomass, wind, solar or other renewable based technologies – each of which has its own cost structure.

[56] Aguiar, A., Chepeliev, M., Corong, E., McDougall, R., & van der Mensbrugghe, D. (2019). The GTAP Data Base: Version 10. *Journal of Global Economic Analysis*, 4(1), 1-27. Retrieved from https://www.jgea.org/ojs/index.php/jgea/article/view/77.

The other key feature of the database is that the cost structure of each industry is also represented in detail. Each industry purchases intermediate inputs (from domestic and imported sources) primary factors (labour, capital, land and natural resources) as well as paying taxes or receiving subsidies.

Table B.1 Standard sectors in the *Tasman Global* CGE model

no	Name	no	Name
1	Paddy rice	**39**	Diesel (incl. nonconventional diesel)
2	Wheat	**40**	Other petroleum, coal products
3	Cereal grains nec	**41**	Chemical, rubber, plastic products
4	Vegetables, fruit, nuts	**42**	Iron ore
5	Oil seeds	**43**	Bauxite
6	Sugar cane, sugar beet	**44**	Mineral products nec
7	Plant- based fibres	**45**	Ferrous metals
8	Crops nec	**46**	Alumina
9	Bovine cattle, sheep, goats, horses	**47**	Primary aluminium
10	Pigs	**48**	Metals nec
11	Animal products nec	**49**	Metal products
12	Raw milk	**50**	Motor vehicle and parts
13	Wool, silk worm cocoons	**51**	Transport equipment nec
14	Forestry	**52**	Electronic equipment
15	Fishing	**53**	Machinery and equipment nec
16	Brown coal	**54**	Manufactures nec
17	Black coal	**55**	Electricity generation
18	Oil	**56**	Electricity transmission and distribution
19	LNG	**57**	Gas manufacture, distribution
20	Other natural gas	**58**	Water
21	Minerals nec	**59**	Construction
22	Bovine meat products	**60**	Trade
23	Pig meat products	**61**	Road transport
24	Meat products nec	**62**	Rail and pipeline transport
25	Vegetables oils and fats	**63**	Water transport
26	Dairy products	**64**	Air transport
27	Processed rice	**65**	Transport nec
28	Sugar	**66**	Warehousing and support activities
29	Food products nec	**67**	Hydrogen, renewable gasses
30	Wine	**68**	Communication
31	Beer	**69**	Financial services nec
32	Spirits and RTDs	**70**	Insurance
33	Other beverages and tobacco products	**71**	Business services nec
34	Textiles	**72**	Recreational and other services
35	Wearing apparel	**73**	Public Administration and Defence
36	Leather products	**74**	Education
37	Wood products	**75**	Human health and social work activities
38	Paper products, publishing	**76**	Dwellings

Note: nec = not elsewhere classified.

Source: ACIL Allen

B.3 Model structure

Given its heritage, the structure of the *Tasman Global* model closely follows that of the GTAP and GTEM models and interested readers are encouraged to refer to the documentation of these models for more detail.[57] In summary:

- The model divides the world into a variety of regions and international waters.
  - Each region is fully represented with its own 'bottom-up' social accounting matrix and could be a local community, an LGA, state, country or a group of countries. The number of regions in a given simulation depends on the database aggregation. Each region consists of households, a government with a tax system, production sectors, investors, traders and finance brokers.
  - 'International waters' are a hypothetical region in which global traders operate and use international shipping services to ship goods from one region to the other. It also houses an international finance 'clearing house' that pools global savings and allocates the fund to investors located in every region.
  - Each region has a 'regional household'[58] that collects all factor payments, taxes, net foreign borrowings, net repatriation of factor incomes due to foreign ownership and any net income from trading of emission permits.
- The income of the regional household is allocated across private consumption, government consumption and savings according to a Cobb-Douglas utility function, which, in practice, means that the share of income going to each component is assumed to remain constant in nominal terms.
- Private consumption of each commodity is determined by maximising utility subject to a Constant Difference of Elasticities (CDE) function which includes both price and income elasticities.
- Government consumption of each commodity is determined by maximising utility subject to a Cobb-Douglas utility function.
- Each region has *n* production sectors, each producing single products using various production functions where they aim to maximise profits (or minimise costs) and take all prices as given. The nature of the production functions chosen in the model means that producers exhibit constant returns to scale.
  - In general, each producer supplies consumption goods by combining an aggregate energy-primary factor bundle with other intermediate inputs and according to a Leontief production function (which in practice means that the quantity shares remain in fixed proportions). Within the aggregate energy-primary factor bundle, the individual energy commodities and primary factors are combined using a nested Constant Elasticity of Substitution (CES) production function, in which energy and primary factor aggregates substitute according to a CES function with the individual energy commodities and individual primary factors substituting with their respective aggregates according to further CES production functions.
  - Exceptions to the above include the electricity generation, iron and steel and road transport sectors. These sectors employ the 'technology bundle' approach developed by ABARE[59] in which non-homogenous technologies are employed to produce a homogenous output with the choice of technology governed by minimising costs according to a modified Constant Ratios of Elasticities of Substitution, Homothetic (CRESH) production function. For example, electricity may be generated from a variety of

[57] Namely Hertel, T. (1997). Op. cit. and Pant, H.M. (2007). Op. cit., respectively.

[58] The term "regional household" was devised for the GTAP model. In essence it is an agent that aggregates all incomes attributable to the residents of a given region before distributing the funds to the various types of regional consumption (including savings).

[59] Hanslow, K. & Hinchy, M. (1996). Op. cit.

technologies (including brown coal, black coal, gas, nuclear, hydro, solar etc.), iron and steel may be produced from blast furnace or electric arc technologies while road transport services may be supplied using a range of different vehicle technologies. The 'modified-CRESH' function differs from the traditional CRESH function by also imposing the condition that the quantity units are homogenous.

— There are 4 primary factors (land, labour, mobile capital and fixed capital). While labour and mobile capital are used by all production sectors, land is only used by agricultural sectors while fixed capital is typically employed in industries with natural resources (such as fishing, forestry and mining) or in selected industries built by ACIL Allen.
  - Land supply in each region is typically assumed to remain fixed through time with the allocation of land between sectors occurring to maximise returns subject to a Constant Elasticity of Transformation (CET) utility function.
  - Mobile capital accumulates as a result of net investment. It is implicitly assumed in *Tasman Global* that it takes one year for capital to be installed. Hence, supply of capital in the current period depends on the last year's capital stock and investments made during the previous year.
  - Labour supply in each year is determined by endogenous changes in population, given participation rates and a given unemployment rate. In policy scenarios, the supply of labour is positively influenced by movements in the real wage rate governed by the elasticity of supply. For countries where sub-regions have been specified (such as Australia), migration between regions is induced by changes in relative real wages with the constraint that net interregional migration equals zero. For regions where the labour market has been disaggregated to include occupations, there is limited substitution allowed between occupations by individuals supplying labour (according to a CET utility function) and by firms demanding labour (according to a CES production function) based on movements in relative real wages.
  - The supply of fixed capital is given for each sector in each region.

  The model has the option for these assumptions to be changed at the time of model application if alternative factor supply behaviours are considered more relevant.

— It is assumed that labour (by occupation) and mobile capital are fully mobile across production sectors implying that, in equilibrium, wage rates (by occupation) and rental rates on capital are equalised across all sectors within each region. To a lesser extent, labour and capital are mobile between regions through international financial investment and migration, but this sort of mobility is sluggish and does not equalise rates of return across regions.

— For most international regions, for each consumer (private, government, industries and the local investment sector), consumption goods can be sourced either from domestic or imported sources. In any country that has disaggregated regions (such as Australia), consumption goods can also be sourced from other intrastate or interstate regions. In all cases, the source of non-domestically produced consumption goods is determined by minimising costs subject to a CRESH utility function. Like most other CGE models, a CES demand function is used to model the relative demand for domestically produced commodities versus non-domestically produced commodities. The elasticities chosen for the CES and CRESH demand functions mean that consumers in each region have a higher preference for domestically produced commodities than non-domestic commodities and a higher preference for intrastate- or interstate-produced commodities than foreign commodities.

— The capital account in *Tasman Global* is open. Domestic savers in each region purchase 'bonds' in the global financial market through local 'brokers' while investors in each region sell bonds to the global financial market to raise investible funds. A flexible global interest rate clears the global financial market.

— It is assumed that regions may differ in their risk characteristics and policy configurations. As a result, rates of return on money invested in physical capital may differ between regions and therefore may be different from the global cost of funds. Any difference between the local rates of return on capital and the global cost of borrowing is treated as the result of the existence of a risk premium and policy imperfections in the international capital market. It is maintained that the equilibrium allocation of investment requires the equalisation of changes in (as opposed to the absolute levels of) rates of return over the base year rates of return.

— Any excess of investment over domestic savings in a given region causes an increase in the net debt of that region. It is assumed that debtors service the debt at the interest rate that clears the global financial market. Similarly, regions that are net savers gives rise to interest receipts from the global financial market at the same interest rate.

— Investment in each region is used by the regional investor to purchase a suite of intermediate goods according to a Leontief production function to construct capital stock with the regional investor cost minimising by choosing between domestic, interstate and imported sources of each intermediate good via the CRESH production function. The regional cost of creating new capital stock versus the local rates of return on mobile capital is what determines the regional rate of return on new investment.

— In equilibrium, exports of a good from one region to the rest of world are equal to the import demand for that good in the remaining regions. Together with the merchandise trade balance, the net payments on foreign debt add up to the current account balance. *Tasman Global* does not require that the current account be in balance every year. It allows the capital account to move in a compensatory direction to maintain the balance of payments. The exchange rate provides the flexibility to keep the balance of payments in balance.

— Detailed bilateral transport margins for every commodity are specified in the starting database. By default, the bilateral transport mode shares are assumed to be constant, with the supply of international transportation services by each region solved by a cost-minimising international trader according to a Cobb-Douglas demand function.

— Emissions of 6 anthropogenic greenhouse gases (namely, carbon dioxide, methane, nitrous oxide, HFCs, PFCs and SF_6) associated with economic activity are tracked in the model. Almost all sources and sectors are represented; emissions from agricultural residues and land-use change and forestry activities are not explicitly modelled but can be accounted for externally. Prices can be applied to emissions which are converted to industry-specific production taxes or commodity-specific sales taxes that impact on demand. Abatement technologies similar to those adopted in a report released by the Commonwealth Government (2008) are available and emission quotas can be set globally or by region along with allocation schemes that enable emissions to be traded between regions.[60]

More detail regarding specific elements of the model structure is discussed in the following sections.

B.4 Population growth and labour supply

Population growth is an important determinant of economic growth through the supply of labour and the demand for final goods and services. Population growth for each region represented in the *Tasman Global* database is projected using ACIL Allen's in-house demographic model. The demographic model projects how the population in each region grows and how age and gender composition changes over time and is an important tool for determining the changes in regional labour supply and total population over the projected period.

For each of region, the model projects the changes in age-specific birth, mortality and net migration rates by gender for 101 age cohorts (0-99 and 100+). The demographic model also projects

[60] Australian Government (2008), *Australia's Low Pollution Future: the economics of climate change mitigation*, Australian Government, Canberra.

changes in participation rates by gender by age for each region, and, when combined with the age and gender composition of the population, endogenously projects the future supply of labour in each region. Changes in life expectancy are a function of income per person as well as assumed technical progress on lowering mortality rates for a given income (for example, reducing malaria-related mortality through better medicines, education, governance etc.). Participation rates are a function of life expectancy as well as expected changes in higher education rates, fertility rates and changes in the work force as a share of the total population.

Labour supply is derived from the combination of the projected regional population by age by gender and regional participation rates by age by gender. Over the projected period labour supply in most developed economies is projected to grow slower than total population because of ageing population effects.

For the Australian states and territories, the projected aggregate labour supply from ACIL Allen's demographic module is used as the base level potential workforce for the detailed Australian labour market module, which is described in the next section.

B.5 The Australian labour market

Tasman Global has a detailed representation of the Australian labour market which has been designed to capture:

- different occupations
- changes to participation rates (or average hours worked) due to changes in real wages
- changes to unemployment rates due to changes in labour demand
- limited substitution between occupations by the firms demanding labour and by the individuals supplying labour, and
- limited labour mobility between states and regions within each state.

Tasman Global recognises 97 different occupations within Australia – although the exact number of occupations depends on the aggregation. The firms that hire labour are provided with some limited scope to change between these 97 labour types as the relative real wage between them changes. Similarly, the individuals supplying labour have a limited ability to change occupations in response to the changing relative real wage between occupations. Finally, as the real wage for a given occupation rises in one state relative to other states, workers are given some ability to respond by shifting their location. The model produces results at the 97 3-digit Australian New Zealand Standard Classification of Occupations (ANZSCO) level which are presented in Table C2. The labour market structure of *Tasman Global* is thus designed to capture the reality of labour markets in Australia, where supply and demand at the occupational level do adjust, but within limits.

Labour supply in *Tasman Global* is presented as a three-stage process:

1. labour makes itself available to the workforce based on movements in the real wage and the unemployment rate
2. labour chooses between occupations in a state based on relative real wages within the state
3. labour of a given occupation chooses in which state to locate based on movements in the relative real wage for that occupation between states.

By default, *Tasman Global*, like all CGE models, assumes that markets clear. Therefore, overall, supply and demand for different occupations will equate (as is the case in other markets in the model).

Table B.2 Occupations in the *Tasman Global* database, ANZSCO 3-digit level (minor groups)

ANZSCO code, Description	ANZSCO code, Description	ANZSCO code, Description
1. MANAGERS 111 Chief Executives, General Managers and Legislators 121 Farmers and Farm Managers 131 Advertising and Sales Managers 132 Business Administration Managers 133 Construction, Distribution and Production Managers 134 Education, Health and Welfare Services Managers 135 ICT Managers 139 Miscellaneous Specialist Managers 141 Accommodation and Hospitality Managers 142 Retail Managers 149 Miscellaneous Hospitality, Retail and Service Managers **2. PROFESSIONALS** 211 Arts Professionals 212 Media Professionals 221 Accountants, Auditors and Company Secretaries 222 Financial Brokers and Dealers, and Investment Advisers 223 Human Resource and Training Professionals 224 Information and Organisation Professionals 225 Sales, Marketing and Public Relations Professionals 231 Air and Marine Transport Professionals 232 Architects, Designers, Planners and Surveyors 233 Engineering Professionals 234 Natural and Physical Science Professionals 241 School Teachers 242 Tertiary Education Teachers 249 Miscellaneous Education Professionals 251 Health Diagnostic and Promotion Professionals 252 Health Therapy Professionals 253 Medical Practitioners 254 Midwifery and Nursing Professionals 261 Business and Systems Analysts, and Programmers 262 Database and Systems Administrators, and ICT Security Specialists 263 ICT Network and Support Professionals 271 Legal Professionals 272 Social and Welfare Professionals	**3. TECHNICIANS & TRADES WORKERS** 311 Agricultural, Medical and Science Technicians 312 Building and Engineering Technicians 313 ICT and Telecommunications Technicians 321 Automotive Electricians and Mechanics 322 Fabrication Engineering Trades Workers 323 Mechanical Engineering Trades Workers 324 Panel beaters, and Vehicle Body Builders, Trimmers and Painters 331 Bricklayers, and Carpenters and Joiners 332 Floor Finishers and Painting Trades Workers 333 Glaziers, Plasterers and Tilers 334 Plumbers 341 Electricians 342 Electronics and Telecommunications Trades Workers 351 Food Trades Workers 361 Animal Attendants and Trainers, and Shearers 362 Horticultural Trades Workers 391 Hairdressers 392 Printing Trades Workers 393 Textile, Clothing and Footwear Trades Workers 394 Wood Trades Workers 399 Miscellaneous Technicians and Trades Workers **4. COMMUNITY & PERSONAL SERVICE** 411 Health and Welfare Support Workers 421 Child Carers 422 Education Aides 423 Personal Carers and Assistants 431 Hospitality Workers 441 Defence Force Members, Fire Fighters and Police 442 Prison and Security Officers 451 Personal Service and Travel Workers 452 Sports and Fitness Workers	**5. CLERICAL & ADMINISTRATIVE** 511 Contract, Program and Project Administrators 512 Office and Practice Managers 521 Personal Assistants and Secretaries 531 General Clerks 532 Keyboard Operators 541 Call or Contact Centre Information Clerks 542 Receptionists 551 Accounting Clerks and Bookkeepers 552 Financial and Insurance Clerks 561 Clerical and Office Support Workers 591 Logistics Clerks 599 Miscellaneous Clerical and Administrative Workers **6. SALES WORKERS** 611 Insurance Agents and Sales Representatives 612 Real Estate Sales Agents 621 Sales Assistants and Salespersons 631 Checkout Operators and Office Cashiers 639 Miscellaneous Sales Support Workers **7. MACHINERY OPERATORS & DRIVERS** 711 Machine Operators 712 Stationary Plant Operators 721 Mobile Plant Operators 731 Automobile, Bus and Rail Drivers 732 Delivery Drivers 733 Truck Drivers 741 Storepersons **8. LABOURERS** 811 Cleaners and Laundry Workers 821 Construction and Mining Labourers 831 Food Process Workers 832 Packers and Product Assemblers 839 Miscellaneous Factory Process Workers 841 Farm, Forestry and Garden Workers 851 Food Preparation Assistants 891 Freight Handlers and Shelf Fillers 899 Miscellaneous Labourers

Source: ABS (2009), ANZSCO – Australian and New Zealand Standard Classifications Of Occupations, First edition, Revision 1, ABS catalogue no. 1220.0.

The *Tasman Global* database includes a detailed representation of the Australian labour market that has been designed to capture the supply and demand for different skills and occupations by industry. To achieve this, the Australian workforce is characterised by detailed supply and demand matrices.

On the supply side, the Australian population is characterised by a 5-dimensional matrix consisting of:

— 7 post-school qualification levels
— 12 main qualification fields of highest educational attainment
— 97 occupations
— 101 age groups (namely 0 to 99 and 100+)
— 2 genders.

The data for this matrix is measured in persons and was sourced from the ABS 2011 Census. As the skills elements of the database and model structure have not been used for this project, it will be ignored in this discussion.

The 97 occupations are those specified at the 3-digit level (or Minor Groups) under the ANZSCO (see Table C2).

On the demand side, each industry demands a particular mix of occupations. This matrix is specified in units of FTE jobs where an FTE employee works an average of 37.5 hours per week. Consistent with the labour supply matrix, the data for FTE jobs by occupation by industry was also sourced from the ABS 2011 Census and updated using the latest labour force statistics.

Matching the demand and supply side matrices means that there is the implicit assumption that the average hours per worker are constant, but it is noted that mathematically changes in participation rates have the same effect as changes in average hours worked.

B.6 Labour market model structure

In the model, the underlying growth of each industry in the Australian economy results in a growth in demand for a particular set of skills and occupations. In contrast, the supply of each set of skills and occupations in a given year is primarily driven by the underlying demographics of the resident population. This creates a market for each skill by occupation that (unless specified otherwise) needs to clear at the start and end of each time period.[61] The labour markets clear by a combination of different prices (i.e. wages) for each labour type and by allowing a range of demand and supply substitution possibilities, including:

— changes in firms' demand for labour driven by changes in the underlying production technology
  – for technology bundle industries (electricity, iron and steel and road transportation) this occurs due to changes between explicitly identified alternative technologies
  – for non-technology bundle industries this includes substitution between factors (such as labour for capital) or energy for factors
— changes to participation rates (or average hours worked) due to changes in real wages
— changes in the occupations of a person due to changes in relative real wages
— substitution between occupations by the firms demanding labour due to changes in the relative costs
— changes to unemployment rates due to changes in labour demand, and
— limited labour mobility between states due to changes in relative real wages.

All of the labour supply substitution functions are modified-CET functions in which people supply their skills, occupation and rates of participation as a positive function of relative wages. However,

[61] For example, at the start and end of each week for this analysis. *Tasman Global* can be run with different steps in time, such as quarterly or bi-annually in which case the markets would clear at the start and end of these time points.

unlike a standard CET (or CES) function, the functions are 'modified' to enforce an additional constraint that the number of people is maintained before and after substitution.[62]

Although technically solved simultaneously, the labour market in *Tasman Global* can be thought of as a 5-stage process:

— labour makes itself available to the workforce based on movements in the real wage (that is, it actively participates with a certain number of average hours worked per week)
— the age, gender and occupations of the underlying population combined with the participation rate by gender by age implies a given supply of labour (the potentially available workforce)
— a portion of the potentially available workforce is unemployed, implying a given available labour force
— labour chooses to move between occupations based on relative real wages
— industries alter their demands for labour as a whole and for specific occupations based on the relative cost of labour to other inputs and the relative cost of each occupation.

By default, *Tasman Global*, like all CGE models, assumes that markets clear at the start and end of each period. Therefore, overall, supply and demand for different occupations will equate (as is the case in other markets in the model). In principle, (subject to zero starting values) people of any age and gender can move between any of the 97 occupations while industries can produce their output with any mix of occupations. However, in practice the combination of the initial database, the functional forms, low elasticities and moderate changes in relative prices for skills, occupations etc. means that there is only low to moderate change induced by these functions. The changes are sufficient to clear the markets, but not enough to radically change the structure of the workforce in the timeframe of this analysis.

Factor-factor substitution elasticities in non-technology bundle industries are industry specific and are the same as those specified in the GTAP database[63], while the fuel-factor and technology bundle elasticities are the same as those specified in GTEM.[64] The detailed labour market elasticities are ACIL Allen assumptions, previously calibrated in the context of the model framework to replicate the historical change in the observed Australian labour market over a 5 year period[65]. The unemployment rate function in the policy scenarios is a non-linear function of the change in the labour demand relative to the base case with the elasticity being a function of the unemployment rate (that is, the lower the unemployment rate the lower the elasticity and the higher the unemployment rate the higher the elasticity).

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[62] As discussed in Dixon et al (1997), a standard CES/CET function is defined in terms of *effective units*. Quantitatively this means that, when substituting between, say, X_1 and X_2 to form a total quantity X using a CET function a simple summation generally does not actually equal X. Use of these functions is common practice in CGE models when substituting between substantially different units (such as labour versus capital or imported versus domestic services) but was not deemed appropriate when tracking the physical number of people. Such 'modified' functions have long been employed in the technology bundles of *Tasman Global* and GTEM. The Productivity Commission have proposed alternatives to the standard CES to overcome similar and other weaknesses when applied to internationally traded commodities. See Dixon, P.B., Parmenter, B., Sutton, J., & Vincent, D. (1997), *ORANI: A Multisectoral Model of the Australian Economy*, Amsterdam: North Holland.

[63] Narayanan et al. (2012).

[64] Pant, H.M. (2007), GTEM: *Global Trade and Environment Model*, ABARE Technical Report, Canberra, June.

[65] This method is a common way of calibrating the economic relationships assumed in CGE models to those observed in the economy. See for example Dixon, P.B. and Rimmer, M.T. (2002), *Dynamic General Equilibrium Modelling for Forecasting and Policy*. Contributions to Economic Analysis 256, Amsterdam: North Holland.

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