THE UNIVERSITY OF SYDNEY

Path to Net Zero
The Net Zero Initiative

Accelerating Australia's path to Net Zero through innovative partnerships backed by world-class research

Faculty of Engineering

Acknowledgement of Country

We recognise and pay respect to the Elders and communities – past, present and emerging – of the lands that the University of Sydney's campuses stand on. For thousands of years they have shared and exchanged knowledges across innumerable generations for the benefit of all.

Preface

There is no greater challenge than addressing climate change and the need for an urgent transition to net zero emissions.[1] The World Economic Forum's Global Risks Report[2] for 2023 places failure to mitigate climate change and failure to adapt to climate change as the two greatest risks to our future. The UN states: "Climate Change is the defining issue of our time, and we are at a defining moment."[3]

In response to this critical challenge, the University of Sydney launched the Net Zero Initiative (NZI) in March 2022. This initiative represents a visionary effort aimed at expediting the frontier research, development, commercialisation, and responsible deployment of cutting-edge technologies and solutions. Its ultimate goal is to facilitate the transition toward achieving net zero emissions.

The NZI is a bold call-to-action:

- **Accelerate Progress:** Driving swift progress towards net zero emissions through cutting-edge research and its translation. Our focus: reducing demand, eliminating emissions, removing greenhouse gases and understanding climate risks. All backed by rigorous evaluations from multidisciplinary and cross-sector teams.

- **Foster Innovation:** Nurturing a dynamic, socially conscious entrepreneurial culture across our university and in our students. Together, we are sharing experiences, sparking innovation, and engaging with our communities.

- **Shape the Future:** By sharing best practices and making a lasting impact on governance, finance, policy, and legislation, we are influencing the nation's trajectory for generations to come.

- **Build a Skilled Workforce:** Building capacity to meet Australia's workforce demands and enhancing our national competitiveness.

The NZI has four central themes: reducing demand, achieving zero emissions in energy and industry, removing greenhouse gases, and understanding climate change risks. These themes encompass various initiatives aimed at facilitating the transition to net-zero emissions. By actively collaborating with diverse partners across economic sectors, the NZI emphasises cutting-edge research, development, and the transformation of innovative ideas from laboratory concepts to practical applications.

This White Paper serves as a 'snapshot in time' of our current and potential future solutions within a national framework. It represents a collective pool of expertise aimed at addressing challenges in the transition to net zero emissions and identifying solutions for further advancement.

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Executive Summary

This White Paper is written to inform government and industry about the multidisciplinary and international program of work within the NZI which is aimed at building capacity, researching cutting edge solutions and translating these solutions to address the transition towards a Net Zero emissions target.

The NZI functions as a central hub for pioneering multidisciplinary research and innovative thinking, forming the foundation for comprehensive solutions in the pursuit of net zero goals. Moreover, the NZI serves as a platform for fostering collaborative partnerships across various faculties and sectors, a crucial step in identifying holistic and investment-worthy solutions, and building the capacity necessary to translate these solutions into actionable outcomes.

There is no "silver bullet", and achieving net zero targets for Australia and the world requires a portfolio of solutions. The NZI team is developing solutions across four enabling themes—demand reduction, zero emissions energy and industry, greenhouse gas removal, and climate change risk. The technology readiness levels (TRLs) have been mapped and a pipeline of opportunities in the short-, mid-, and long-term are presented for Australia's and the world's transition to net zero. Addressing the gaps, obstacles, and requirements associated with these solutions provides a clear call-to-action.

Key themes that emerged from our discussions of the solutions are:

- **Enabling and deepening University partnerships and collaborations with the public and private sectors**: In Australia and overseas, building on multidisciplinary research is needed to develop and translate solutions.
- **Workforce solutions:** Addressing workforce capacity and capability gaps through education, training and skills development to drive outcomes.
- **Solutions at scale:** Does it make economic sense? Considerations include production costs, manufacturing implications, and the reliance on resources (minerals, land, products, services) that should be shared to enhance efficiency.
- **Role of government:** Governments at all levels must establish the guidelines and parameters that guide decision-making, project planning, reporting, resilience, risk assessment, and post-implementation reviews for new technologies and methods.
- **Hard to abate sectors:** The transition requires creating solutions for industries or activities that are hard to decarbonise and implementing regulations with enforceable penalties.
- **Adapting:** Embracing opportunities and change has its advantages, but also requires sacrifices, including adjusting to new technologies, phasing out existing infrastructures, and moving away from current CO_2 revenue streams.
- **Inclusivity:** Address various scales from local to national and global levels, ensuring that everyone is involved in the process.

Lastly, this White Paper highlights key areas of shared concern, which encompassed challenges related to research funding and facilities limitations, especially for prototyping and scaling solutions. Additionally, we noted issues regarding the availability of supply chains and the need for community acceptance, which necessitates ongoing education efforts and collaborative partnerships spanning various sectors.

The outcomes of this White Paper guide our strategy of 'how' the NZI will help deliver on the imperative of a more sustainable future for our planet and people.

The NZI functions as a central hub for pioneering research and innovative thinking, forming the foundation for comprehensive solutions in the pursuit of net zero goals.

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Setting *the scene*

The NZI's transformative vision involves developing a suite of solutions grounded in technological and scientific innovations.

On July 25th, 2023, the Net Zero Initiative (NZI) convened a multidisciplinary and cross-sector workshop that brought together members of the NZI team from various faculties at the University of Sydney along with external partners and advisors. This White Paper serves as a foundational document outlining the vision of the NZI in addressing the critical challenge of achieving net zero emissions, both nationally and globally. It starts with an examination of the broader context, considering national and global commitments to attain net zero emissions. Additionally, it reflects on the current state of net zero technologies. The University of Sydney has committed to achieving net zero emissions by 2030 as outlined in its recent Sustainability Strategy.[4]

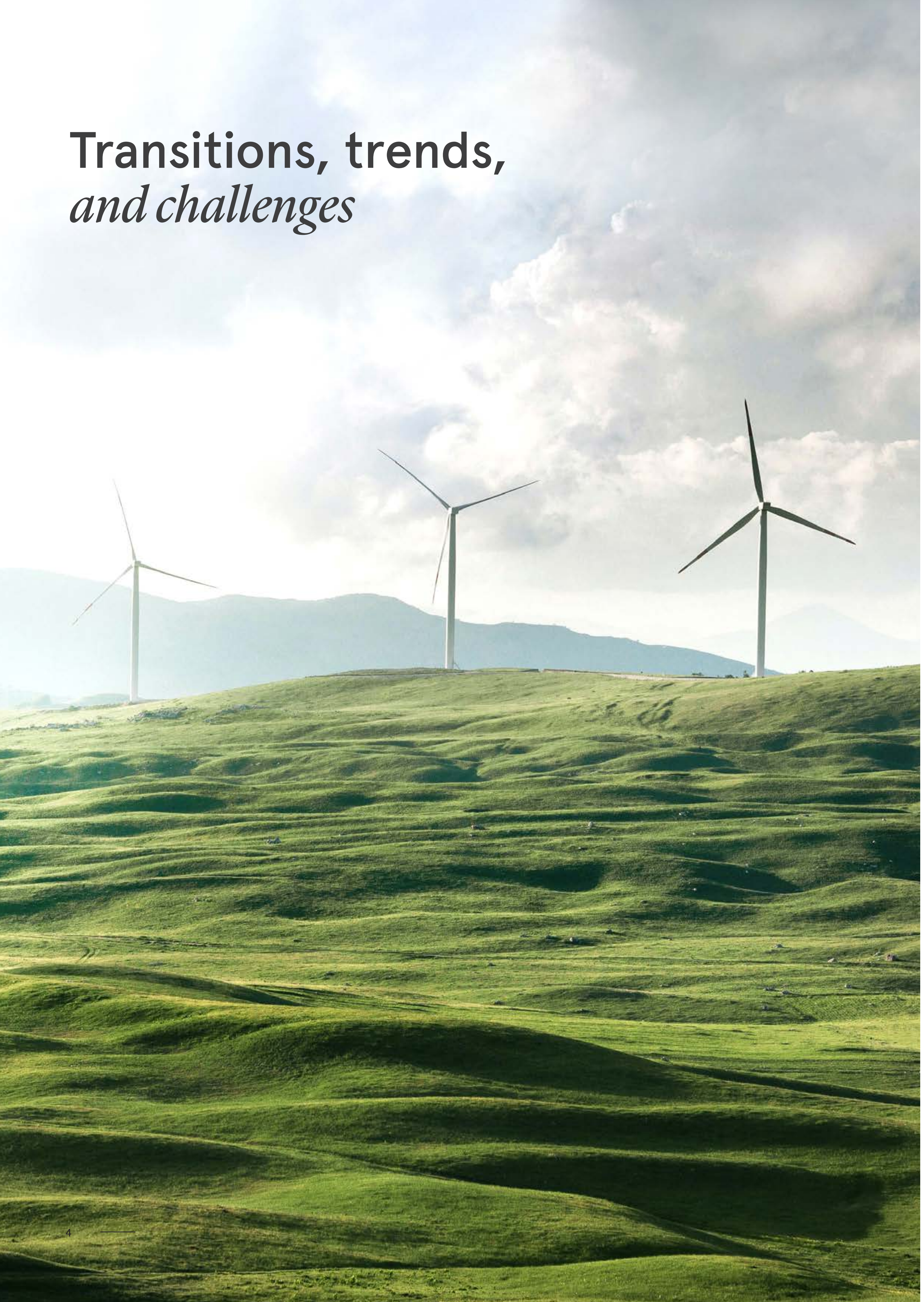
To fulfill our mission of disseminating knowledge and building an understanding of the NZI's array of solutions, we have conducted an analysis of the research activities within the NZI. This assessment includes an evaluation of the technical readiness levels (TRLs) to identify gaps, challenges, and opportunities. These endeavours enable us to outline short-, mid-, and long-term projects to guide our efforts in seeking partnerships, funding, skills development, solution testing, translation, and commercialisation. The information presented in this document offers strategic and timely guidance, particularly at a crucial juncture where Australia must chart its path towards achieving its national aspirations. It is important to note that there is no single solution; rather, a diverse portfolio of solutions, including emerging and unknown technologies, will be necessary to expedite the transition to net zero emissions.

The NZI's transformative vision involves developing a suite of solutions grounded in technological and scientific innovations. These solutions fully integrate economic, financial, legal, and social considerations. They directly contribute to Sustainable Development Goals (SDGs) 6 and 7 (Clean water and affordable and clean energy), 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable cities and communities), 12 (Responsible production and consumption), 13 (Climate action), and also align with SDGs 16 and 17 (Peace, justice, and partnerships). Furthermore, they underpin many other SDGs.

Recognising the acute workforce shortages in Australia for the net zero transition, as indicated by the Clean Energy Capacity Study[5] and the ongoing Australian Universities Accord process,[6] the NZI's mission extends to capacity building to aid the development of a skilled workforce to address the nation's needs. These aspects fall outside the scope of this White Paper.

- How do we reach Net Zero by 2050 or sooner?
- What portfolio of solutions and technologies do we need? How do we prioritise these in the short-, mid- and long-term? How do we scale them?
- How do we make a responsible transition that is inclusive of environmental, governance, policy, legislative, economic, and social issues?
- Who do we engage with, including stakeholders, communities and First Nations peoples, to co-design solutions for translation and integration of solutions?
- Where do we need educational innovations to address acute workforce shortages for the transition to Net Zero?

Transitions, trends, *and challenges*



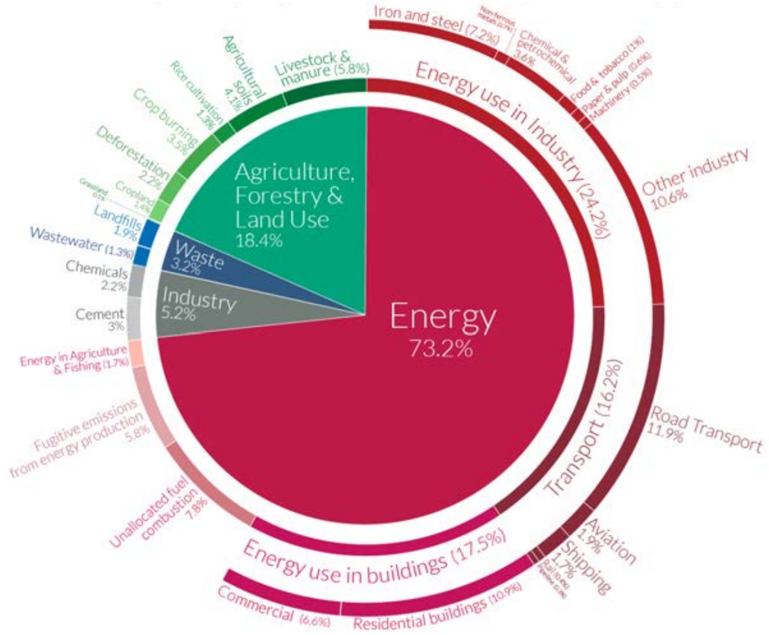


Figure 1: Global emissions by sector. Reproduced from Our World in Data.[7] Data show the major contribution from the Energy sector.

In this section, we explore the global and national journey toward achieving net zero emissions. The White Paper provides a concise overview of the global framework guiding this transition, including targets established on both global and national scales. It also sheds light on the numerous challenges encountered in the pursuit of these objectives.

To begin, we examine the origins of emissions.

The primary origin of greenhouse gases stems from energy usage. Emissions arise from the combustion of fossil fuels and the inadvertent release of methane or carbon dioxide during fossil fuel extraction and processing. Notably, methane carries a greater than twenty-fold global warming potential compared to carbon dioxide.

The second most significant source of emissions arises from the land and agricultural sector. This category encompasses various sources, including emissions from livestock digestion, manure decomposition, alterations to carbon in soils, or the anaerobic breakdown of organic matter in rice paddies.

A third substantial emissions source results from changes in vegetation cover. This occurs when forests are replaced by agricultural land, leading to the release of carbon from decaying or burnt trees.

Emissions from industry originate from sources beyond energy consumption. Examples include carbon dioxide released during the conversion of limestone into cement and the carbon dioxide produced when hydrogen is derived from natural gas.

As we examine the distribution of emissions sources, it becomes evident why the primary focus is on reducing emissions linked to energy usage. However, it's crucial not to disregard the other sources of emissions, as they include some of the most challenging emissions to mitigate. The world embarked on the journey to reduce emissions three decades ago. Yet, progress has proven to be a formidable challenge, as we explore in the following section.

As we examine the distribution of emissions sources, it becomes evident why the primary focus is on reducing emissions linked to energy usage.

Global achievements and challenges

In 1992, the United Nations introduced the United Nations Framework Convention on Climate Change (UNFCCC),[8] marking the inaugural global effort to combat climate change. This convention had a primary objective: to stabilise greenhouse gas (GHG) concentrations and prevent harmful human-induced disruptions to the climate system. As part of its mechanisms, the UNFCCC established an annual gathering known as the Conference of the Parties (COP). These international meetings were convened to facilitate discussions on methods to stabilise greenhouse gas concentrations in the atmosphere. Subsequently, these gatherings led to the creation of two significant agreements, namely the Kyoto Protocol and the Paris Agreement.

The Kyoto Protocol, adopted in 1997 and enforced in 2005, marked the world's first legally binding climate treaty. It imposed obligations on developed nations to reduce their emissions by an average of 5% compared to 1990 levels by 2020, while also establishing a monitoring system to track countries' progress. Importantly, the treaty did not impose requirements on developing countries, including major carbon emitters like China and India. Although the United States signed the agreement in 1998, it never ratified it and subsequently withdrew its signature. Australia, on the other hand, signed the Kyoto Protocol in 1998 and ratified it in 2007.[9]

The Kyoto Protocol included two commitment periods. The first commitment period (CP1) of the Kyoto Protocol ran from 2008 to 2012. Australia met and exceeded its first period Kyoto Protocol target of 108% of 1990 emissions levels by 2012.

Countries generally met their targets in the first commitment period. Shishlov, Morel and Bellassen[10] studied the compliance of parties to the Kyoto Protocol during the CP1 based on the final data on national emissions and exchanges in carbon units (also known as offsets) that became available at the end of 2015. They found that only nine of 36 countries that fully participated in the CP1 emitted higher levels of GHGs than committed under the Kyoto Protocol. Figure 2 reproduced from Shishlov *et al.*, shows the outcomes of their study.

Three points emerge from this analysis. First, the high-achieving nations in terms of emissions reductions primarily hailed from Eastern Europe or the former USSR. Their significant reductions in emissions, often referred to as "hot air," stemmed from economic transitions that took place prior to 1997. This underscores the substantial influence that modernising production facilities can have on emissions. However, it is crucial to recognise that these circumstances were exceptional and are unlikely to be replicated on a similar scale in the future.

Secondly, the emission targets set for CP1 were rooted in the emissions data from 1990. The period spanning from

Figure 2: Absolute difference between the average annual emissions of Annex B-2012 countries in 2008-2012 and their respective Kyoto targets including Land Use, Land Use Change and Forestry (LULUCF) (in MtCO2e). Reproduced from Shishlov *et al.*[10]

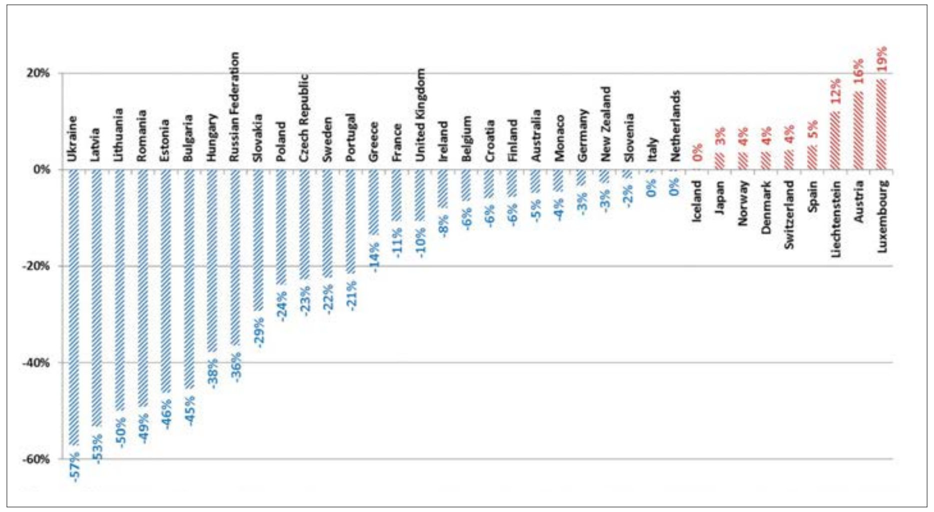
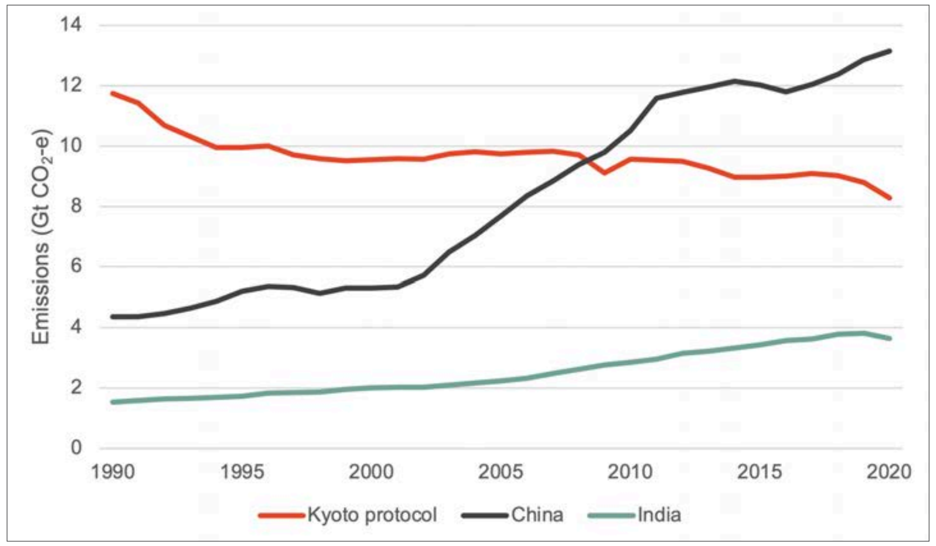


Figure 3: Emissions covered by Kyoto Protocol commitments. Reproduced from Our World in Data.[1]



1990 to 2012 coincided with what's often referred to as the "dash for gas." During this time, numerous countries, notably the UK, embraced fuel switching as a response to the accessibility of low-cost domestic natural gas, primarily from North Sea fields. A similar trend was observed in the USA, driven by the exploitation of tight gas fields. Notably, fuel switching has played a significant role in driving emissions reduction within the electricity sector. This shift involves transitioning from coal to gas and adopting variable renewable electricity sources such as wind and solar photovoltaics.

Thirdly, it is important to account for the carbon accounting regulations outlined in the Kyoto Protocol, specifically within articles 3.3, 3.4, and 3.7. These rules permitted nations to incorporate net emissions linked to land use, land use change, and forestry (LULUCF) into their national emissions records. In the case of Australia, the decline in emissions related to LULUCF amounted to approximately 27% of the emissions recorded in the base year of 1990. However, it's vital to note that this reduction in LULUCF emissions primarily resulted from the discontinuation of extensive land clearing activities, particularly in Queensland.[11] This circumstance is unlikely to recur.

In the initial commitment period, 37 countries were tasked with achieving an average emissions reduction of 5% compared to their 1990 emissions levels. Moving on to the second commitment period (CP2), participating Parties committed to reducing emissions by a minimum of 18% below their 1990 levels over the span of eight years, from 2013 to 2020.[12] Detailed data for CP2 is not available but overall results are available (Figure 3).

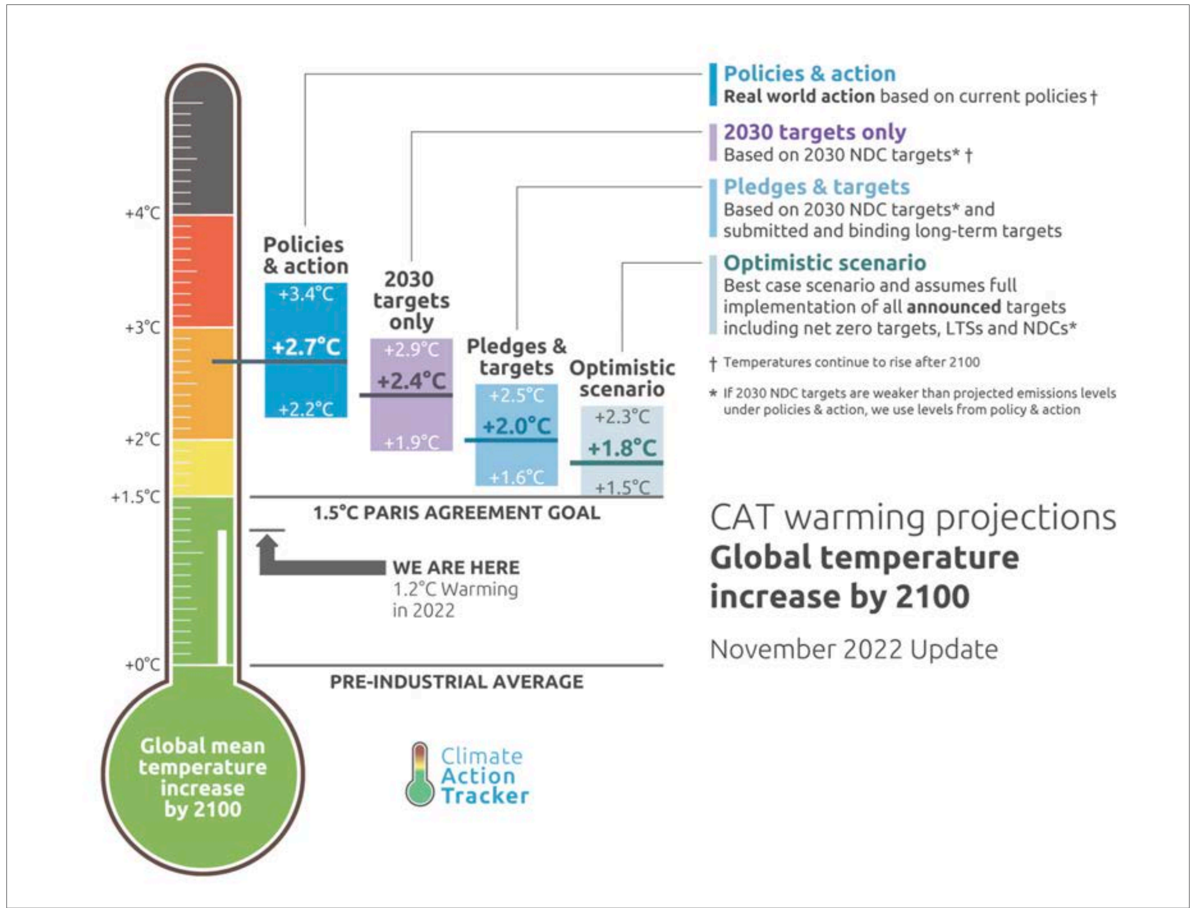
The figure shows how emissions from committed parties declined in the early 1990's due to the economic transitions of the former communist bloc. Since 1995, emissions have fallen at a steady rate with dips associated with the global financial crisis and the global pandemic.[13] Overall, emissions from committed nations in 2020 were around 30% below the emissions in 1990, demonstrating that the Kyoto Protocol successfully achieved its reduction goals.

Figure 3 also displays the emissions trends of China and India during the same period, revealing that emissions reductions driven by the Kyoto Protocol were offset by the increasing emissions from these two nations. It's worth noting that developing nations were not obligated to make commitments under the Kyoto Protocol. However, this has changed, and these nations are now required to pledge emissions reductions under the Paris Agreement.[14]
The Paris Agreement requires all countries to establish emissions reduction pledges known as nationally determined contributions (NDCs). These targets are designed to prevent the global average temperature from exceeding a 2°C increase above preindustrial levels and to strive for a limit below 1.5°C. Additionally, the Agreement calls for achieving a balance between greenhouse gas emissions and removals in the latter half of this century, effectively setting a global goal for achieving net zero emissions.

The NDCs, even if nations achieved them, are not sufficient to restrict global warming to 1.5°C. According to the Climate Action Tracker (CAT) compiled by the Germany-based non-profit organisations Climate Analytics and the NewClimate Institute,[15] the policies and actions in place as of late 2021 could result in a temperature rise of 2.7°C by 2100. Figure 4, which includes the CAT thermometer, highlights the disparity between climate ambitions and the current reality.

Recognising the imperative for further measures, numerous countries, Australia included, have reevaluated, and reinforced their goals for reducing emissions. The subsequent section of this document delves into Australia's situation and the obstacles it faces in meeting its 2030 emission reduction objectives.

Figure 4: The Climate Action Tracker thermometer. Reproduced from Climate Action Tracker.[15]



Despite the measures implemented by the Australian government, the country faces significant challenges in achieving its goal of reducing emissions by 43%.

Australia – running out of easy options

Australia has committed to reducing its emissions by 43% by 2030 and achieving net zero emissions by 2050, in accordance with its obligations under the Paris Agreement. This target became law under the Albanese Government in 2022 following their victory in the federal election, which was centred on a platform of more robust climate action. This target was an increase on the previous 28% target by 2030 set by the Abbott government in 2015 and maintained by subsequent governments until 2021.

Australia's emissions reduction goal has been a source of political contention and instability for over a decade, with differing opinions among various parties and factions on how to balance economic interests with environmental responsibilities. Many stakeholders, including business associations, labour unions, farmers, and environmental advocates, view the targets as an opportunity to resolve the "climate wars" and provide certainty and confidence for investors and consumers.

There are certain actions that governments should take to increase the likelihood of reaching the target. These include:

- **Strengthening the policy framework:** Actions like enshrining the 43% reduction target in Australian law and enhancing the Safeguard Mechanism (SGM) contribute to this effort.
- **Supporting renewable energy:** Australia's transition to cleaner electricity has been driven by the Renewable Energy Target (RET). These RET schemes will remain in effect until 2030, encouraging investments in large-scale renewable power generation and facilitating the adoption of small-scale renewable technologies like household solar panels and solar hot water systems.
- **Carbon pricing mechanisms:** The enhanced SGM effectively introduces a large carbon market into Australia.[16] The SGM requires large greenhouse gas emitters in Australia to reduce their emissions in line with the national target.
- **Promote new technologies:** Governments in Australia have been supporting innovation and research in clean energy technologies, such as hydrogen, carbon capture and storage, battery development and low-emissions agriculture through agencies such as the Australian Renewable Energy Agency (ARENA) and the Australian Research Council (ARC).

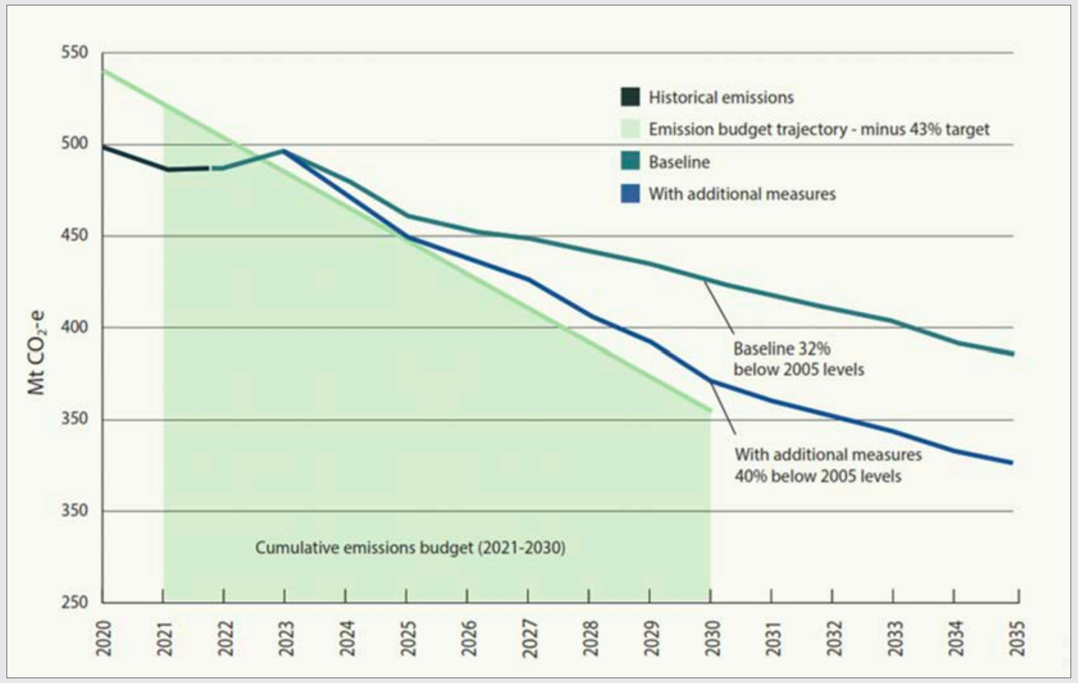
Despite the measures implemented by the Australian government, the country faces significant challenges in achieving its goal of reducing emissions by 43%.[17]

The latest Annual Climate Change Statement[18] highlights the issues. Figure 5 displays Australia's expected emissions for two scenarios. The 'baseline' scenario reflects policies and actions implemented by previous administrations, indicating a 32% reduction in emissions by 2030 compared to 2005 levels, aligning with the nation's earlier emissions reduction target.

Figure 5 also incorporates the impact of certain additional measures proposed by the current Australian Government, as outlined in the previous Labor Opposition's Powering Australia manifesto.[19] The two primary additional measures involve reaching an 82% national renewable electricity target by 2030 and implementing Safeguard Mechanism reforms. According to the government's projections, these two measures are expected to lead to a 40% reduction in emissions by 2030 compared to 2005 levels.

The Powering Australia initiative encompasses other components, including elements of the Powering the Regions Fund, the National Electric Vehicle Strategy, and the National Energy Performance Strategy. The government asserts its confidence in achieving the 43% emissions reduction target by 2030.

Figure 5: Australia's emissions projections baseline and 'with additional measures' scenario, 2020 to 2035, Mt CO2-e. Reproduced from Australia's Annual Climate Change Statement, 2022.[18]



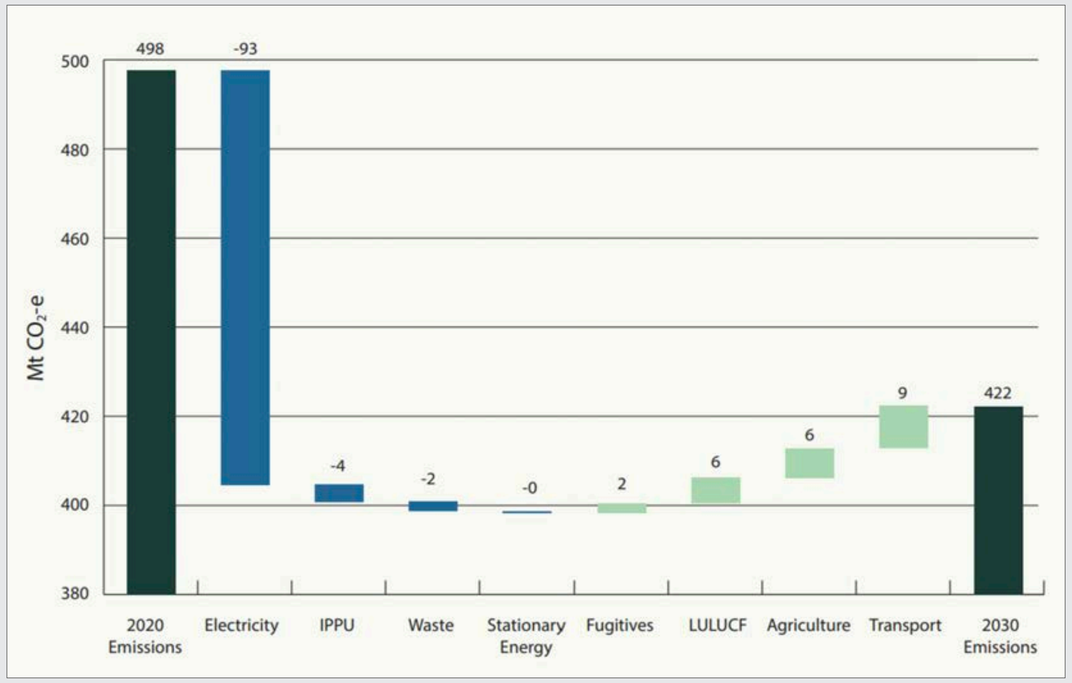


Figure 6: Change in Australia's baseline scenario emissions from 2020 to 2030, Mt CO_2-e. Reproduced from Australia's Annual Climate Change Statement, 2022.[18]

Australia's ambition to achieve a 43% emissions reduction by 2030 faces significant challenges. Some of these challenges extend beyond government influence and are associated with technical limitations, engineering constraints, cost pressures, and limitations in the supply chain.

Australia's emissions have gradually declined since 1990, primarily due to reductions in emissions related to Land Use, Land Use Change, and Forestry (LULUCF), as well as the partial decarbonisation of electricity generation. This trend is also evident in the change in emissions over the past decade. Figure 6 illustrates the factors contributing to emissions reduction from 2012 to 2022. A significant portion of this reduction can be attributed to LULUCF, while emissions from the electricity sector declined at a rate slightly more than half that of the land use sector.

LULUCF emissions have now become negative, and achieving further substantial reductions in net emissions from LULUCF will necessitate efforts like reafforestation, afforestation, or other innovative biosequestration approaches. These measures are notably more challenging to implement than the straightforward cessation of land clearing.

The Australian Government's strategy heavily relies on the continuous decarbonisation of electricity generation from now until 2030 to achieve the majority of the required emissions reduction, as indicated in Figure 6. In contrast, other sectors are anticipated to make relatively minor reductions or may even experience an increase in emissions.

The additional measures proposed by the Australian Government primarily concentrate on further decarbonising the electricity supply and reducing emissions from significant emitters through the Safeguard Mechanism (SGM). Under the SGM, large greenhouse gas emitters in Australia must align their emissions with the national target. If their emissions surpass their individual target, they must acquire and utilise Australian Carbon Credit Units (ACCUs) to ensure that their net emissions (actual emissions minus surrendered ACCUs) fall below the target.

Source	MT CO2-e
Electricity	-41.4
Transport	-2.7
Stationary energy	16.4
Fugitive Emissions	4.1
Industrial Processes	0.8
Agriculture	-0.8
LULUCF	-66.1
Waste	-0.7

Table 1: Change in emissions 2012 to 2022.[18]

Emissions originating from facilities falling under the SGM are primarily associated with stationary energy use and fugitive emissions. Importantly, these covered facilities are responsible for the majority of Australia's emissions from stationary energy and fugitive sources.

Consequently, Australia's strategy for achieving the 2030 emissions target hinges on two challenging aspects: the decarbonisation of electricity generation and the reduction of emissions from large-scale energy-consuming facilities. Both of these elements pose formidable challenges. The difficulties associated with expanding renewable energy generation in Australia's power systems have been well documented.[20,21,22]

Additionally, the essential enhancements to transmission systems[23,24,25] and the deployment of large-scale energy storage are not progressing at the required pace.[26,27]

The decarbonisation of stationary energy necessitates technologies that are not yet prepared for widespread commercial use (e.g., zero-emissions cement kilns, electric heavy mining vehicles), are not cost-effective when retrofitted (e.g., electric drives for compressors in LNG trains), or are not readily available at a large scale (e.g., biofuels).

Historically, Australia's decarbonisation efforts benefited from ending land clearing and making some fuel switches in power generation, notably transitioning from coal to renewables. Globally, we've also seen transitions from coal to gas. However, these transitions have been relatively straightforward to implement. The degree of difficulty involved in further emissions reduction is explored in the following section.

Australia's emissions have gradually declined since 1990, primarily due to reductions in emissions related to Land Use, Land Use Change, and Forestry.

The grand challenge

A simple equation defines the challenge:

Emissions = Emissions intensity (tCO_2e/$ of GDP) * GDP ($)

Conventional climate and environmental policies have evolved with the underlying belief that we can decrease emissions while maintaining and even improving our quality of life. This objective can be achieved by primarily focusing on reducing the first aspect in the equation, which is the emissions intensity of the economy, as opposed to the second aspect, which pertains to the overall size or growth of the economy. In simpler terms, the emphasis has been on making the economy more environmentally efficient rather than restricting its growth.

Business as usual improvements in technology drive some of the reduction in emissions intensity. This is seen in Figure 7, which shows how the emissions intensity of the global economy has fallen. The trend is consistent and spans several technological developments such as LEDs and low-cost solar PV. The period also spans several economic disruptions such as the recession in the early 1990's, the global financial crisis, and the era of cheap money over the past decade. The period also included the "dash for gas" discussed earlier.

And to quote William Nordhaus, Nobel Prize winning economist:

"The central goal of climate policies is to bend the emission curve downward. Yet even with all of the international agreements of the last three decades—the UN Framework Convention on Climate Change of 1992, the Kyoto Protocol of 1997, the Copenhagen accord of 2009, and the Paris climate accord of 2015, along with 25 conferences of the parties—over the same period the rate of decarbonisation has remained unchanged."[28]

The decrease in emissions intensity, as shown in Figure 7, is not as rapid as the rate at which global GDP (Gross Domestic Product) is expected to increase in the coming decades.[29] This situation presents a challenge because if emissions intensity cannot be sufficiently reduced, yet there is a pressing need to lower emissions, the only alternative is to reduce GDP. However, it is generally not acceptable for societies to endure a decline in their living standards.

Given this scenario, it becomes crucial to focus on further reducing the emissions intensity of economies. This entails developing new technologies and related solutions that can significantly accelerate the process of decarbonising the economy. The urgency of this task cannot be overstated.

There has been some good progress. Solar and wind power technologies have become increasingly efficient and cost-effective, leading to significant deployment and rapid capacity growth worldwide. Economies of scale, technological improvements, and supportive policies have contributed to cost reductions, making renewables competitive with fossil fuels. Similarly, advancements in energy storage technologies have improved grid integration and the reliability of renewable energy sources. This said, 2021 saw the highest ever emissions from coal.[30] Global emissions in 2021 were also the highest ever. The transition is now constrained by the need for new infrastructure.[31] We also see that clean energy systems are significantly more material intensive than their fossil-fuel based alternatives,[32] and supplying these critical minerals will be a challenge. Fortunately, some emerging low-emissions systems such as perovskite solar cells require fewer materials. However, more R&D is needed to realise these options.

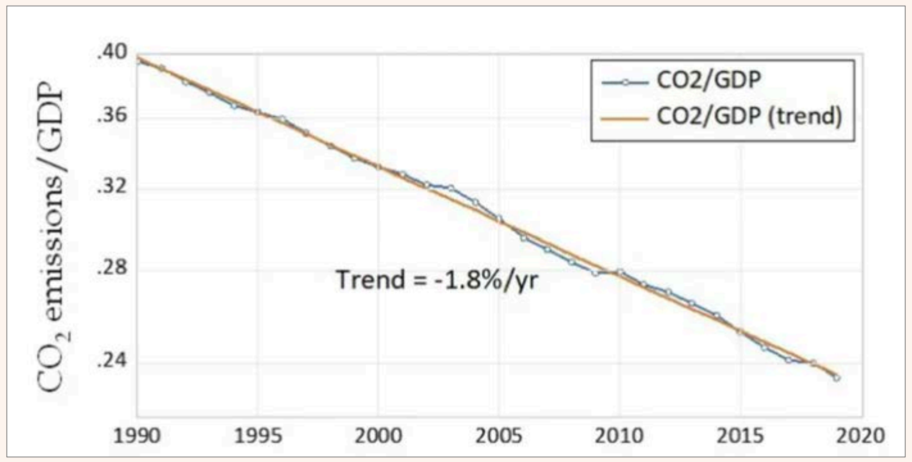


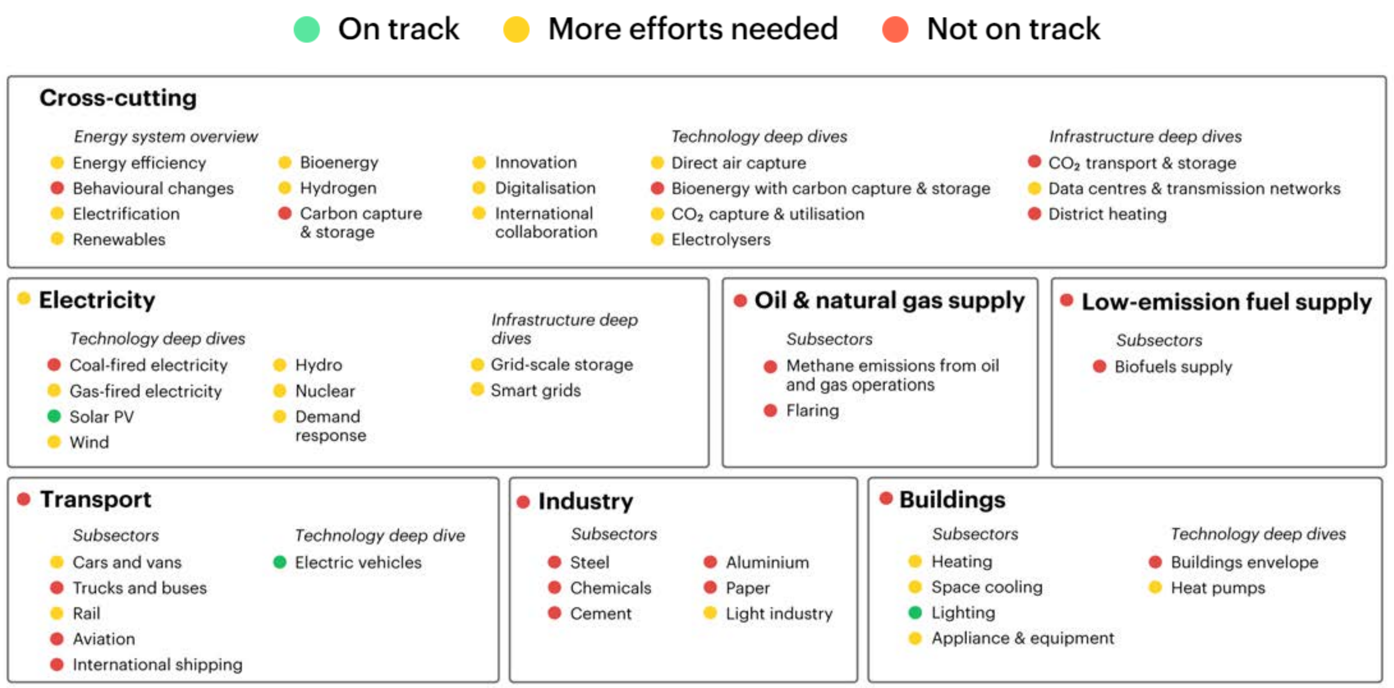
Figure 7: The reduction in emissions intensity, 1990–2019. Reproduced from Foreign Affairs.[28]

Energy efficiency measures have proven to be a key strategy in reducing emissions. Enhanced building insulation, efficient appliances, and industrial processes have contributed to significant energy savings. Furthermore, the electrification of transportation through the adoption of electric vehicles (EVs) and the development of charging infrastructure has the potential to reduce emissions from the transportation sector. However, progress is slow, and constraints linked to the supply of batteries are emerging.[33,34]

While there are several organisations such as Climate Analytics that track progress to net zero in terms of overall emissions, few look at the emerging technologies needed to realise the goal. The International Energy Agency (IEA) is one, and it produces annual reviews of progress in the energy space, including industries that use energy as a feedstock.[35] According to the IEA, technologies are rated as being:

- **On track:** if recent trends continue, in 2030 this area will comfortably be in line with the Net Zero by 2050 Scenario.
- **More efforts needed:** recent trends are positive and generally in the right direction to being in line by 2030 with the Net Zero by 2050 Scenario trajectory. However, progress needs to be faster, as a continuation of recent trends without any acceleration would still fall short of the Net Zero by 2050 Scenario trajectory.
- **Not on track:** recent trends are either in the wrong direction or substantially insufficient to get in line by 2030 with the Net Zero by 2050 Scenario trajectory. This does not exclude that there may be positive developments on certain aspects or in certain regions; however, a step-change in effort is needed at the global level.

The various technologies were rated as follows:



The IEA does acknowledge that recent policy action and technology developments such as record renewable electricity capacity additions and increasing momentum in hydrogen and carbon capture project announcements indicate that the clean energy transitions are gaining pace.

Comprehensive data about sectors other than energy are less available. The second largest source of emissions after energy is agriculture. Food production is responsible for 25% of global emissions, with those emissions split between livestock & fisheries (31%), crop production (27%), land use (24%) and emissions from supply chains (18%). Importantly, emissions from agriculture are predominately due to methane (enteric emissions and decay of organic material) and nitrous oxide (breakdown of fertilizer or organic matter rich in nitrogen) rather than CO_2. The European Environment Agency reports on progress and prospects for decarbonisation in the agriculture sector.[37] The table below shows the current progress.

Some 16% of Australia's emissions are from agriculture (noting that emissions from land use change are not counted as agricultural emissions) and of this, around 70% are enteric emissions.

The common thread of the analysis above is that while many technology options are being explored, progress is slow, and many results are disappointing despite the best efforts of proponents. An example is carbon capture and storage (especially post-combustion CCS) which has faced challenges in Australia with demonstration projects.[38] Other applications for carbon storage such as the decarbonisation of some industrial processes are more promising. Carbon storage linked to negative emissions technologies including Direct Air Capture (DAC) also have a role to play in the net zero transition, particularly in light of the stress placed on natural ecosystems as sinks for carbon.[39]

The transition to net zero emissions represents a global imperative in mitigating the impacts of climate change. The efforts and initiatives taken since 2000 have set the stage for a transformative shift towards a sustainable and resilient future. But there is still much to be done. The rapid development and deployment of multiple vaccines to help address the COVID-19 pandemic over a period of a few months shows what can be achieved through focused and concerted efforts.

Focus area	Most frequently reported measures	'Gaps' in reported measures
Livestock	Optimising livestock diets, breeding, health and disease management; improving manure management systems; and promoting anaerobic digestion 'biogas'.	Reducing livestock numbers is still uncommon. Supporting targeted breeding and using feed additives to reduce enteric methane emissions are rare, and these measures are mostly yet to be implemented.
Reduction in crop and soil N_2O	Reducing the quantity of nitrogen applied to soils, using low emission-spreading equipment, supporting organic farming and introducing organic fertilisers.	Support for nitrification or urease inhibitors is rare, despite their potential efficacy. Precision farming allowing more effective use of inputs (e.g., variable-rate nitrogen technology, pesticide application and precision irrigation) is also lacking.
Carbon storage	Maintaining or enhancing woody biomass on farmland (e.g., through agroforestry), implementing grassland management to enhance soil carbon stocks, using cover crops, and conserving organic soils.	Explicit support for permanent conversion of arable land to grassland or wetland, including ponds where appropriate, is lacking. This would limit drainage and restore carbon-rich ecosystems and incentivise sustainable soil management.
Energy mitigation	Improving on-farm energy efficiency, excluding measures relating to biogas (this is covered as a manure management measure).	Carbon-auditing tools are not frequently mentioned, despite their high mitigation potential.
Wider food system	Awareness-raising and education among consumers, food labelling and repealing the waste status of by-products to allow use/reuse as a resource were measures proposed to encourage dietary shifts and reductions in food waste. Some Member States included plans to reduce reliance on imports by increasing domestic food and animal feed production.	Relatively few countries reported measures to encourage dietary change, shortening supply chains or reductions in food waste (e.g., through improvements in food redistribution systems, financial mechanisms supporting reductions in food waste, registration and monitoring of procedures).

Table 2: Progress in the decarbonisation of the agricultural sector

Addressing *the grand challenge*

"If we're to be serious about net zero, we're going to have to focus not just on more rapid cuts in emissions in the future, but also carbon removal . . . We never talk enough about carbon removal. And for me, that is a huge missing part and also a massive opportunity for governments and the private sector."

Claire O'Neill, co-chair of the WBCSD Imperatives Advisory Board

A view of the path to net zero

The quote from Claire O'Neill points to two key elements of the net zero transition – the need to reduce emissions and the need to remove historical emissions from the atmosphere. But there are additional elements and refinements.

Emissions can be reduced in two ways – by reducing the demand for goods and services that result in greenhouse gas emissions or by introducing new technologies that reduce the emissions required to deliver those goods and services. This is the difference between an LED light that provides the same illumination but demands less electricity, and solar PV which produces electricity without any emissions.

The changing climate and society's response introduces risks associated with the transition for society and businesses. The management of climate change risk is essential to minimise the physical and economic damage due to the changing climate.

In the next section, we explore these elements in more detail within the context of the four founding themes of the NZI (Figure 8).

Figure 8: The 4 founding themes of the Net Zero Initiative

We explain why our themes align with global efforts to realise the net zero objective and then describe research work being carried out within the NZI. This includes a summary of the potential impact of our work in terms of the emissions reduction. We also present the pipeline of future work that will see our solutions progress to higher Technology Readiness Levels (TRLs).[40] While not relevant to all solutions, the TRLs have been mapped across the enabling themes to understand what the potential is for the NZI to contribute short-, mid- and long-term solutions, noting that in the latter case, the R&D efforts are currently early stage.

We also illustrate how the portfolio of solutions addressed by the NZI are applicable to the sectoral plans being developed by the recently announced Net Zero Authority within the Prime Minister's Cabinet.[41] Before this, there will be the formation of a Net Zero Agency and an Advisory Board. This collective will collaborate with various stakeholders, including governments, regional bodies, labour unions, industries, investors, and Indigenous First Nations groups, to effectively oversee the transition towards a net zero emissions economy.

The strategy involves developing six sector-specific plans for decarbonisation, encompassing critical areas of the economy such as electricity and energy, industry, resources, the built environment, agriculture, and land transportation.

The plan for the industry sector will also incorporate waste management, and the concept of a circular economy will be integrated across all sectors. Figure 9 illustrates how the portfolio of solutions addressed by the NZI is applicable to these sectors.

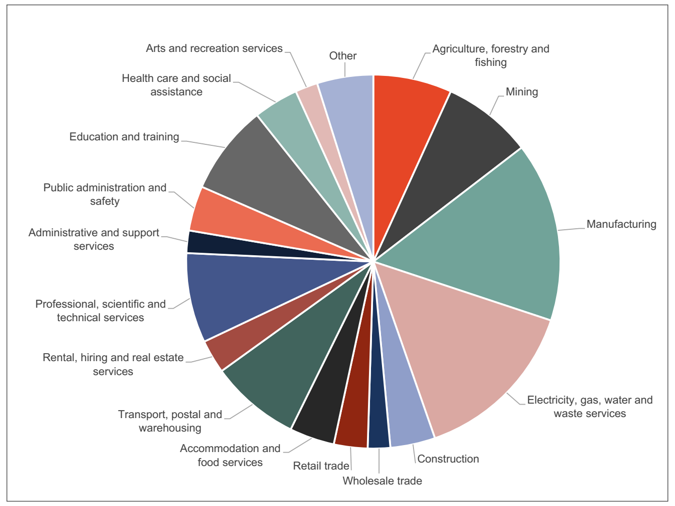


Figure 9: Current contributions to sectors from the Net Zero Initiative across its 4 themes

Theme 1. Demand Reduction

Why this theme is important

As we discussed above, the use of energy is the major source of emissions, and if all energy sources were zero emissions, then it would not matter how much energy humanity used – emissions would still be zero.

However, unless those zero emission fuels are cheaper than the fuels that they are replacing, the world will pay a high price to reduce emissions from energy use. Demand reduction is different. The aim of demand reduction measures is to reduce the amount of energy used without reducing the benefits that the use of the fuel provides. The important concept here is that people do not use energy for the sake of using energy; they use it to obtain the services that the energy provides – heat, light, motive power. Providing the same service, but using less energy is a win-win outcome – emissions go down and energy users spend less on energy.

The situation is more complicated because there is usually a cost associated with using less energy – new equipment could be required like a 5-star heater replacing a 3-star heater. Behaviour may need to change – people may need to remember to adjust thermostats when leaving the house.

Reducing the demand for energy means increasing energy efficiency.[42] The IEA begins its 2022 report into the status of energy efficiency with the following quote:

"This year record-high consumer energy bills and securing reliable access to supply are urgent political and economic imperatives for almost all governments. In response to the energy crisis countries are prioritising energy efficiency action due to its ability to simultaneously meet affordability, supply security and climate goals."

The IEA views accelerated action on energy efficiency and related avoided energy demand measures reducing final energy demand by around 5% in 2030 while the global economy grows by 40%. This corresponds to an annual 5.6% improvement in economy wide energy productivity. Stated policies will result in a 2.4% annual improvement in energy productivity.[43] So, the IEA believes that a doubling in the improvement of energy productivity is possible. The question is where to direct the efforts. The IEA sees the largest emissions reductions coming from improving the energy performance of transport i.e., electric vehicles and improvements in fuel efficiency for remaining petroleum powered vehicles.

Significant savings can also be delivered from improvements to the energy performance of industry. But in the IEA's latest report into the status of energy efficiency, the IEA reported disappointing progress with respect to energy efficiency improvements in industry.[44] The IEA noted that industrial demand is pushing global energy consumption higher as intensity progress slows. This is certainly the case in Australia.

The other avoided energy demand comes from measures including digitalisation such as smart controls and the application of data science and AI, material efficiency including the increased recycling of plastics and scrap steel and fuel switching such as electrification of process heating. These technologies are available today, and easy to implement. Many industrial processes involve chemical reactions and high-temperature heat that cannot be fully decarbonised with current commercially available technology. The IEA reports that around 60% of heavy industry emission reductions by 2050 will come from technologies that have been proven to work, but are not currently market ready.[45] However, many of the measures based on digitisation, material efficiency and fuel switching can be implemented immediately.

The IEA sees electrification as a demand reduction measure – a heat pump can provide four units of heating for every one unit of electricity used; electric vehicles required one third of the amount of energy in the form of electricity than the amount of energy in the form of petrol that an internal combustion engine vehicles car requires. Electrification is a form of fuel switching, where the same energy service is provided by a different fuel.

Fuel switching is a key transition mechanism on the path to net zero emissions. While not eliminating emissions, the switch can reduce emissions without burdening the end consumer of the service with the disruption that comes from a dramatic change in technology. Further, the reduction in emissions allows businesses to begin the transition to net zero emissions while waiting for the new technologies to emerge. A good example is in the mining industries, where it is easier to switch from diesel to compressed natural gas for powering trucks, than it is to switch from diesel to electric trucks. A switch that provides a zero-emissions outcome with minimum disruption is a move to a zero-emissions liquid fuel such as biodiesel.

The airline industry is focused on zero-emissions fuel because the power density of liquid fuels is critical to their operation and to date, batteries cannot provide solutions except in special circumstances.

From electric vehicles, to electricity networks, solar panels, and wind turbines, critical minerals are essential for solutions for a net zero future. Australia is home to some of the most significant critical minerals on Earth, including lithium, vanadium, cobalt, manganese and rare earths. Australia's Critical Minerals Strategy released in June 2023 targets the growth of a globally significant critical minerals sector (for both raw and processed minerals) with geostrategic and economic benefits that support diverse, resilient and sustainable supply chains.[46]

As we change the focus from demand reduction to technologies such as hydrogen and sustainable aviation fuel, we enter the space of zero emissions energy and industry.

How the NZI is addressing Demand Reduction

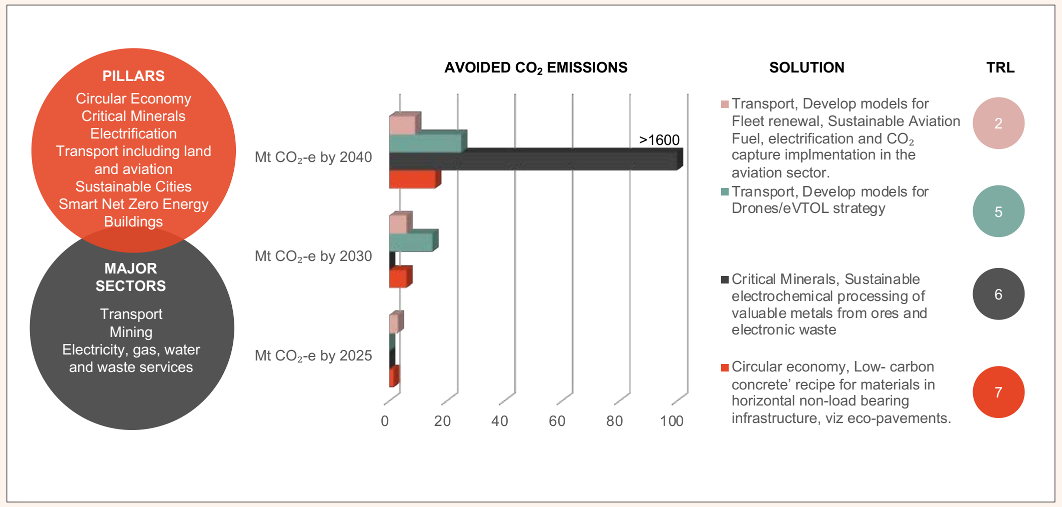


Figure 10: Snapshot of selected solutions from the Demand Reduction theme including Pillars, Major sectors contributed to by the solutions, Avoided CO_2 emissions and TRL (where relevant).

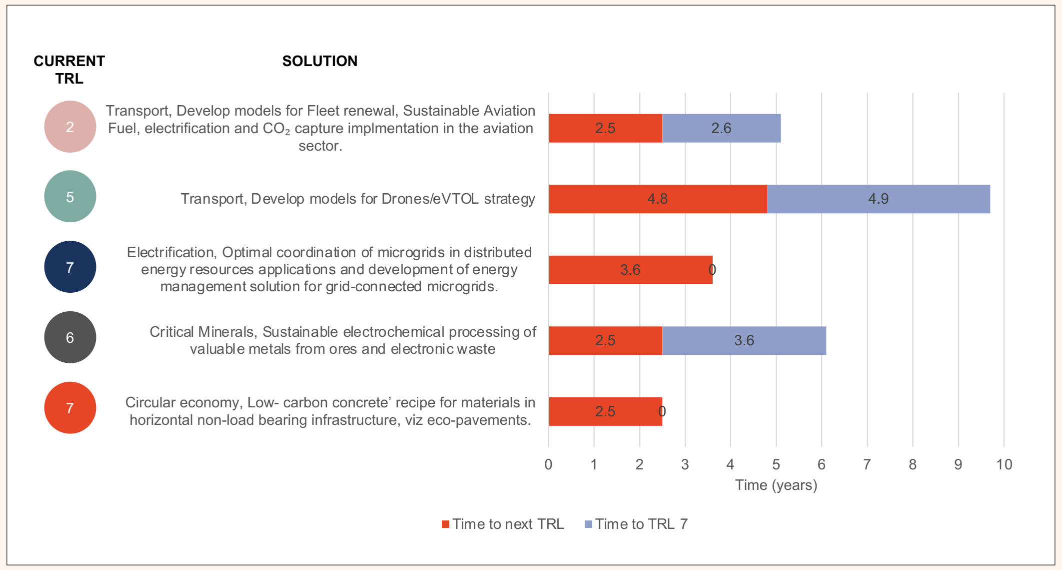


Figure 11: A pipeline of selected solutions from the Demand Reduction theme showing current TRL, time required to the next TRL and to TRL 7 (prototyping demonstration in an operational environment where the solution is at or near scale with most functions available).

Delivering co-benefits

- Demand reduction is focused on delivering energy services while using less energy, so it delivers reductions in all resources associated with the delivery of energy.
- We focus on solutions that extract valuable resources from waste streams and in so doing reduce emissions, energy use, virgin resources and waste streams.
- Our work will develop novel ways to extract resources critical to the net zero transition which will reduce the use of toxic chemicals in mineral extraction.
- The NZI is exploring new ways to manage road transport which will reduce fuel use and deliver the co-benefit of reducing congestion of roads.
- Our solutions are applicable at the local, regional and national scale, and so offer opportunities for remote Australian communities to implement net zero solutions that deliver benefits to the local communities.

Snapshot:
Reducing the demand for fuel in transport

Walking and cycling, known as active travel, are healthy and environmentally friendly options for shorter trips. However, the prevalence of active travel to schools has been decreasing for several reasons, including the growth of urban areas. We possess compelling evidence that the way our surroundings are built significantly influences active travel in general. Understanding how this impacts children's active travel to school can aid in designing cities that promote sustainable transportation habits from an early age.
Our modelling studies are particularly pertinent to regions experiencing new construction or redevelopment, making them valuable for organisations like the NSW Departments of Planning & Environment, and Education & Health.

Pressure Points: Cultural and political obstacles that hinder the expansion of walkable areas pose a challenge that our team intends to tackle through multidisciplinary NZI partnerships.

Contributed by Dr Emily Moylan (Civil Engineering), Dr Jennifer Kent (Architecture, Design & Planning), Laya Hossein Rashidi (PhD student, Civil Engineering). Photo attribution Dr Emily Moylan.

Snapshot:
Models for the Aviation Sector to Achieve Net Zero

The aviation industry is responsible for 2-5% of greenhouse gas emissions, and several airlines, including those in Australia, have pledged to achieve Net Zero emissions by 2050. Given the industry's continued growth and its challenging emissions reduction prospects, there are doubts about whether reaching net zero goals within the designated timeframe is attainable.

Teams from the University of Sydney Business School (specifically, the Institute of Transport and Logistics Studies), along with experts from the fields of Engineering and Science, are actively working on developing models tailored to the aviation sector. These models take into account various factors such as fleet modernisation, the adoption of sustainable aviation fuels, electrification, carbon dioxide capture methods, and behavioural changes.

For instance, one strategy involves integrating ground transportation seamlessly into the overall aviation value chain, which could potentially reduce CO_2 emissions by as much as 15%. The feasibility of this solution could be rapidly advanced from its current technology readiness level of 2 to 7 within the next three years if key challenges are effectively addressed. This solution has been specifically designed for Australia's busiest domestic air route, linking Sydney, Melbourne and Brisbane, and holds the potential for broader application in other geographical areas.

Pressure Points: The International Air Transport Association's Net Zero roadmap[47] envisions 13% of global airline emission reductions through electric and hydrogen propulsion, with 65% from sustainable aviation fuels. Achieving this demands extensive research and investment with associated risks and costs, possibly raising travel prices. Airlines and researchers strive for decarbonisation but face doubts about feasibility. Recent studies indicate potential for 13.5% emission reductions on Sydney-Melbourne journeys today and over 20% on other routes by shifting travellers from fossil-fuel cars to greener options. This overlooked opportunity warrants greater attention from airlines, airports, and travellers to reduce emissions in the entire travel process.

Contributed by Prof. Rico Merkert (USyd Business School)

Snapshot:
Western Sydney Aerotropolis Energy Hub

An energy hub is a comprehensive energy system that combines and manages various energy sources like electricity, gas, and heat to optimise energy production, storage, distribution, and use. It enhances energy supply efficiency, reliability, and sustainability, creating a versatile system that adapts to changing consumer needs.

In our collaborative project with Mitsubishi Heavy Industries for the Western Sydney Aerotropolis, we are establishing planning and operational models for system integration, using readily available technologies. These new development areas provide an opportunity to satisfy some energy needs locally. This reduces network expansion costs and improves efficiency by coordinating energy generation, storage, distribution, and consumption via a multi-energy system approach, essentially transforming these areas into energy hubs.

Pressure Points: The regulatory framework is lagging rapid technological developments.

Contributed by Prof. Gregor Verbic (Electrical Engineering) and Prof. Ali Abbas (Chemical & Biomolecular Engineering)

Snapshot:
Critical Minerals from e-Waste

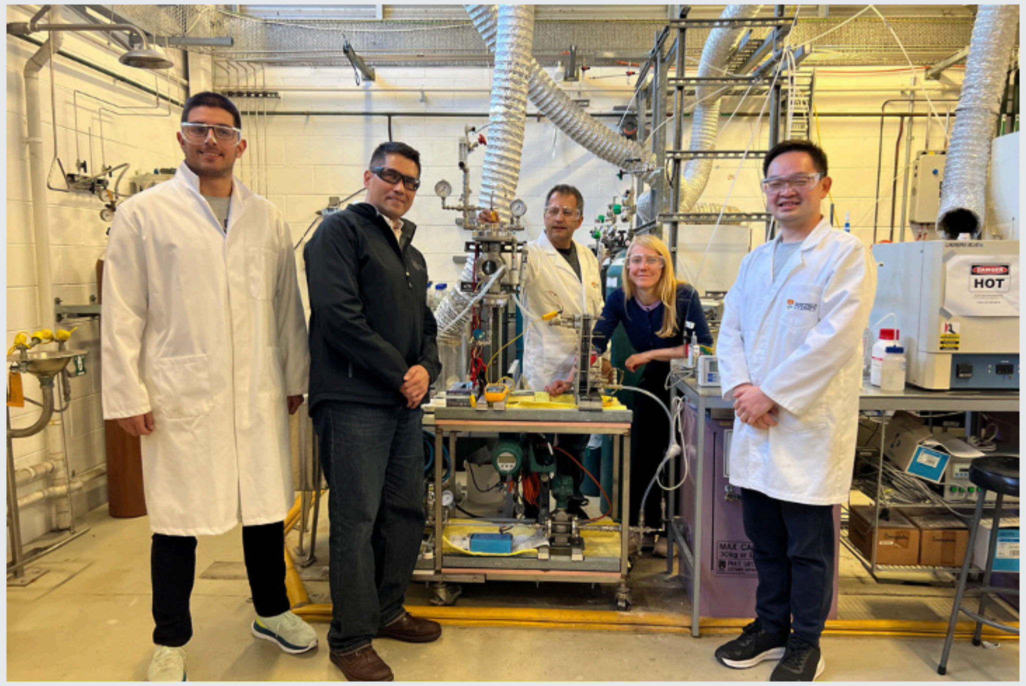
In a three-year project starting in June 2023, Associate Professor Alejandro Montoya and his team have partnered with the Mineral Research Institute of Western Australia and Separtis Pty Ltd, with contributions from stakeholders like Emew Clean Technologies, IGO Ltd, and Eilenburger Elecktrolise (EUT). A startup called Separtis Pty Ltd has recently been founded to seek investment for implementing this technology within the community.

The advanced electrometallurgical process is currently at technology readiness level 5. It has progressed beyond basic research, demonstrated a proof-of-concept, and validated its effectiveness at the laboratory scale for similar applications. The prototype reactor improves the efficiency of extracting copper, nickel, zinc, and tin from electronic waste and mineral ores while minimizing chemical waste. This technology offers environmental and cost benefits by producing green hydrogen as a by-product, contributing to Net Zero goals.

This solution addresses challenges faced by traditional mining operations, which consume significant energy and use hazardous chemicals, leading to toxic by-products that need careful management to reduce long-term environmental harm. With increasing demand for critical minerals in electronics, construction, and renewable energy, there's a need to reduce the environmental impact of resource extraction and adopt innovative, sustainable practices. This project promotes the use of electrolysers to enhance mineral extraction efficiency through in-situ chemical synthesis of potent oxidizers, streamlining the process of extracting critical minerals from solid resources. Additionally, it focuses on minimizing hazardous waste and selectively separating mixed products, driving broader environmental improvements.

By 2026, the project aims to develop a semi-integrated system for mineral extraction from various new materials, selectively purify specific minerals from soluble mixtures, and design a large pilot-scale prototype system for testing in community settings.

Pressure Points: Securing regulatory approvals from the Australian Environmental Protection Agency (EPA) is a crucial necessity for operating any pilot-scale electrolyser facility, encompassing activities like utilisation, storage, manufacturing, and handling of chemicals. Research-related uncertainties arise during the process of patent application submissions. Additionally, there are challenges in establishing and maintaining confidentiality agreements with external parties while also controlling the dissemination of sensitive information.



Contributed by A/Prof. Alejandro Montoya and Team including Dr Fengwang Li (Chemical & Biomolecular Engineering)

Theme 2. Zero Emissions Energy and Industry

Why this theme is important

Australia's transition to net zero emissions has an important waypoint, which is a 43% reduction in emissions by 2030. In turn, that short-term target is underpinned by a challenging target of 82% renewable electricity by 2030. Alongside the ambition of transitioning to zero emissions energy, the need to mitigate greenhouse gas emissions from the industrial sector, including many hard-to-abate processes (e.g. cement and steel production) is essential.

Zero emissions energy strategies such as electrification play an important role in the net zero transition because they can immediately reduce the energy used to provide an energy service. However, on its own, it does not get us to zero emissions. That only comes if the electricity itself is zero emissions or renewable electricity. The second part of the transition to net zero is the development of cost-effective zero emissions energy and industry.

The rollout of renewable electricity requires investment in new renewable generators such as wind farms and solar PV, and investment in new electricity grids to better link distributed renewable generators with consumers. Australia's evolution to 82% renewables penetration is experiencing significant headwinds that are reflected in challenges being experienced around the world. These barriers point to the research that is needed to realise the net zero roadmap.

We have seen a slowing of investment in renewable generation, which reflects a more challenging environment for investments in renewable energy generation. The Clean Energy Finance Corporation (CEFC) has flagged that Australia is "well behind the pace" to achieve 82% renewable energy generation by 2030.[48] Research is needed to better identify if structural weaknesses in the renewable energy industry are constraining investment in renewable electricity, and if our energy markets need to be redesigned to better reflect the wider benefits of renewable energy.

Community opposition is now impacting both new renewables projects and investment in transmission infrastructure. The Renewable Energy Alliance (RE-Alliance)[49] reported seeing examples of community resistance to new transmission infrastructure roll-out. RE-Alliance noted that this situation is not dissimilar to the one the wind industry found itself in about five to ten years ago, when instances of poor community engagement, inadequate benefit sharing, and a lack of awareness of local impacts led to widespread community opposition. A rising trend in local communities challenging renewable energy projects in the courts is also increasing the risk to developers, which leads to increases in costs and time to implement.[50]

New ways to manage the development of essential zero emissions infrastructure are needed. The falling investment also points to the need to both reduce the cost of renewable generation and to develop technologies that will enable the operators of renewable power systems such as wind farms to extract the maximum amount of electricity from the renewable resources. Developments in digital science provide a robust platform to build new systems that will drive improvements in renewable power generation.

An electricity network with a high penetration of variable renewable generators will rely on energy storage to stabilise the grids and ensure that electricity is available when it is needed. The deployment of storage in the future networks in Australia is proving to be more difficult than was hoped. Research is needed into new forms of energy storage to facilitate the deployment of low-cost renewable generation.

One route to future energy storage is the development of new types of batteries, which can involve novel battery chemistries or better ways to make existing batteries.

Electricity can also be stored by converting it to a high-energy fuel that can be readily stored and converted back to electricity as required. Hydrogen, with its high energy density and ability to be produced from renewable sources, has emerged as a potential solution for storing excess renewable electricity.[51] Used as a means of mid- and long-term storage of renewable electricity, the hydrogen must be generated using electrolysis. This has the additional benefit of generating green hydrogen that can be used as a fuel in other applications. It would then be competing with low-emissions hydrogen generated via steam methane reforming of natural gas coupled with carbon capture and storage.

Once generated from renewable electricity, the hydrogen must be stored. This is possible using different technologies, including compressed hydrogen gas, liquid hydrogen, and solid-state hydrogen storage materials. Compressed hydrogen gas is stored in tanks at high pressures, while liquid hydrogen requires extremely low temperatures. Solid-state storage materials, such as metal hydrides and chemical hydrogen storage compounds, offer potential advantages in terms of safety and storage capacity. Longer-term and larger storage options would be required if hydrogen were used to bridge major seasonal changes in electricity supply or heat demand, or to provide system resilience. The most appropriate storage medium depends on the volume to be stored, the duration of storage, the required speed of discharge, and the geographic availability of different options. In general, however, geological storage is the best option for large-scale and long-term storage, while tanks are more suitable for short-term and small-scale storage.[52]

The economic feasibility of hydrogen storage depends on various factors, including the cost of hydrogen production, storage technology, infrastructure development, and market demand. For instance, pumped-storage hydropower, compressed air storage and/or batteries will likely out-compete hydrogen for short- or even medium-term storage in support of power systems. Despite significant advancements, hydrogen storage still faces challenges in terms of cost competitiveness compared to other energy storage solutions. However, ongoing research and innovation are expected to drive down costs and improve overall economic viability.

Finally, we acknowledge the R&D that is required to realise future energy sources for Australia such as nuclear technologies, including fusion and fission. While outside the scope of this White Paper, the NZI does seek to provide an objective lens for such research in the future.

As well as being a potential medium for storing renewable electricity, hydrogen from renewable electricity can be used as a zero-emissions fuel. But there are other options. The challenge with hydrogen as a fuel lies in its transportation and storage. One option available is to further process the hydrogen into a zero-emissions liquid fuel that can be more easily transported and stored, such as ammonia (NH_3) or methane (CH_4). An example is the production of sustainable aviation fuel. Producing a zero-emissions liquid fuel requires more than just zero-emissions hydrogen. It also requires zero-emissions carbon which can be sourced from biomass, organic waste or withdrawn from the atmosphere. The latter falls into the domain of Greenhouse Gas Removals.

One route to future energy storage is the development of new types of batteries, which can involve novel battery chemistries or better ways to make existing batteries.

How the NZI is addressing Zero Emissions Energy and Industry

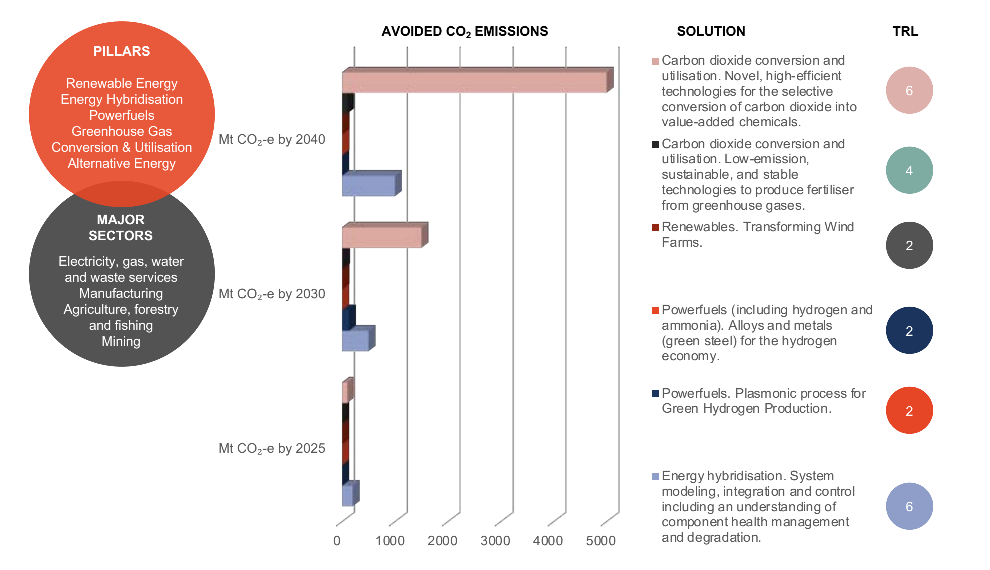


Figure 12: Snapshot of some solutions within the Zero Emissions Energy and Industry theme including Pillars, Major sectors contributed to by the solutions, Avoided CO_2 emissions and TRL (where relevant).

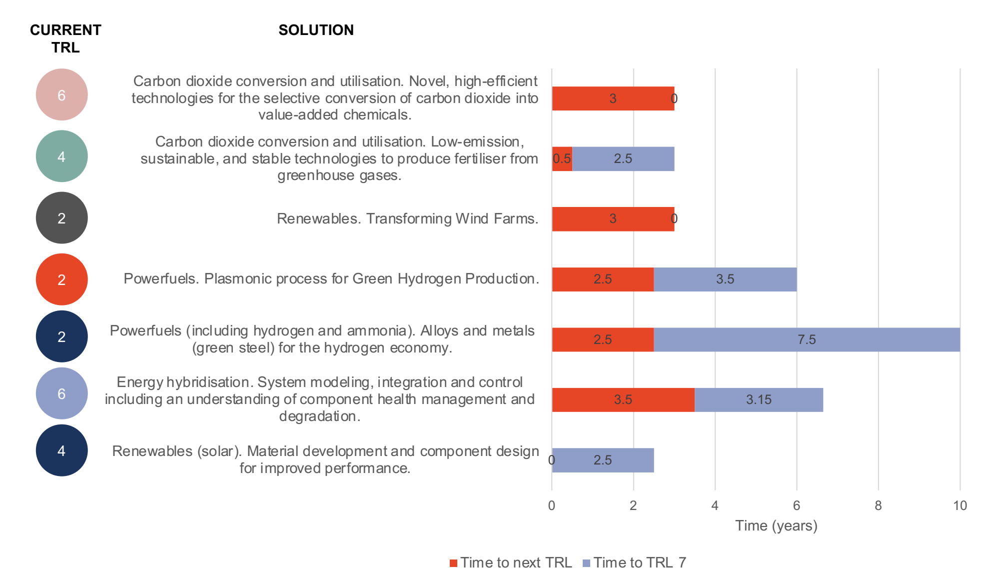


Figure 13: A pipeline of selected solutions from the Zero Emissions Energy and Industry theme showing current TRL, time required to the next TRL and to TRL 7 (prototyping demonstration in an operational environment where the solution is at or near scale with most functions available for demonstration and test).

Delivering co-benefits

- Our research is seeking more efficient solar panels and wind farms, which will reduce the cost of the net zero transition and reduce demand for critical resources required for the transition.
- The NZI is developing ways to utilise carbon dioxide which delivers emissions reductions along with the co-benefit of reduced resource use.
- Our work will reduce carbon emissions by using carbon-free feedstocks to produce green steels.
- Our solutions are improving hydrogen safety.

Snapshot:
Low Carbon Concrete Solutions by Waste Transformation Research Hub (WTRH)

Traditional concrete is notorious for its contribution to global CO_2 emissions, responsible for a staggering 8% of the total. With infrastructure development on the rise and a growing demand for sustainable materials, the need for eco-friendly alternatives has never been more apparent. The Waste Transformation Research Hub (WTRH), led by Professor Ali Abbas, Australia's Chief Circular Engineer, has devised a low-carbon concrete solution that is poised to reshape the construction industry and contribute to a more sustainable future.

The WTRH team has crafted an ingenious formula that combines waste materials and alternative binders to produce concrete with a remarkably reduced carbon footprint. The new formula has been successfully implemented in the creation of "eco-pavements" in several pilot projects. The technology has evolved to include concrete carbon capture, a groundbreaking solution that actively traps carbon emissions within concrete products.

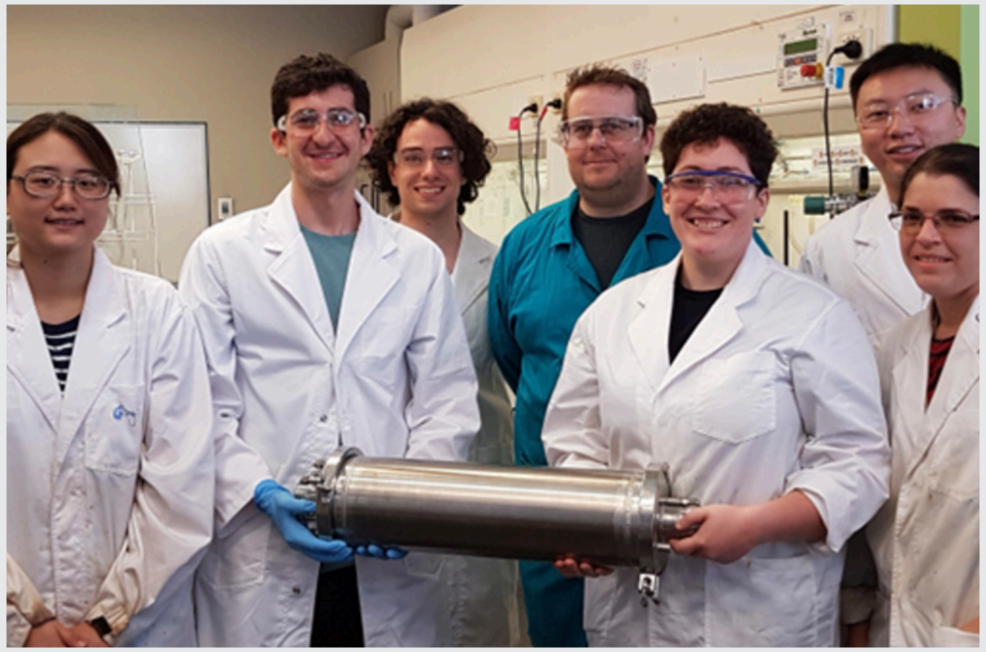
The eco-pavement technology has reached TRL 8, signifying its successful validation in pilot projects.

Ongoing pilot projects for eco-pavements have been in progress since 2020, with licensing in 2022 and council trials in 2023. The commercial availability of the product is expected by 2024, while the carbon capture technology aims for scale-up and commercial viability by 2025. Pilot projects have been conducted on the university campus and are soon to be trialled in local council areas in Sydney. The project is led by the University of Sydney with partners, Australian city councils, and construction companies all coming together to support and advance this pioneering work.

Pressure Points: Widespread implementation may require revisions in existing building codes, necessitating strong policy support. Engaging stakeholders, including construction companies and government bodies, is vital for scaling up these technologies. Additionally, securing funding for further R&D, particularly for optimising the carbon capture technology, remains a hurdle. Finally, market adoption by both the public and private sectors will be instrumental in realising the full potential of these innovations.

Contributed by Prof. Ali Abbas and Dr Gustavo Fimbres-Weihs (Chemical & Biomolecular Engineering)

Snapshot:
Direct Air Capture



The Sydney Sustainable Carbon Team who received the Musk Foundation's XPrize Student Prize to support the development of Metal-Organic Frameworks (MOFs) for Direct AIr Capture (DAC); Solar-powered DAC module in SGG's pre-production facility at the Brisbane Advanced Robotics for Manufacturing (ARM) Hub

In partnership with Southern Green Gas (SGG), a renewable energy company, the University of Sydney has developed and is fine-tuning Metal-Organic Frameworks (MOFs), which are central to Direct Air Capture (DAC) technology. This project has reached a technology readiness level of 5, and DAC modules are in pre-production at the Brisbane Advanced Robotics for Manufacturing (ARM) Hub. This technology is powered entirely by Australia's abundant solar energy resources.

The captured CO_2 can serve two purposes: it can either be employed for negative emissions through geochemical storage or used as a raw material for producing sustainable e-fuels like Sustainable Aviation Fuel. This partnership is actively pursuing both avenues.

Pressure Points: To enable the combination of DAC technology with long-term carbon storage for negative emissions, suitable locations need to be identified. In NSW, there is an ongoing assessment of the geological storage potential.[56] However, it's important to note that there's currently no supportive policy or legislation for this outside of QLD, SA, VIC, and offshore in WA.

Furthermore, in Australia, there are a lack of financial incentives for long-term carbon removal projects because the current costs are at least ten times higher than the target cost of US$100 per ton of CO_2. To address these challenges, there are opportunities for collaboration and shared benefits with regional, remote, and First Nations communities. Strong community involvement in such projects is vital for their success.

Contributed by Southern Green Gas and Sydney Sustainable Carbon (Chemistry and Chemical & Biomolecular Engineering)

Snapshot:
Fertilizer Production using Low Emissions Technology

This solution addresses several critical challenges faced by the traditional fertilizer production industry, including high greenhouse gas emissions, inefficiency, and dependency on fossil fuels. By developing advanced catalyst methods that are more efficient and selective, the project seeks to revolutionize fertilizer production, reduce emissions, and promote sustainable agriculture. The catalytic technology (currently at TRL 4) facilitates the integration of renewable hydrogen sources, such as electrolysis-powered hydrogen, into the production process, reducing emissions and supporting renewable energy technologies. The catalytic processes also enable the recovery of nutrients from waste streams, promoting the circular economy concept, reducing resource extraction, and minimizing environmental impact.

Key industry partner Incitec bring expertise in modeling costs, supply chain, and energy security to this project. Other stakeholders include the government, the agriculture sector, end-users and beneficiaries of sustainable fertilizer production, QUDOS, farmers and producers, as well as communities who may benefit from localised ammonia production.

Pressure Points: Strong policy support is crucial to facilitate the transition to catalytic fertilizer production and promote sustainability in agriculture. Practical implementation requires further development and scaling up of catalytic processes. The success of this project hinges on engaging stakeholders, including government, industry, and farming communities to ensure that they are well-informed about the benefits and feasibility of catalytic fertilizer production. Assessing economic viability and competitiveness against traditional methods is paramount. Equally vital is ensuring access to renewable energy sources for hydrogen production and ammonia synthesis.

These challenges highlight the importance of catalytic technologies in addressing sustainability challenges in the fertilizer industry and the need for collaborative efforts to bring about this transformation.

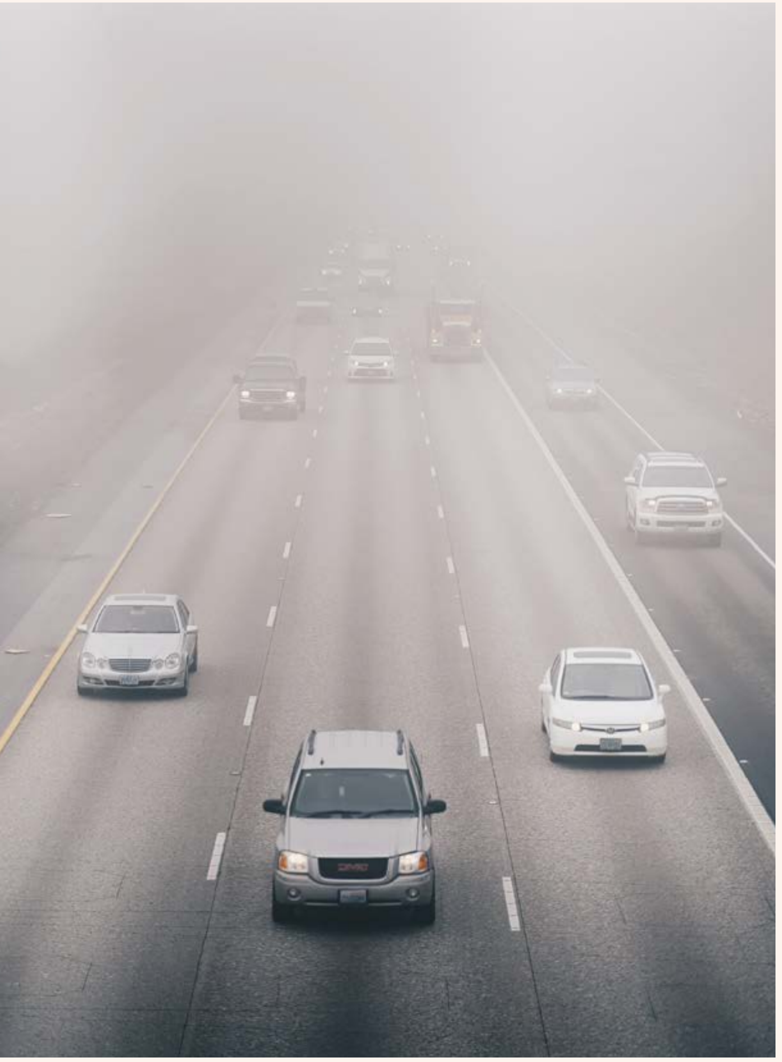
Contributed by Prof. Jun Huang, Dr Weibin Liang and Prof. Timothy Langrish (Chemical & Biomolecular Engineering) with Rupal Ismin (Sydney Knowledge Hub)

Theme 3. Greenhouse Gas Removals

Why this theme is important

While a significant focus is on emissions reductions, the Intergovernmental Panel on Climate Change (IPCC) says this will not be enough to avoid dangerous levels of global warming: the world must actively remove historical emissions already in the atmosphere through negative emissions, also known as Greenhouse Gas Removals (GHG Removals), or Carbon Dioxide Removal (CDR) in the case of removal of CO_2.

GHG Removals can be achieved in two ways. The first is by enhancing carbon storage in natural ecosystems, such as planting forests, storing carbon in soil or enhancing biological carbon fixation (e.g., synthetic biology and improving the capacity of marine systems). The second is by using chemical or geochemical approaches such as Enhanced Mineral Weathering or Direct Air Capture (DAC). In the Australian context, the NZI team has recently contributed to reports from the Australian Academy of Science on novel negative emissions approaches,[53] and from the Climate Change Authority on Australia's Carbon Sequestration Potential.[54]



DAC separates CO_2 from the ambient air using an engineered system, then either stores it underground (negative emissions) or turns it into products, creating a circular economy for carbon. DAC can be used to reduce the concentration of CO_2 in the atmosphere and mitigate its impact on climate change. Unlike carbon capture from point sources, such as power plants or industrial facilities, DAC can be deployed at any location and capture CO_2 from any source, including those that are mobile and dispersed. DAC can also provide CO_2 for various applications, such as synthetic fuels, carbon sequestration or utilisation.

There are different methods for DAC, but they generally involve a chemical process that binds CO_2 to a sorbent material, such as a liquid solution or a solid adsorbent. The sorbent material is then regenerated by applying heat, pressure or electricity, releasing pure CO_2 gas that can be stored or used. The energy required for DAC depends on the concentration of CO_2 in the air, the efficiency of the sorbent material and the purity of the CO_2 product. DAC is currently more expensive and energy-intensive than carbon capture from point sources, but it has the potential to become more cost-effective and scalable with further innovation and policy support.

Estimates of the future cost of DAC lie between \$100/t CO_2 and \$200/t CO_2 and even dropping below \$60/t CO_2 by 2040 or 2050.[55] This cost is higher than most other carbon removal options, such as afforestation, bioenergy with carbon capture and storage, or enhanced weathering. However, DAC has some advantages over these options, such as its scalability, flexibility, and low land and water requirements. It can also provide the renewable carbon for zero-emissions fuels.

DAC is still an emerging technology that requires further research and development to reduce its cost and improve its performance. The economics of DAC will also depend on the evolution of the energy system, the climate policy, and the social acceptance of this technology. DAC is not a "silver bullet" for solving the climate crisis, but it could be a valuable tool in the portfolio of carbon removal solutions.

How the NZI is addressing Greenhouse Gas Removals

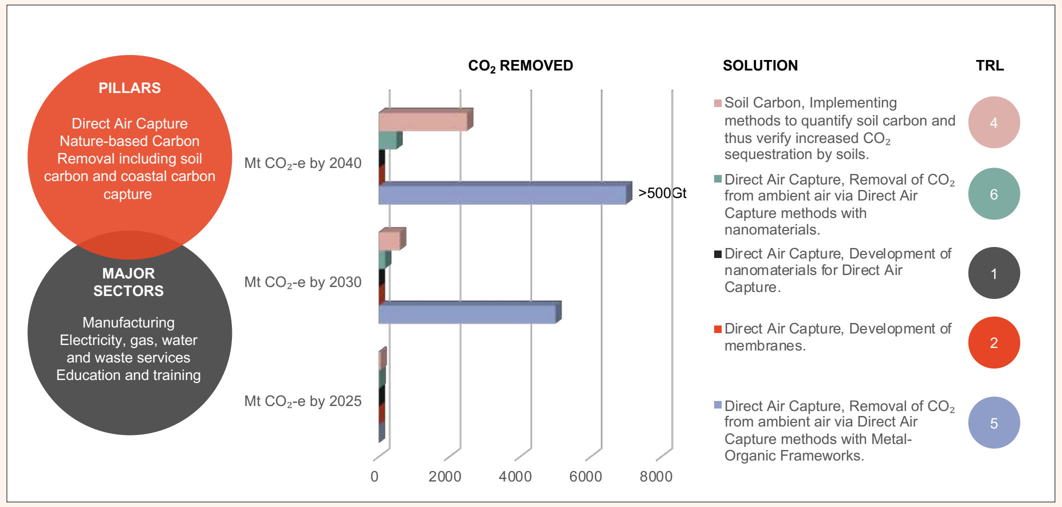


Figure 14: Snapshot of selected solutions within the Greenhouse Gas Removals theme including Pillars, Major sectors contributed to by the solutions, CO_2 removed and TRL (where relevant).

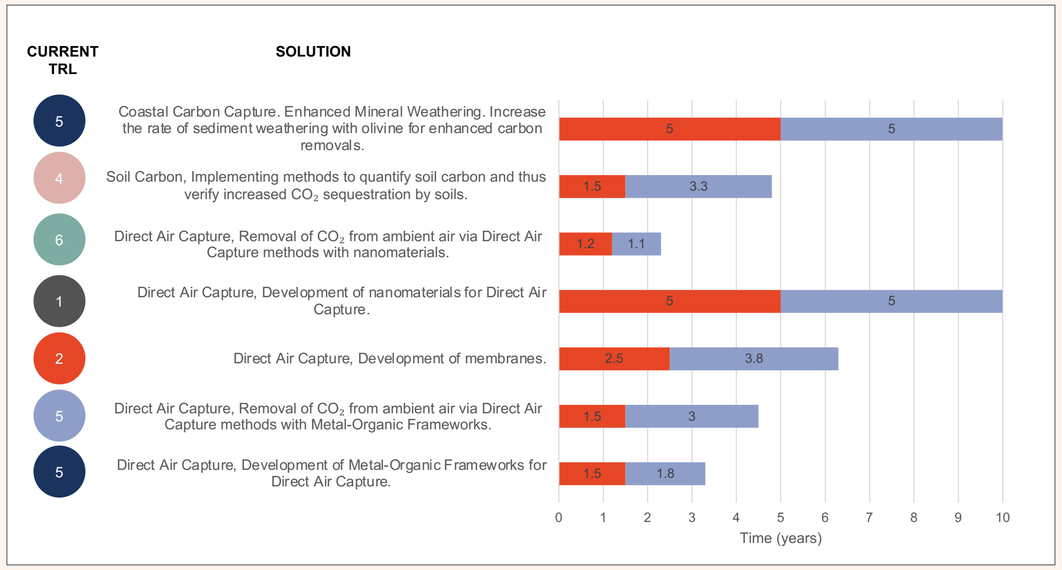


Figure 15: A pipeline of selected solutions from the Greenhouse Gas Removals theme showing current TRL, time required to the next TRL and to TRL 7 (prototyping demonstration in an operational environment where the solution is at or near scale with most functions available for demonstration and test). Note that several solutions for Direct Air Capture are available.

Delivering co-benefits

- We are developing novel DAC technologies that will provide opportunities to Australian industry to produce net zero solutions for the world.
- The NZI's carbon removal solutions are modular and deployable in regional communities, delivering economic benefits to those communities.
- Our technologies for removing CO_2 from the air are more widely applicable for various separation applications beyond CO_2 capture, such as production of zero emissions fuels and clean water.
- The nature-based carbon removal systems offer co-benefits such as improved soil condition/health and new approaches to agriculture.

Theme 4. Climate Change Risk

Why this theme is important

The transition to a low-carbon economy is essential to mitigate the effects of climate change. However, this transition also entails significant risks and disruption for various sectors, regions, communities and individuals.

The agriculture sector is particularly prone to climate change factors, and is the second largest source of emissions after energy. In Australia, agriculture contributes some 16% of Australia's emissions (emissions from land use change are not counted as agricultural emissions) and of this, around 70% are enteric emissions.

Contributions from the health care sector to net zero transition include improvements to sustainability of the health care system, as well as understanding and addressing the impacts of a changing environment on human health and wellbeing. To date, our researchers have begun investigating effects of climate change on occular health, with other health conditions (e.g., cardiovascular diseases) presenting further avenues for future investigation.

Asset owners and investors face the physical risks of climate change that encompass a wide range of environmental hazards posing significant challenges to both natural and built environments. Asset owners, whether they are individuals, businesses, or institutions, must recognise and address these risks to protect their investments and ensure long-term resilience. The physical risks include extreme weather events such as the severe flooding in Pakistan in 2023, rising sea levels which are threating coastal regions and leading to saltwater intrusion into freshwater resources,[57] and temperature extremes such as those seen in Europe and North America in mid-2023.

There are a range of actions that asset owners can take to mitigate the physical risk. Examples include diversifying investment portfolios to include climate-resilient sectors to help minimise the impact of climate-related market fluctuations and physical adaptation such as incorporating climate resilience measures into their properties and infrastructure. This might involve elevating structures in flood-prone areas, using heat-resistant materials, and designing buildings to withstand extreme weather events. Utilising climate risk insurance products and exploring options for risk transfer mechanisms can provide financial protection against climate-related losses.

But to properly assess the mitigation actions needed, asset owners need to understand and to qualify physical risks. This will rely on understanding how the changing climate will affect assets. Scenario analysis is a key technique as it helps asset owners understand how different climate futures may affect their investments. This informs strategic planning, stress testing, and the development of adaptive strategies.

Climate change poses not only physical risks but also transition risks to businesses, which stem from the shift towards a low-carbon and sustainable economy. As societies and governments worldwide aim to reduce greenhouse gas emissions and transition to cleaner technologies, businesses must adapt to new regulations, market dynamics, and consumer preferences. The net zero transition can result in policy and regulatory risks as governments implement stricter environmental regulations and climate policies, market risks and the transition to a low-carbon economy leads to shifts in market demand and preferences, technological risks as the rapid development of new technologies driven by the urgent need to reduce emissions sees the emergence of new cost-effective technologies, reputation risks if businesses fail to adapt to the reality of climate change or are found to be "greenwashing," and financial risks as investors are increasingly scrutinising companies' climate-related risks and opportunities.

The tools to undertake the necessary risk assessments are still being developed. However, the financial regulators and the capital markets are demanding greater visibility of the risks. McKinsey and Company estimate that the global annual expenditure on the physical assets required for the net zero transition is the order of $US9.2 trillion, including $1.0 trillion redirected to low-emissions assets and $3.5 trillion of new spending on low-emissions assets. Corresponding figures for Australia were estimated by Net Zero Australia in 2023.58 They found that Australia must spend on the order of $AU9 trillion on the transition over the next 37 years. These figures provide a view of the scale of the net zero transition and also the magnitude of potential financial disruption. Because most of this investment will come from private capital, it is essential for the research community who are focused on developing new low-emissions technologies and new systems to manage risk and engage with the business community to ensure that the challenges faced by businesses are being addressed.

Climate change poses not only physical risks but also transition risks to businesses, which stem from the shift towards a low-carbon and sustainable economy.

As the world grapples with the urgent need to address climate change, the concept of a "just transition" has gained prominence as a crucial framework for guiding the shift towards a more sustainable and low-carbon economy. The just transition seeks to ensure that the profound changes required to mitigate climate change do not disproportionately harm vulnerable communities and workers, and instead promote social equity, economic inclusivity, and environmental sustainability. The just transition is rooted in the recognition that climate policies and actions have real-world consequences for people's lives and livelihoods. As societies transition away from fossil fuels and other carbon-intensive industries, there is a risk that certain communities and workers may bear the brunt of these changes.

For instance, workers in coal mines, oil refineries, and other carbon-intensive sectors might face job losses and economic hardships. Achieving a just transition requires collaborative efforts among governments, businesses, labour unions, and civil society to develop and implement policies that safeguard workers, empower communities, and promote a fair distribution of the benefits of climate action.

But beyond this, it is important to explore the policy landscape and to understand how different polices, implemented in response to the disruption of the net zero transition can effectively shield citizens and communities form the full impact of the net zero transition.

How the NZI is addressing Climate Change Risk

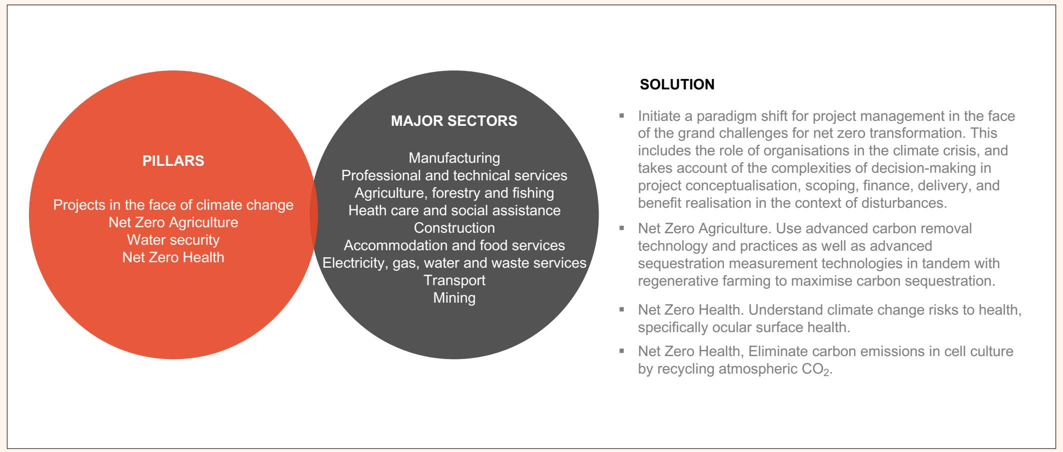


Figure 16: Snapshot of the Climate Change Risk theme including Pillars, Major sectors contributed to by the solutions.

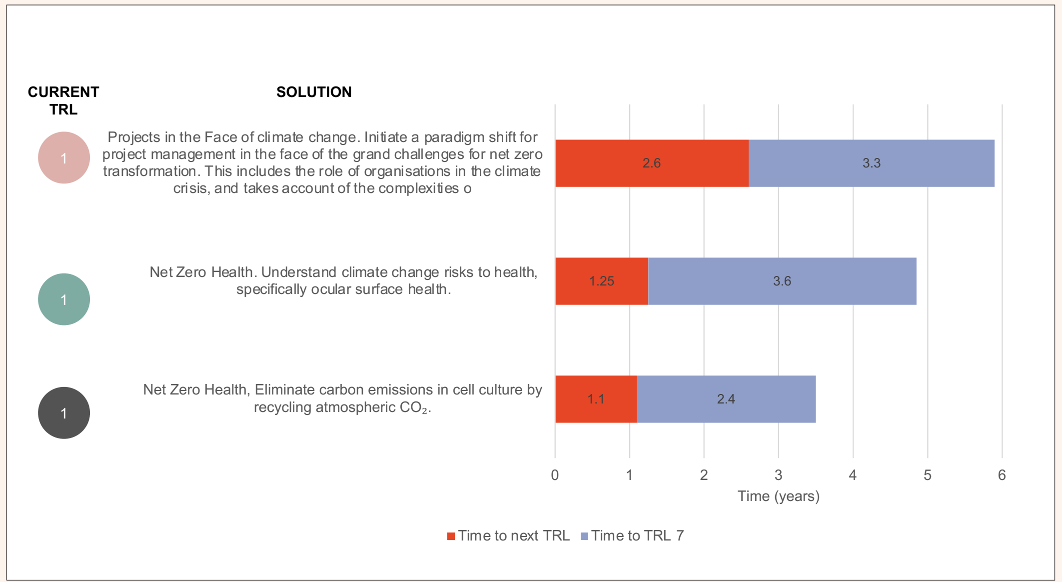


Figure 17: A pipeline of selected solutions from the Climate Risk theme showing current TRL, time required to the next TRL and to TRL 7 (prototyping demonstration in an operational environment where the solution is at or near scale with most functions available for demonstration and test).

Delivering co-benefits

- Net zero agriculture has the potential to deliver significant positive effects on our food systems, water and nutrient cycling, biodiversity, and our ecosystem.
- We are looking at ways that the health system can better manage its CO_2 use which reduced costs and risks as well as reducing emissions.
- The supply of clean water is another grand challenge that we face. The NZI is developing new, low energy approaches to water supply that will deliver robust water supply systems.

Snapshot:
Improving resilience of drinking water systems to support thriving communities

The increasing impact of climate change on the water industry requires the development of new approaches for operations and maintenance. These changes, in turn, have implications for the strategies of service providers such as owners and operators of water infrastructure. In response, this project has formulated guidelines that include recommendations for adjusting the business plans of water service providers to align with future climate change scenarios. These guidelines also explored how this adaptation can contribute to supporting net zero strategies.[59]

17 recommendations were made to aid resilience development. While some apply broadly, others can be adapted for specific situations. The classification is based on their contribution to enhancing resilience. The study, carried out by a team from Resilient Organisations (Tracy Hatton and Ellie Kay), RMIT University (A/Prof. Nader Naderpajouh, who is now at the University of Sydney), and Daniel Aldrich of Northeastern University, was based on the specific case of Australia and New Zealand but offers insights that can be applied on a global scale.

Pressure Points: This project concentrated on evaluating vital policies, community involvement, and strategies required to successfully expand and tackle the complexities presented by climate change. Thoughtful attention to these elements is imperative for future endeavours.

Contributed by A/Prof. Nader Naderpajouh (Project Management)

ANTICIPATION · MONITORING · LEARNING · RESPONSE

ANTICIPATION	1	Understanding your risks
ANTICIPATION	2	Engage citizens in better understanding of the risks and vulnerabilities
MONITORING	3	Create public resilience metrics
LEARNING	4	Find your burning platform
LEARNING	5	Tell good stories
LEARNING	6	Consider what message is appropriate
LEARNING	7	Learn from other countries and cultures
RESPONSE	8	Create effective organisational structures
ANTICIPATION	9	Continue building an adequate number of advocates and voices for resilience
LEARNING	10	Engineering education and professional bodies
RESPONSE	11	Provide the legislative mandate to act
RESPONSE	12	Build organisational resilience capabilities
LEARNING	13	Ensure water is valued
LEARNING	14	Embed resilience thinking at inception
RESPONSE	15	Consider alternative funding options
RESPONSE	16	Reflect system boundaries in governance arrangements
RESPONSE	17	Build and continue to best utilise co-operative networks

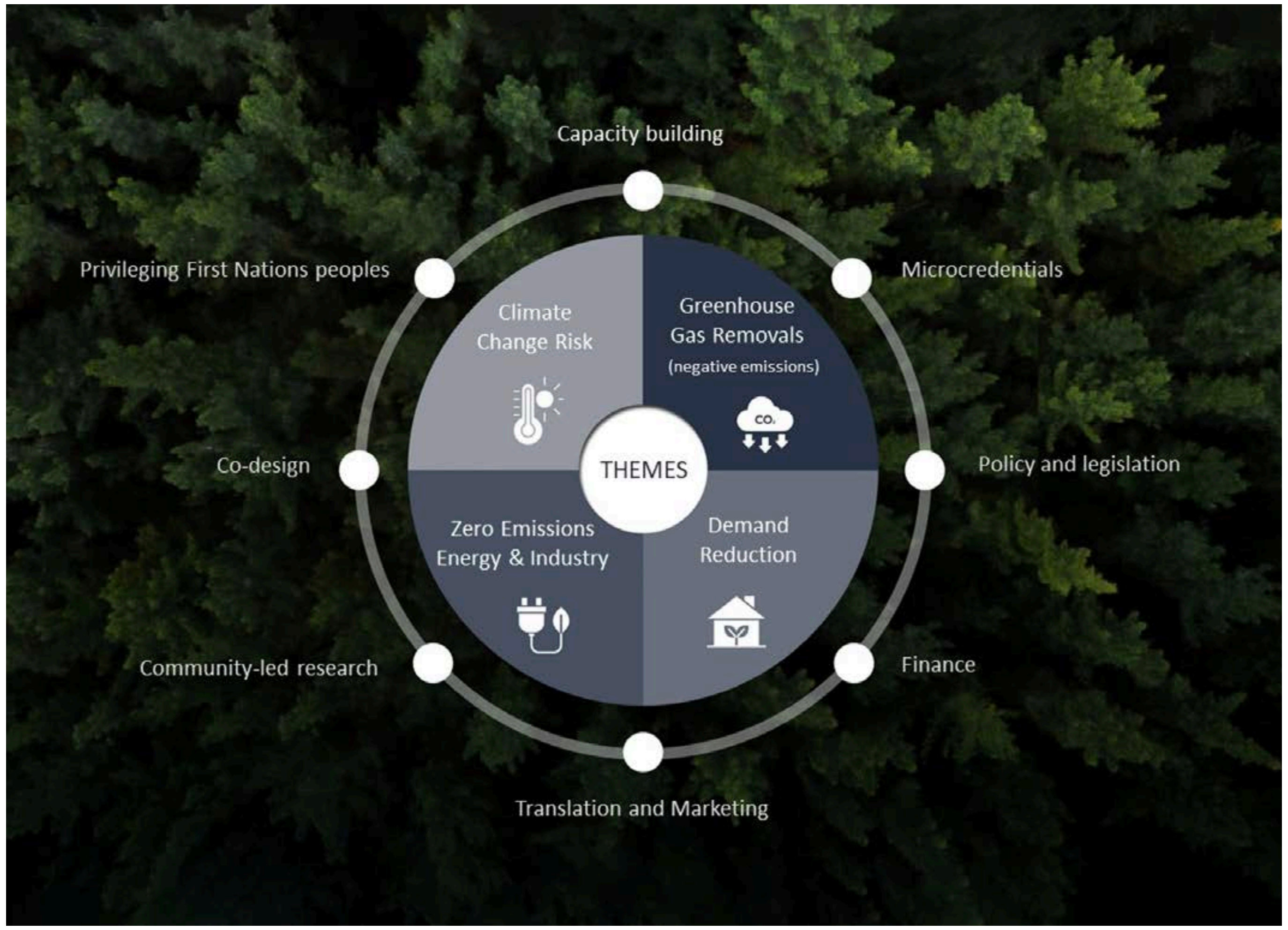


Figure 18: The NZI ecosystem

Integrating *NZI Solutions*

The Net Zero Initiative represents a portfolio of solutions that are STEMM-enabled (STEMM = Science, Technology, Engineering, Mathematics, and Medicine) and cross multiple disciplines to carefully integrate economic, social, legal and governance structures to ensure successful implementation. Underpinning the net zero transformation is the need for outcomes that repair and regenerate species and ecosystems. In response to Australia's 2021 State of the Environment Report,[60] the Federal Government has committed to a Nature Positive Plan (2022)[61] aimed at enhancing environmental and heritage outcomes.

Embracing circular economy principles, models, and systems is a fundamental requirement for all these solutions. This shift toward circular economy principles will receive federal support through the newly established Circular Economy Ministerial Advisory Group.[62]

Achieving a net zero transformation demands the integration of all these elements and necessitates a departure from traditional "business as usual" approaches. This shift in thinking is challenging but serves as a call-to-action for the research sector. The NZI directly confronts and addresses this challenge.

Underpinning the net zero transformation is the need for outcomes that repair and regenerate species and ecosystems.

Building solutions *through strong partnerships*

Solving complex problems for net zero transformation transcends the status quo of universities and elevates the conversation because the stakes are high: partnerships are essential to accelerate the transition, share knowledge and best practice, and avoid reinventing the wheel such that we accelerate the translation of solutions into practice.

As the NZI tackles complex challenges vital for achieving net zero objectives, its unique value proposition is rooted in providing answers to the question of how to execute this transition successfully. This approach entails forward-looking collaboration within our distinctive academic environment, as well as with external partners and stakeholders, to facilitate efficient co-design efforts.

Interdisciplinary research – the key to effective solution

There is no "silver bullet" to address the net zero challenge. The problem demands a portfolio of solutions that are STEMM-enabled and co-designed across multiple disciplines to carefully integrate economic, social, legal and governance structures to ensure successful implementation.

The NZI is actively pursuing this approach by fostering partnerships across all University Faculties, including its Multidisciplinary Initiatives, the Sydney Policy Lab, Sydney Knowledge Hub, Sydney Environment Institute, and Sydney Nano. Additionally, it collaborates with essential research facilities such as the Sydney Manufacturing Hub, Sydney Analytical, and Australian Institute for Microscopy & Microanalysis, among others.

Bringing stakeholders along

The NZI is guided by an expert Industry Advisory Board. This board is led by Dr. Clare Anderson, who serves as the Chair and holds the position of Director of Sustainability Performance at Worley. It includes representatives from both government and industry sectors, featuring partners from the NSW Government, HSBC, Hyundai, Mitsubishi Heavy Industries, Origin, Rio Tinto, Veolia, and Arnott's.

Learning from others – R&D Partnerships

The NZI's Scientific Advisory Board, led by A/Prof.(Hon) Alexandra Meldrum, plays a crucial role in guiding international R&D collaborations. These collaborations foster cutting-edge research and facilitate the exchange of researchers with partner institutions around the world. Our Board members include colleagues from partner institutions in Singapore (NTU Nanyang Environment and Water Research Institute), Japan (Yokohama National University), Finland (VTT Technical Research Centre), Vietnam (Vietnam Initiative for Energy Transition), the UK (Imperial College London), Italy (Eni), Korea (Korea Institute of Energy Research, KIER), and the Pacific (Asian Development Bank).

Furthermore, the NZI is actively expanding its network by forging connections with institutions in India, the USA, Canada, Indonesia, Thailand, and Malaysia. These partnerships contribute to the NZI's mission of driving innovation and advancing research in the pursuit of net zero emissions.

Where to *from here*

The NZI's focus on 'how' to actively achieve net zero emphasises a holistic approach that highlights the intricate fusion of environmental, economic, social, legal, and governance structures required to achieve a responsible transition. Partnerships are critical, fostering both spirited competition and collaborative efforts in our collective work. Adding biodiversity and embracing a nature-positive ethos injects an essential dimension.

Questions arise: how do biodiversity and Nature Positive intersect with net zero goals? As we embark on this transformative journey, the passion of our youth, represented in the next stage of the NZI by a dedicated Youth Advisory Board, contribute crucial perspectives and unwavering commitment to being part of the solution. This reinforces that our path to a sustainable, net zero future demands a skillful blend of innovation, collaboration, and inclusivity.

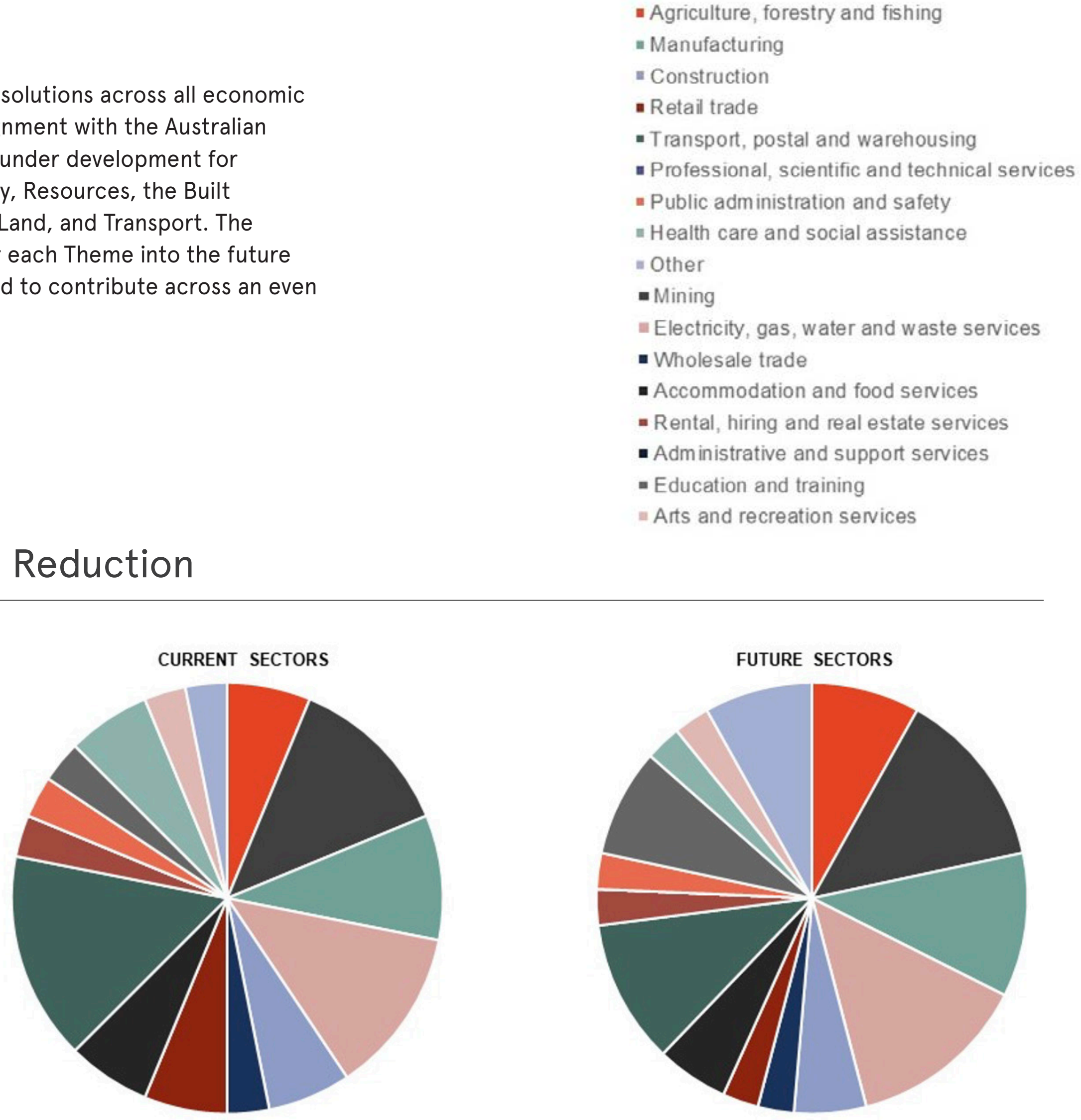
To successfully address the challenges ahead, we recognise the importance of finding more robust R&D funding opportunities, including embarking on partnerships that support major program grants. The strong foundation of the NZI team provides a degree of risk mitigation of our efforts as we embark on these ambitions, as we are already on a transformative pathway. Additionally, we must diversify our funding streams, moving beyond traditional government support. Building resilience in funding mechanisms that includes support from industry, business, philanthropy, and impact investment, offers the agility needed to nurture new ideas and accelerate their progress along the technology readiness scale. This approach operates on a different timescale, well-suited to the rapid pace of innovation.

Moreover, our analysis has demonstrated the significant need for dedicated spaces for prototyping and initial scaling of solutions. Leveraging local and state-based resources including our University farms, Special Activiation Precincts and NSW Investment Tech Central precincts will be instrumental in driving innovation. Finally, our team forms the core of our mission. Strengthening their capabilities within our community and guaranteeing they have access to the necessary support and resources is paramount to the NZI's success.

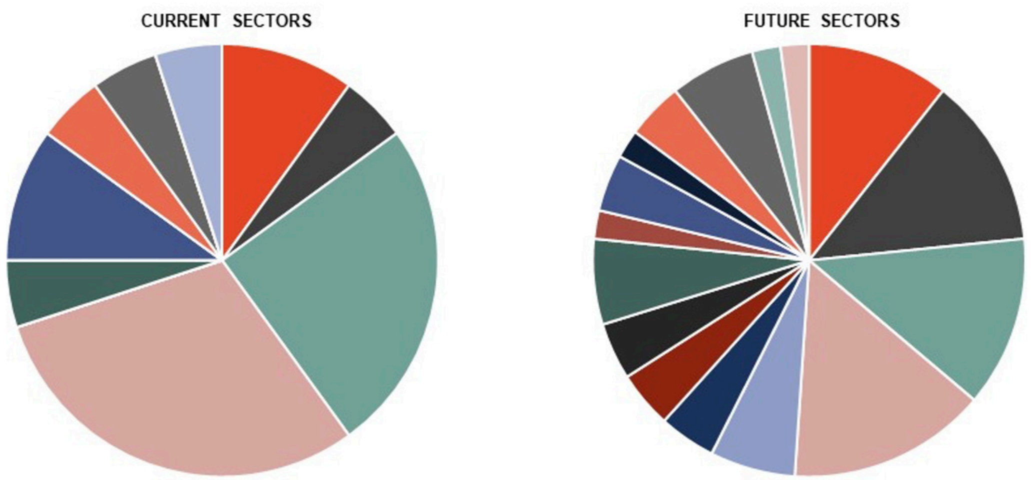
Appendix 1: NZI Contribution to Sectors

The NZI currently contributes solutions across all economic sectors wiich are in strong alignment with the Australian government's sectoral plans[65] under development for Electricity and Energy, Industry, Resources, the Built Environment, Agriculture and Land, and Transport. The projection of our solutions for each Theme into the future shows that they are anticipated to contribute across an even wider range of sectors.

Theme 1. Demand Reduction



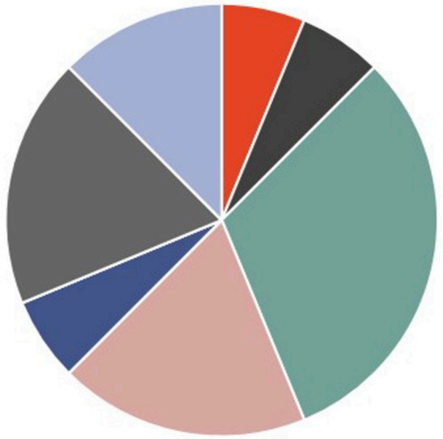
Theme 2. Zero Emissions Energy and Industry



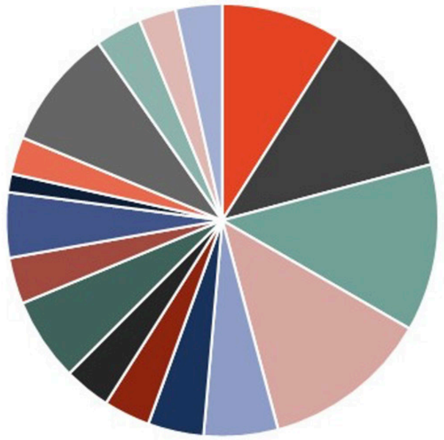
Appendix 1: NZI Contribution to Sectors

Theme 3. Greenhouse Gas Removals

CURRENT SECTORS

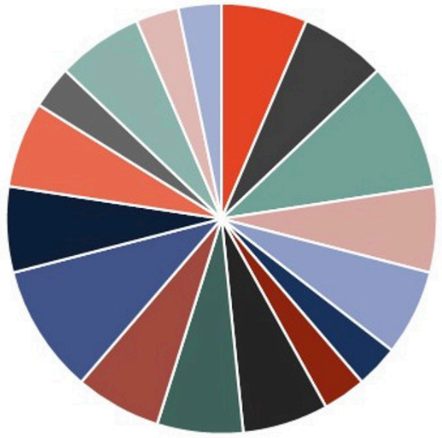


FUTURE SECTORS

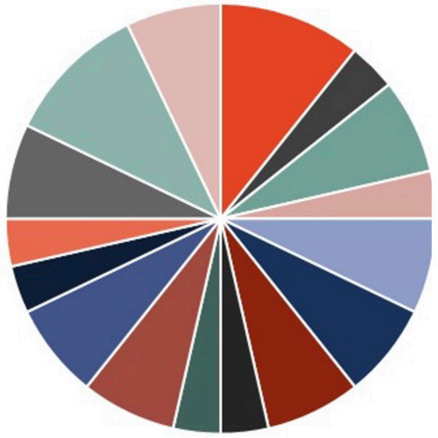


Theme 4. Climate Change Risk

CURRENT SECTORS



FUTURE SECTORS



- Agriculture, forestry and fishing
- Manufacturing
- Construction
- Retail trade
- Transport, postal and warehousing
- Professional, scientific and technical services
- Public administration and safety
- Health care and social assistance
- Other
- Mining
- Electricity, gas, water and waste services
- Wholesale trade
- Accommodation and food services
- Rental, hiring and real estate services
- Administrative and support services
- Education and training
- Arts and recreation services

Appendix 2: NZI Solutions Requirements

Theme 1. Demand Reduction

SOLUTION	Current TRL	Time to reach next TRL (years)	REQUIREMENTS	Funding to reach next TRL	Time to reach TRL 7 (years)	Funding to reach TRL 7
Transport, Develop models for Fleet renewal, Sustainable Aviation Fuel, electrification and CO_2 capture implmentation in the aviation sector.	2	2.5		$1M - $5M	2.6	$1M - $5M
Transport, Develop models for Drones/eVTOL strategy	5	4.8		$5M+	4.9	$5M+
Electrification, Optimal coordination of microgrids in distributed energy resources applications and development of energy management solution for grid-connected microgrids.	7	3.6	energy management, control and aggregation of distributed energy resources		already there	
Critical Minerals, Sustainable electrochemical processing of valuable metals from ores and electronic waste	6	2.5	biotechnology, geologist, materials scientist pilot carbonation space for pilot plant or field study	$500k - $1M	3.6	$5M+ (to increase TRL e.g., with mining companies)
Circular economy, Low-carbon concrete' recipe for materials in horizontal non-load bearing infrastructure, viz eco-pavements.	7	2.5	CO2 fixation certification, mineral analysis carbonation reactor with CO2 sensors, XRD analysis, etc. small laboratory space	$250k - $500k	already there	$100k - $250k

Theme 2. Zero Emissions Energy and Industry

SOLUTION	Current TRL	Time to reach next TRL (years)	REQUIREMENTS	Funding to reach next TRL	Time to reach TRL 7 (years)	Funding to reach TRL 7
Carbon dioxide conversion and utilization. Novel, high-efficient technologies for the selective conversion of CO2 into value-added chemicals such as methanol, ethanol etc.	6	3		$1M - $5M	3	$1M - $5M
Carbon dioxide conversion and utilization. Exploring low-emission, sustainable, and stable technologies to produce fertiliser from greenhouse gases.	4	0.5		$250k - $500k	2.5	$1M - $5M
Renewables. Transforming Wind Farms	2	3	Research investment of 2 personnel for 3 years, High Performance Computing time; Access to wind farm site and operator.	$1.5M	3	$5M+
Powerfuels. Plasmonic process for Green Hydrogen Production	2	2.5	Research Associates and funds for consumables	$1M - $5M	3.5	$5M+
Powerfuels (including hydrogen and ammonia). Alloys and metals (green steel) for the hydrogen economy.	2	2.5	Research investment of personnel; Steel Furnace Simulator; 50 m x 50 m space; access to low cost hydrogen and handling infrastructure; hydrogen storage and transmission infrastructure	$800k	7.5	$1M - $5M
Energy hybridization. System modeling, integration and control including an understanding of component health management and degradation.	6	3.6		$5M+	3.2	$1M - $5M
Renewables (solar). Material development and component design for improved performance.	4		IP generation required to reach next TRL, in addition to increased cell and module area for demonstration of 10 m x 10 m. To reach TRL 7, need for customer evaluation leading to pilot production (40 m x 20 m).	$1M - $5M	2.5	$5M+

Appendix 2: NZI Solutions Requirements

Theme 3. Greenhouse Gas Removals

SOLUTION	Current TRL	Time to reach next TRL (years)	REQUIREMENTS	Funding to reach next TRL	Time to reach TRL 7 (years)	Funding to reach TRL 7
Coastal Carbon Capture. Enhanced Mineral Weathering.	5	5	Methods and equipment to accurately measure rates of carbon removal. Technology scale-up required.		5	
Soil Carbon. Implementing methods to quantify soil carbon and thus verify increased CO_2 sequestration by soils.	4	1.6	Investment; Development in the field and field testing; Multiple testing units distributed across the country.	$4M	3.3	$4-5M
Direct Air Capture. Removal of CO_2 from ambient air via Direct Air Capture methods with nanomaterials.	6	1.2		$1M - $5M	1.1	$1M - $5M
Direct Air Capture. Development of nanomaterials for Direct Air Capture.	1	5		$1M - $5M	5	$5M+
Direct Air Capture. Development of membranes.	2	2.5	Research Assistant with membrane engineering background; Demonstration rig; On-site sponsoring by a company. To reach TRL 7, need for research team and pilot rig.	$500k - $1M	3.8	$1M - $5M
Direct Air Capture. Removal of CO_2 from ambient air via Direct Air Capture methods with Metal-Organic Frameworks.	5	1.6	Measurement/modelling of dynamic performance; Prototype/scale-up space. To reach TRL 7, need for lifecycle analysis for operational performance under real-world conditions; dynamic breakthrough experiments, mixed gas/vapour adsorption.	$500k - $1M	3	$5M+
Direct Air Capture. Development of Metal-Organic Frameworks for Direct Air Capture.	5	1.5	Scale-up synthesis apparatus and physicochemical testing under dynamic conditions; prototyping space.	$500k - $1M	1.8	$5M+

*Enhanced mineral weathering. Increase the rate of sediment weathering by intentionally mining, grinding, and spreading olivine on beaches where the increased surface area (from mechanical grinding) and tumbling action of waves results in dissolution rates thousands of times faster than typically found in nature.

Theme 4. Climate Change Risk

SOLUTION	Current TRL	Time to reach next TRL (years)	REQUIREMENTS	Funding to reach next TRL	Time to reach TRL 7 (years)	Funding to reach TRL 7
Projects in the Face of climate change. Initiate a paradigm shift for project planning and execution in the face of such grand challenges. This includes the role of organisations in the climate crisis, and takes account of the complexities of decision-making in project conceptualisation, scoping, finance, delivery, and benefit realisation in the context of disturbances.	1	2.6	Funding required to conduct research which includes accommodating and supporting the development of a revised methodology, tool and demonstrated case studies. Computers and office space are also required.	$250k - $500k	3.3	$500k - $1M
Net Zero Agriculture. Use advanced carbon removal technology and practices as well as sequestration measurement technologies in tandem with regenerative farming to maximise carbon sequestration.						
Net Zero Health. Understand climate change risks to health, specifically ocular surface health.	1	1.25	Funding and industry/community collaboration.	$250k - $500k	3.6	$500k - $1M
Net Zero Health. Eliminate carbon emissions in cell culture by recycling atmospheric CO2.	1	1.1	Funding required for researchers in CO2 recycling and in mechanical engineering. Industry partner required to help accelerate the translation.	$100k - $250k	2.4	$500k - $1M

Appendix 3: NZI Solutions

Theme 1. Demand Reduction

Demand Reduction: Circular economy | Low-carbon concrete recipe for materials in horizontal non-load bearing infrastructure, viz eco-pavements

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		■
Manufacturing		■
Electricity, gas, water and waste services		
Construction	■	■
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

Other: *Infrastructure, it could affect how CO_2 is being transported.*

SOLUTION IMPACT

DIRECT IMPACTS

1. Providing a long-term carbon sink for captured/separated CO_2
2. Reducing impact of a high-emitting industry sector
3. Reducing embedded carbon emissions from infrastructure

INDIRECT IMPACTS

1. Fly ash waste impact reduction
2. Heavy metal pollution impact reduction
3. Other waste reduction (e.g. glass, plastic, agricultural, etc)

CUSTOMERS OF THE SOLUTION

Councils
Government roads departments
Developers
Construction industry

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

New green concrete production industry will open new opportunities for workers. skills such as waste recycling, contaminated waste stabilisation and reuse.

Regions & Communities

Regional industries with no access to long-term carbon sinks (e.g. too far from geological storage or CO_2 transport lines) will have a new proven option for sequestering ans abating their emissions.

Investors & Companies

Reduce environmental impact and carbon footprint of new infrastructure, potentially negative emissions if biogenic CO_2 sources are sequestered.

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

Significant implications for concrete manufacturers and their customers as this is a hard to abate sector.

FURTHER SOLUTION IMPACTS

Solution impacts could potentially be much higher, depending on level of carbonation.
Impacts concrete manufacturers and their customers.

ALIGNMENT WITH GLOBAL/NATIONAL DECARBONISATION STRATEGIES

Will make a small but useful contribution of 6T CO_2 per km of road.

CASE STUDY: The Waste Transformation Research Hub at USyd, led by Prof. Ali Abbas, with collaborators including Dr Gustavo Fibres-Weihs has been instrumental in developing low carbon engineered ecopavements, and their collaboration with Circrete has been a key factor in this success. Recently, USyd and Circrete have conducted eco-pavement trials, pouring low-carbon concrete on the campus, and have ongoing trials of the ecopavements with local councils, resulting in successful optimisation of the workability of the low-carbon concrete ecopavement products.

Demand Reduction: Critical Minerals | Sustainable processing of minerals: Sustainable electrochemical processing of valuable metals from ores and electronic waste

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining	■	■
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction	■	■
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing	■	■
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		■
Health care and social assistance		
Arts and recreation services		

Other: *Infrastructure*

SOLUTION IMPACT

DIRECT IMPACTS

1. Extraction of critical minerals from wastes
2. Generation of hydrogen at no extra cost
3. Reduce energy inputs
4. Net Zero mining
5. Potential to remove CO_2 from other industries
6. Revenue stream for mining industry through carbon certification

INDIRECT IMPACTS

1. Reduce use of toxic chemicals in mineral extraction
2. New modular systems to use in remote locations
3. De-risk electrification

KEY PARTNERS

Manufacturers
Mining Industry
Electronic generators
Fuel and Energy Producers
Farmers
Indigenous Communities

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Overseas locations currently handle the extraction of critical minerals from electronic waste (e-waste), while Australian workers remain engaged in their current recycling practices. The emergence of the new technology presents fresh prospects for the creation of a domestic industry focused on the recovery and reutilisation of these vital minerals. Electrification will demand significant metal production and a corresponding workforce in mining.

Regions & Communities

The new technology can be implemented in modular systems, enabling the local execution of recycling and the recovery of value-added products. Local implementation minimises logistical complexities and carbon emissions associated with long-distance transportation, thereby promoting sustainability and reducing environmental impact. The capture and storage of CO_2 will buy out the time to enable industries and communities to transition to electrification.

Investors & Companies

As the demand for renewable energy technologies, electric vehicles, and other low-carbon solutions continues to rise, the availability of these essential minerals becomes crucial. By recovering and reusing these minerals from electronic wastes, companies can reduce their reliance on virgin resources, which often require energy-intensive extraction methods.

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https://www.bhp.com/news/articles/2020/09/unlocking-the-potential-of-mineral-carbonation
https://www.riotinto.com/en/news/releases/2021/rio-tinto-and-carbfix-partner-for-carbon-capture-and-storage
https://www.vale.com/w/vale-begins-reusing-tailings-at-carajas-dam-using-equipment-with-zero-co2-emissions

Internal information (not published yet due to patent pending)

OTHER CRITICAL MINERALS SOLUTIONS FROM THE NZI TEAM

Our researchers are also working on the exploitation of microbiome for the efficient extraction of metals from ores and metallic wastes.

Theme 1. Demand Reduction

Demand Reduction: Electrification | Optimal coordination of microgrids in distributed energy resources applications: development energy management solution for grid-connected microgrids

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		■
Manufacturing		■
Electricity, gas, water and waste services	■	■
Construction		■
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		■
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

- Building development
- Technology developers
- Business opportunities, especially for Small to Medium Enterprises (SMEs)

SOLUTION IMPACT

DIRECT IMPACTS

1. Reduction of CO_2 emissions
2. Better utilisation of distributed energy resources
3. Reduced cost of electricity

INDIRECT IMPACTS

1. Empowering of end energy users (prosumers)
2. New business opportunities
3. Democratisation of electricity supply

INVESTMENT REQUIREMENTS

All the technology is ready now.
Needs to move to integration.

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Grid and market integration of distributed energy resources will require new skills in the electric power industry workforce, including 'non- traditional' ICT and data science skills.

Regions & Communities

Microgrids will create job opportunities in regional Australia.

Investors & Companies

New business models will emerge.

BANKABILITY

Depends on regulation - currently this is fragmented so a key requirement is unified policy.
Incentives for individual households.
Transparency of investments is required, e.g., through Super funds.

Demand Reduction: Electrification | Modelling and analysis of renewable energy grid: development of a planning and operational model for green energy hubs

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		■
Mining	■	■
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing	■	■
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

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https://www.dcceew.gov.au/climate-change/publications/australias-long-term-emissions-reduction-plan
https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-updates

SOLUTION IMPACT

DIRECT IMPACTS

1. Reduction in CO_2 emissions
2. Better utilisation of distributed energy resources
3. Reduced cost of the energy transition

INDIRECT IMPACTS

1. Empowering of end energy users (prosumers)
2. New business opportunities
3. Democratisation of the electricity supply

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

New technologies, e.g. wind and solar generation, distributed energy resources (rooftop solar PV, home batteries, electric vehicles) and ICT and big data technologies will require a workforce with new skills.

Regions & Communities

The energy transition will require new skills in the electricity sector, which will create job opportunities particularly in regional Australia but also elsewhere.

Investors & Companies

New business models will be required to integrate new energy resources, particularly at the distribution level (e.g. virtual power plants, home energy management solutions, and operation of fleets of electric vehicles).

CASE STUDY: ARENA commissioned NERA Economic Consulting and Energy Synapse (https://arena.gov.au/knowledge-bank/valuing-load-flexibility-in-the-nem/) to model the potential value of flexible demand in the electricity transition. This study provides important information on how increased demand-side participation across major sectors of the Australian economy can contribute to the energy transition.

Theme 1. Demand Reduction

Demand Reduction: Transport (land) | Use choice modelling to understand and predict behaviour and social licence related to low-carbon travel under various future scenarios

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services	■	■
Construction		
Wholesale trade		
Retail trade	■	■
Accommodation and food services	■	■
Transport, postal and warehousing	■	■
Rental, hiring and real estate services	■	■
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training	■	■
Health care and social assistance	■	■
Arts and recreation services	■	■

CASE STUDY: The Institute of Transport and Logistics Studies at the University of Sydney has a strong track record of modelling choices to support decisions about big scale investment in sustainable transport (e.g. Australian high speed rail).

SOLUTION IMPACT

DIRECT IMPACTS

1. Predict/forecast consumer demand for net zero technologies
2. Model hypothetical future scenarios based on various combinations of net zero technologies

INDIRECT IMPACTS

1. Broaden the application of choice modelling to many contexts and markets within the Net Zero space

TRL AND INVESTMENT REQUIREMENTS

Solution is TRL 9 and ready

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

Transport budget
Mode share
Sustainability

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Use choice modelling to understand how workers decide to upskill or not. Specifically, building on knowledge of the transport network and accessibility concepts to ensure that the right workers have access to the right jobs.

Regions & Communities

Due to land use and demographic patterns, there are deeply entrenched spatial correlations in travel choices. Understanding the impact on regions and communities requires methods for quantifying this spatial heterogeneity.

Investors & Companies

Companies need to know their market, and choice modelling in the net zero space will let them predict who their customers are.

CUSTOMERS OF THE SOLUTION

Individuals
People responsible for curb-side EV charging.
This "solution" is a mechanism to understand and influence social license for net zero efforts. Before we attack social license, there needs to be political will and a conducive policy environment. These can evolve together.

BANKABILITY

Consider whether conversation of trips could result in credits.
Firms meeting targets could be an incentive.

WIDER APPLICATIONS OF THIS SOLUTION

Since its invention, choice modelling has been applied to transport decisions. The NZI will have many stakeholders making decisions (especially consumers in energy markets) that have not been as well modelled as transport choices.

Demand Reduction: Transport (land) | Measuring social impacts of the NSW Electric Vehicle Strategy

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services		
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing	■	■
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Identify the social distribution of (dis)benefit of the transition to electric vehicles.
2. Identify issues likely to influence social license to make changes.
3. Informs where we do not need to waste money to maximise the electrification process (we have enough EV charger locations already).

INDIRECT IMPACTS

1. Guidance for how we can quantify social impacts in the Net Zero space.

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Access to green jobs is one of the measures of social impact that we covered in our literature review. In the context of the EV strategy, this includes car mechanics, petrol station workers, and the bus industry.

Regions & Communities

The EV Strategy already has a focus on regions and communities hosting chargers and supporting consumers to purchase EVs. Our work is looking at the equity between regions and communities.

Investors & Companies

Pivoting on the regulatory model for petrol stations, and measuring the evolving social impact of the strategies, investors could use our work to make informed decisions about the equity impacts of investing in EV charging infrastructure.

NOTES

This solution is technical in the sense that it is data-rich analytics, but it is not a technology we are developing.

CASE STUDY: The Institute for Transport and Logistics Studies at the University of Sydney partnered with the NSW Department of Planning and Environment to check for unintended equity outcomes of the portfolio of electric vehicle policies. Outcomes will be incorporated into guidelines for monitoring and evaluating government programs.

Theme 1. Demand Reduction

Demand Reduction: Transport (including land and aviation) | Development of models for Drones/eVTOL strategy

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing	■	■
Mining	■	■
Manufacturing		■
Electricity, gas, water and waste services		■
Construction		■
Wholesale trade		
Retail trade		
Accommodation and food services		■
Transport, postal and warehousing		■
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		■
Health care and social assistance		
Arts and recreation services		

Other: if this takes off, it will revolutionalise people mobility and freight logistics and all that with zero CO_2 emissions

SOLUTION IMPACT

DIRECT IMPACTS

1. Mobility and freight transport at zero carbon emissions
2. Mobility and freight transport to hard to reach locations
3. More resilient supply and travel chains

INDIRECT IMPACTS

1. Slowing down climate change
2. Less congestion on the roads
3. Economic growth (i.e. in regional and rural Australia)

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

This will be an entirely new industry. Remote pilots, traffic controllers, maintenance engineers and software/data scientists will be in high demand.

Regions & Communities

It will connect regions and communities in terms of both mobility and freight logistics (i.e. last mile delivery). Tourism in the regions will also benefit.

Investors & Companies

There is extensive investment going into this already. Again, an emerging industry and if it becomes scalable this will be revolutionary and highly profitable, but also good for economies and society in the transformation towards Net Zero.

Demand Reduction: Transport (aviation)| Development of models for Fleet renewal, Sustainable Aviation Fuel, electrification and hydrogen implementation in the aviation sector

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing	■	■
Mining	■	■
Manufacturing	■	■
Electricity, gas, water and waste services		■
Construction		
Wholesale trade	■	■
Retail trade	■	■
Accommodation and food services	■	■
Transport, postal and warehousing	■	■
Rental, hiring and real estate services		■
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety	■	■
Education and training		
Health care and social assistance	■	■
Arts and recreation services		

Other: Aviation will support even more industries in the future here in Australia both through passenger and freight services. NOTE: all AUS airlines have committed to net zero by 2050

SOLUTION IMPACT

DIRECT IMPACTS

1. Reduce emissions by up to 35%.
2. Reduce cost and as such make flying also financially more sustainable.
3. Introduce newer/modern aircraft and hence keep the public satisfied.

INDIRECT IMPACTS

1. Slow down climate change
2. Put Australia on the map as a leader in sustainable aviation (i.e., electric for short and hydrogen/SAF for long haul)
3. Keep communities (remote/regional/ island/rural) connected both in terms of passenger but also freight services
4. Reducing emissions of other GHGs - in percentage terms similar to the above (up to 30% by 2040) which is important, especially in the context of contrails.

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

There will be a lot of new engineering and business jobs related to aviation decarbonisation directly and also indirectly through the supply chain and the required logistics for SAF/hydrogen etc.

Regions & Communities

Regional, rural and remote communities will benefit immensely from this solution, as they are hit hardest by climate change and also because a more sustainable aviation industry will keep them connected but from a mobility and freight perspective.

Investors & Companies

There are substantial opportunities for investors and companies that come with net zero aviation, not just in hydrogen/SAF but all sort of other fleet and ground related projects.

TRL AND INVESTMENT REQUIREMENTS

READY - SAF (but expensive)
TRL 4/5 - Electric for short flights - needs 10 years
TRL 2/3 - Hydrogen - turn over issues, hybrid hydrogen - needs about 10 years

IMPACTS OF THE SOLUTION

IATA plan - Airlines might not be on board with this
1. Sustainable aviation fuel (SAF)
2. Electrical/hydrogen small
3. Carbon capture

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

More cost for fleets/fuels
Understand how much fleet renewal (30-40 years) will work on its own

REFERENCES

Aviation generally only accounts for 3.5% of (CO_2 +non-CO_2) emissions related to global warming globally but may account for 4-5% by 2030. The industry is still growing and so without the proposed solutions we would not only not contribute to the target but go negative. It is also important to acknowledge that the emissions happen at high altitude where they do more harm in terms of climate change. While the above includes domestic and international emissions of Australian airlines it does not account for international airlines or global emissions at all. The potential here is immense.
https://www.dcceew.gov.au/climate-change/strategies ICAO, AUS Gov, BITRE, Qantas and own data and forecasts.

Theme 2. Zero Emissions Energy and Industry

Zero Emissions Energy & Industry: Renewables (solar) | Material development and component design for improved performance

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		■
Mining		■
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction		■
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing	■	■
Rental, hiring and real estate services		
Professional, scientific and technical services	■	■
Administrative and support services		
Public administration and safety		
Education and training	■	■
Health care and social assistance		
Arts and recreation services		

CASE STUDY: Current projects are underway with SunDrive Solar and Euroka Power.

SOLUTION IMPACT

DIRECT IMPACTS

1. Improved levelled cost of electricity from improved performance from advanced solar photovoltaics solutions
2. Improved levelled cost of electricity from improved lifetime from advanced solar photovoltaics solutions
3. Reduced carbon dioxide emissions from improved performance and lifetime from advanced solar photovoltaics solutions

TRL AND INVESTMENT REQUIREMENTS

Scalability is a challenge
Longevity and stability are other challenges
TRL 4 to TRL 7 will require 2.5 years and $5-10Million

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Education and research training for workers to access new employment and skills specific to new technology developments v ia technology commercialisation for workers to access new employment and skills specific to new technology developments Supporting industry, e.g., those that provide infrastructure, material and equipment suppliers for supporting new technology developments.

Regions & Communities

Same as above plus technology demonstrations in those geographical areas.

Investors & Companies

Same as above but more so via technology commercialisation.

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

50% in efficiency (renewable output increases)
Reducing reliance on fossil fuels
Expanding the surface of renewables
Lower distribution costs

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2. NL Chang, AW Yi Ho-Baillie, et al, "A manufacturing cost estimation method with uncertainty analysis and its application to perovskite on glass photovoltaic modules", *Progress in Photovoltaics: Research and Applications* 25 (5), 390-405
3. J Yates, et al, A Ho-Baille, NL Chang, "Techno-economic analysis of hydrogen electrolysis from off-grid stand-alone photovoltaics incorporating uncertainty analysis", *Cell Reports Physical Science* 1 (10)
4. NL Chang, AWY Ho-Baillie, et al, "Manufacturing cost and market potential analysis of demonstrated roll-to-roll perovskite photovoltaic cell processes", *Solar Energy Materials and Solar Cells* 174, 314-324
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6. NL Chang, A Ho-Baillie, et al, "A techno-economic analysis method for guiding research and investment directions for c-Si photovoltaics and its application to Al-BSF, PERC, LDSE and advanced hydrogenation", *Sustainable Energy & Fuels* 2 (5), 1007-1019
7. J Bing, et al, AWY Ho-Baillie, "Perovskite solar cells for building integrated photovoltaics—Glazing applications", *Joule*, https://doi.org/10.1016/j.joule.2022.06.003

Zero Emissions Energy & Industry: Renewables (wind) | Transforming Wind Farms

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		■
Mining		■
Manufacturing		■
Electricity, gas, water and waste services	■	■
Construction		■
Wholesale trade		■
Retail trade		■
Accommodation and food services		■
Transport, postal and warehousing		■
Rental, hiring and real estate services		■
Professional, scientific and technical services		■
Administrative and support services		■
Public administration and safety		■
Education and training		■
Health care and social assistance		■
Arts and recreation services		■

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1. Estimated lifecycle GHG emissions for different energies, World Nuclear Association 2012 - lifetime GHG. Lifecycle GHG Emissions of Electricity Generation Sources - World Nuclear Association (world-nuclear.org)

SOLUTION IMPACT

DIRECT IMPACTS

1. 5% reduction in levelized cost of electricity through 5% efficiency gain.[1]
2. Reduction in CO_2 emissions.
3. Increasing Australia's energy security by reducing dependency on the volatile fossil fuel market.

INDIRECT IMPACTS

1. Assisting in launch renewable energy industry in Australia
2. Securing jobs
3. Geopolitical security

BANKABILITY

Community development funds
CER + ARENA
Federal Government - Note the Powering the Regions fund
Investment bankers

REQUIREMENTS FOR SUCCESS

- Understanding existing transmission framework - increased funding in transmission, adequacy of existing infrastructure and technology
- Regulatory Framework - planning, transmission, REGO - IREC Scheme: https://www.irecstandard.org/news/supporting-the-development-of-electricity-and-hydrogen-eac-markets-in-australia/
- Community - proven models to increase uptake or decrease resistance
- Funding from industry partners for optimisation

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

We will train early career researchers and students who will move into the industry. Longer term courses and professional development in wind farm optimisation could be envisaged.

Regions & Communities

Wind farms can make better use of land and so will better accommodate needs of the local communities.

Investors & Companies

It will improve siting studies, reduce uncertainty in likely wind yield, improve profitability of wind energy, point towards ancillary services to be provided, or reduce costs for the consumer.

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

TECHNICAL OPTIMISATION AND EFFICIENCY
- Power, steady source of supply
- Foundation - concrete re-cycling and reuse
- Digital twin (computational model) - remote interventions, layers, AI predictive models which impacts transmission (policy implications) leading to grid integration
- wake losses & unplanned maintenance
- better land-use (leasing)

UPTAKE & DEPLOYMENT
- Planning and transmission (these are pain points).
- Transmission has regulatory implications with impacts on community acceptance or opposition (can impact compulsory acquisition).
- Community development funds: e.g.Goulburn (Solar), Dalesford VIC (Wind)
- grid integration
- wind farm operations gap

NOTE SOLAR
- heat transfer efficiency
- community acceptance (dual land use)
- operations

Theme 2. Zero Emissions Energy and Industry

Zero Emissions Energy & Industry: Renewables (solar and wind) | System modeling, integration and control including an understanding of component health management and degradation

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing	■	■
Mining		■
Manufacturing		
Electricity, gas, water and waste services	■	■
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Reduction in greenhouse gas emissions
2. Energy independence
3. Economic benefits

INDIRECT IMPACTS

1. Increased awareness and education
2. Stimulate technological innovation
3. Policy changes

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Community renewable energy projects create opportunities for local employment across various stages including design, construction, operation, and maintenance. These jobs require a wide range of skills, both specialised and non-specialised, thus enabling workers to upskill or reskill as needed. Workers from emission-intensive sectors can transfer their skills to renewable energy or gain new skills in this growing sector.

Regions & Communities

Community renewable energy projects can act as catalysts for local economies, attracting new investments and industries related to clean energy. These projects can enhance local energy resilience, create a sustainable source of income for communities, and attract businesses seeking sustainable operations. Moreover, successful community energy projects often lead to a ripple effect, encouraging the development of additional projects and associated industries in the region.

Investors & Companies

Investing in community renewable energy projects can be a strategic move for companies and investors aiming to align with net zero commitments. These investments not only provide potential financial returns but also demonstrate a commitment to sustainability and social responsibility. Furthermore, companies that invest in or use renewable energy can significantly reduce their carbon footprint, contributing to their own net zero targets.

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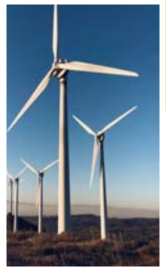


CASE STUDY: One successful example of community renewable energy in Australia is the Hepburn Wind Project in Victoria. This community-owned wind farm has been operational since 2011 and provides enough power for over 2,000 homes, contributing significantly to local sustainability goals.

Zero Emissions Energy & Industry: Hydrogen Embrittlement | Embrittlement-tolerant alloys for safe hydrogen transmission and storage

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety	■	■
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Improve hydrogen safety
2. Reduce hydrogen leakage during transportation
3. Save cost for infrastructural monitoring and management

INDIRECT IMPACTS

1. Reduce societal concerns around hydrogen safety
   Improve the confidence on using steel structure and
   Increase use of steels in hydrogen infrastructure
2. Increase demand on iron ore, benefiting Australia's economy

KEY PARTNERS

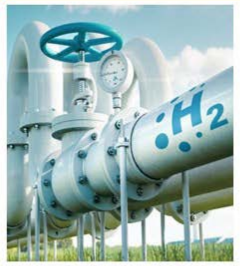
Transmission companies
End uses (appliances)
Government (policy)

ALIGHNMENT WITH NATIONAL DECARBONISATION STRATEGIES

Green Hydrogen Strategy for Australia

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

Infrastructure
Capital, R&D funding and space required



Theme 2. Zero Emissions Energy and Industry

Zero Emissions Energy & Industry: Powerfuels (including hydrogen and ammonia) | Plasmonic process for Green Hydrogen Production

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		■
Mining		■
Manufacturing		■
Electricity, gas, water and waste services		■
Construction		■
Wholesale trade		■
Retail trade		■
Accommodation and food services		■
Transport, postal and warehousing		■
Rental, hiring and real estate services		
Professional, scientific and technical services	■	
Administrative and support services		
Public administration and safety		
Education and training		■
Health care and social assistance		
Arts and recreation services		

Other: We have targeted only the individual houses in the country who could adopt this solution. However, the solution could decarbonise many other sectors like manufacturing and heavy transport.

REFERENCES

1. There is no publication yet of our proposal, however there are many publications about plasmonic induced water splitting, e.g., E. Callagon La Plante, et al., ACS *Sustainable Chemistry & Engineering* 2021 9 (3), 1073-1089 - DOI: 10.1021/acssuschemeng.0c08561

SOLUTION IMPACT

DIRECT IMPACTS

1. Generation of green Hydrogen and hence green energy by splitting water
2. Cutting the current costs of generating Hydrogen by removing the electroliser and the green energy source to power it
3. Delocalising the Hydrogen production and therefore the energy supply, eliminating the delivery and distributions costs.

INDIRECT IMPACTS

1. Decarbonisation of the green and non-green energy production sectors
2. The same device could potentially convert CO_2 store in sea water into limestone, hence decarbonising oceans and air
3. The same device is basically a chemical reactor, hence can be used for other chemical reactions

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

All the sectors that are currently using electricity, e.g. warehouses, will still continue to operate as normal given that our solution will supply the same energy in a different way. Industries like steel manufacturing, will still continue to operate as normal but using hydrogen to produce steel rather than with conventional methods. Industries like long haul and heavy transportation will continue as usual, but using hydrogen powered vehicles. Main electricity grid supplier will operate in a similar way since hydrogen will generate the electricity they manage and distribute.

Regions & Communities

The solution can be delocalised and manufactured it in modules that are portable and passive (almost no maintenance or fuel is required). The solution could also work in the desert by collecting water from air and passively generate hydrogen to power a fuel cell that in turn generate electricity.

Investors & Companies

The solution will open up new markets and technologies that cover not only hydrogen production, but electricity generation, decarbonisation, chemical productions, protein production, etc.

Zero Emissions Energy & Industry: Powerfuels (including hydrogen and ammonia) | Alloys and metals for hydrogen economy

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining	■	■
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services	■	■
Administrative and support services		
Public administration and safety	■	■
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Carbon emission reduction by using carbon-free feedstock to produce green steels
2. Reducing economic impact to mining and steelmaking industries

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

The activities will provide existing workers to learn the science that enables the carbon-free steelmaking process.

Regions & Communities

Australia is in an excellent position to produce green steels and has the potential to decarbonise the steelmaking sector at a global scale. In Japan, Korea, and Taiwan, where steel industry plays an essential role in the economy but has no access to renewable energy and feedstock. Australia's hydrogen act is paramount to decarbonise the steelmaking sector and to mitigate the economic impact to the workers in these countires.

Investors & Companies

The solution will ease the dilemma of investing to support the world's economic growth (by providing materials for infrastructure) and decarbonisation.

Theme 2. Zero Emissions Energy and Industry

Zero Emissions Energy & Industry: Carbon dioxide conversion and utilisation | Exploring low-emission, sustainable, and stable technologies to produce fertiliser from greenhouse gases

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services		
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
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Arts and recreation services		

WHY DOES AUSTRALIA NEED A FERTILIZER INDUSTRY?

- Supply chain security
- Agriculture needs it
- NH_4 potential export
- Industry (and businesses like Incitec) needs to transition now
- We have expertise to optimise/model transformation
- Reduce imports
- Increase exports (a larger market for Australia)
- We have the technical expertise
- Use NH_4 more efficiently

SOLUTION IMPACT

DIRECT IMPACTS

1. Remove green gases NOx and CO_2

INDIRECT IMPACTS

1. Jobs
2. Economic benefits

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

New catalysts, reactor, and reaction system

Regions & Communities

New products and manufacturing

Investors & Companies

New business and products

CUSTOMERS OF THE SOLUTION

Farmers
Producers
Micro communities
H_2 Transporters
Localised ammonia production using H_2
Incitec - approach regrading modelling costs, life cycle supply chain, benefits of energy/ammonia security to Australia

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

FERTILISERS
- Currently - high electricity prices. Thus, fertilizers could be economic in Australia.
- Cheap local renewables - a solution
- % Imported - high risks, supply chain, security

USYD has:
- H_2 expertise
- modeling expertise
- industry candidate for partnership

Addresses
- supply chain for Ammonia
- reduce through solar/wind
- local Australian Production
- food security
- Add value to raw material for export

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Theme 3. Greenhouse Gas Removals

Greenhouse Gas Removals: Direct Air Capture | Development of Metal-Organic Frameworks with highly sought-after physicochemical properties including ultrahigh selectivity for CO_2 combined with air and water stability

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services		
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Materials to remove greenhouse gases from the atmosphere to address the excess CO_2

INDIRECT IMPACTS

1. Advanced Manufacturing (strategic alignment)
2. Jobs creation
3. Value adding to Australian critical minerals
4. Other greenhouse gases can be captured using these materials, e.g. methane, nitrous oxide etc.

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Development of a manufacturing sector for materials used for DAC including Mining, Chemical.

New industry - education, case studies, solar farm revenue. Types of employment include: manufacturing, construction, maintenance.

Regions & Communities

Factories could be located in regional communities (e.g. the NSW Government's Special Activation Precincts).

Build relationships with community - not only exportation but a part of the environment.

Approach/utilise positive engagement of the oil and gas industry to leverage existing technologies and case studies.

Investors & Companies

Adsorbent and absorbent technology for removing CO_2.

CASE STUDY: This project is underway with Australian renewable energy start-up Southern Green Gas (https://www.southerngreengas.com.au/)

Greenhouse Gas Removals: Direct Air Capture | Removal of CO_2 from ambient air via Direct Air Capture methods

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services		
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

MINING AND MANUFACTURING
- Addressing export Scope 3 emissions
- Health and safety paramount

MATERIALS
- Scale is required - supply chain considerations, more than technology
- Materials – requires increase in critical minerals. Therefore, circularity is key consideration.

SOLUTION IMPACT

DIRECT IMPACTS

1. Removing human emissions of carbon dioxide from the atmosphere
2. Sustainable source of carbon dioxide as a feedstock for green fuels (methane, methanol, sustainable aviation fuel) and agriculture
3. Land use changes associated with scaling

INDIRECT IMPACTS

1. Carbon removal certificates
2. Co-benefits for local communities

CUSTOMERS

Wealthy companies where emissions are not high: Apple/Microsoft; Mid stream movers such as airlines and large Scale Government Buyback/Procurement.

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

A new industry. Transition of workforce in regional areas where Direct Air Capture (DAC) may be deployed. Leveraging existing industries like advanced manufacturing, research, site construction, maintenance, project development, geo-sequestration. Types of employment include manufacturing, construction, maintenance, continuity.

Regions & Communities

Direct Air Capture is a platform technology for Sustainable Carbon, and is an industry that the IPCC says must scale. Designing DAC hubs that can benefit communities is crucial. There are lessons to be learned from the oil and gas industry that must be considered.

Investors & Companies

DAC creates carbon removal certificates (an alternative to nature based offsets). These are verifiable (Measurement, Reporting and Verification, MRV). DAC is a platform technology. The CO_2 is a feedstock for e.g. Sustainable Aviation Fuel, sustainable cabon-based energy carriers and sources.

CASE STUDY: This project is underway with Australian renewable energy start-up Southern Green Gas (https://www.southerngreengas.com.au/)

Theme 3. Greenhouse Gas Removals

Greenhouse Gas Removals: Direct Air Capture | Development of Membranes

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		■
Mining		■
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Membranes form part of a carbon removals strategy
2. Low-cost membranes separation will form a versatile solution toolbox for a variety of industries
3. CO_2 capture efficiency and improvement can be easily tuned by thermodynamics

INDIRECT IMPACTS

1. Membrane technology platform is ideal for various separation applications beyond CO2 capture, such as hydrogen purification, natural gas upgradation and clean water production.
2. Reduce reliance on other energy-intensive separation technologies
3. Improves industrial resilience and climate-risk diversification

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Education training of PhD students, researchers, membrane engineers and chemical engineers

Regions & Communities

If DAC membrane technology is successful, the solution can be adopted/implemented at point-source or end-user applications.

Investors & Companies

Improve climate accountability and stewardship by reduced GHG emission.

REQUIREMENTS

Membrane manufacturer stakeholder for large scale membrane system. Membrane solution using advanced membranes is developing but high performance polymeric membranes at large scale is emerging.

CASE STUDY: A patent application is currently in process by the team.

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Greenhouse Gas Removals: Soil Carbon (Redesigning Soils) | Implementing methods to quantify soil carbon and thus verify increased CO_2 sequestration by soils

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing	■	■
Mining		
Manufacturing		
Electricity, gas, water and waste services		■
Construction		
Wholesale trade		■
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services		
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance		
Arts and recreation services		

SOLUTION IMPACT

DIRECT IMPACTS

1. Significant reduction/offset for CO_2
2. Improved soil condition/health
3. Contributes to net zero agriculture and export market assurance

INDIRECT IMPACTS

1. Leadership in international markets
2. Leadership in soil carbon and soil biodiversity accreditation
3. Improved landscapes and agricultural products

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

Will need a new set of agricultural consultants who can manage soil carbon and other agricultural greenhouse projects.

Regions & Communities

Net Zero agriculture will generate and use clean energy on farms.

Investors & Companies

Soil carbon can be used as offsets but probably better used as insets. Investment in superior agricultural products with strong environmental credentials

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Theme 3. Greenhouse Gas Removals

Greenhouse Gas Removals: Coastal Carbon Capture | Enhanced Mineral weathering

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services		
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services	■	■
Administrative and support services		
Public administration and safety		
Education and training	■	■
Health care and social assistance		
Arts and recreation services		

DETAILS OF THE SOLUTION

Increase the rate of sediment weathering by intentionally mining, grinding, and spreading olivine on beaches where the increased surface area (from mechanical grinding) and tumbling action of waves results in dissolution rates thousands of times faster than typically found in nature.

SOLUTION IMPACT

DIRECT IMPACTS

1. Remove atmospheric CO_2
2. Counteract ocean acidification
3. Contribute to the restoration of ecosystems threatened ocean acidification

INDIRECT IMPACTS

Potential carbon removal >0.1–1.0 Gt CO_2/yr (medium confidence). Potential for sequestering >1 Gt CO_2/yr if applied globally. High uncertainty coming from potential aggregation and export to depth of added minerals and unintended chemical impacts of alkalinity addition. >100 years Processes for removing added alkalinity from seawater generally quite slow; durability not dependent simply on return time of waters with excess CO_2 to ocean surface.

CUSTOMERS

Indigenous communities, noting sediments/minerals across lands
Offset Investors and market
CO_2 producers without existing options
Mining industry
(Note - source of Olivine in Norway)

HOW WILL THE SOLUTION SUPPORT…

Investors & Companies

Coastal Enhanced Weathering has the potential to increase the portfolio of the technologies included in Australia's Emissions Reduction Fund and in doing so it will increase Australia's scientific capacity in areas of vital importance to the Australian people and the economy. Thanks to its extensive coastline, Australia is well-positioned to become a leader in Coastal Enhanced Weathering. In addition, Australia has a well-developed carbon market which is a necessary institutional structure to support the scaling of these technologies.

REQUIREMENTS

- >$100–$150/t CO_2 (low–medium confidence). Cost estimates range between tens of dollars and $160/t CO_2.

GAP - The science underpinning coastal carbon capture needs to be properly understood. See the call from the UNFCCC (Enhanced Transparency Framework) to generate robust science that will ensure the transparency of carbon capture global standards.

CHALLENGES

- Natural process increases rates of CO_2 sequestration, but this rate is unknown as it relies on passive carbonation
- The efficiency of CO_2 uptake is dependent on the ocean
- Natural and low-cost solution
- Nature-based but uncertainties exist, e.g., long-term scalability of minerals, long-term lag to effectivenss

Theme 4. Climate Change Risk

Climate Change Risk: Projects in the Face of climate change | Initiate a paradigm shift for project planning and execution in the face of such grand challenges

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		■
Mining	■	■
Manufacturing	■	■
Electricity, gas, water and waste services	■	■
Construction	■	■
Wholesale trade		■
Retail trade		■
Accommodation and food services	■	■
Transport, postal and warehousing	■	■
Rental, hiring and real estate services	■	■
Professional, scientific and technical services	■	■
Administrative and support services	■	■
Public administration and safety	■	■
Education and training		■
Health care and social assistance		■
Arts and recreation services		■

SOLUTION IMPACT

DIRECT IMPACTS

1. Management of transition to Net Zero through quantified CO_2-e impacts
2. Exploring the impact of climate change in transition to Net Zero
3. Exploring the nuances of transition to net zero in the context of climate change
4. Accountability

INDIRECT IMPACTS

1. Understanding the nexus of technical solutions in social systems
2. Effective management of net zero and culture change
3. Stakeholder management in the context of net zero

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

- Penalties for groups operating outside the paradigm
- A framework or guardrails that inform decision-making, project design, reporting/disclosure, resilience, risk assessment
- Due diligence, evaluation at project completion

CUSTOMERS OF THE SOLUTION

Project manager association - changing professional expectations and qualifications
Government

ALIGHNMENT WITH GLOBAL/NATIONAL DECARBONISATION STRATEGIES

Addressing IPCC`s and IEA`s carbon emission scenarios and setting not-to-exceed threshold targets for the building sector.
Opportunity for strong alignment in philosophy and quantification.

BANKABILITY

If implemented, this solution could make others bankable - projects/companies etc.

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Climate Change Risk: Net Zero Health | Eliminate carbon emissions in cell culture by recycling atmospheric CO_2

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing	■	■
Electricity, gas, water and waste services		
Construction		
Wholesale trade		
Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services	■	■
Administrative and support services		
Public administration and safety		
Education and training		
Health care and social assistance	■	■
Arts and recreation services		

Other: *It could affect how CO_2 is being transported.*

SOLUTION IMPACT

DIRECT IMPACTS

1. Reduce the cost of purchasing CO_2
2. Reduce the need for transport of CO_2 to lab and hospitals
3. Reduce health and work safety risks of dealing with heavy CO tanks

INDIRECT IMPACTS

1. A new way of tissue culturing
2. Leads to reduced CO_2 emissions
3. New device(s)

It is unclear how much CO_2 is being used in an incubator or the way this should be calculated. The incubator market in 2022 alone was estimated to be US$3billion and keeps increasing.

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

This can lead to a new device, a new design of incubators, clear research into understanding the CO_2 in this mini-environment, and new skills in tissue culturing.

Regions & Communities

The Universities and hospitals that require use of incubator can reduce their costs of CO_2 use.

Investors & Companies

New industry, or improved sectors in CO_2 transport, recycling, incubator manufacturing, sensor design.

REQUIREMENTS

As this is a device used for cell culturing, we anticipate that the regulatory path will be straightforward. As it will require no CO_2 tank attachment or CO_2 purchase in hospitals and universities, it may lead to a national priority of implementing the new designed incubators/device. Calculations of mass balance are required.

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY

Loss of existing CO_2 revenue
Adapting new technologies
Training new skilled workers

REFERENCES

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Appendix 3: NZI Solutions

Theme 4. Climate Change Risk

Climate Change Risk: Net Zero Health | Climate-related health issues, specifically, ocular health

INDUSTRIES	CURRENT	FUTURE
Agriculture, forestry and fishing		
Mining		
Manufacturing		
Electricity, gas, water and waste services		
Construction		
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Retail trade		
Accommodation and food services		
Transport, postal and warehousing		
Rental, hiring and real estate services		
Professional, scientific and technical services	■	■
Administrative and support services		
Public administration and safety		■
Education and training	■	■
Health care and social assistance	■	■
Arts and recreation services		

Other: *Depending on what has been achieved, it may lead to new health care guidance and policy*

SOLUTION IMPACT

DIRECT IMPACTS

1. Awareness of climate risk to health
2. Reduction of clinical waste

INDIRECT IMPACTS

1. New ways of monitoring climate related heath issues
2. New ways of protecting health or preventative measurements under extreme climate

Ocular surface health is only the beginning. Climate health risk as reported in the health care climate footage, is associated with many diseases including cardiovascular diseases. It is the goal of this solution to extend its reach to other clinicians and climate-related health care issues.

KEY PARTNERS

Need to raise awareness
Incentives for change
Behavioral adjustments
Education programs - primary, secondary & university

HOW WILL THE SOLUTION SUPPORT…

Workers & New Employment

The recognised climate risk can be embedded into the education courses for healthcare workers, and therefore equip them with new knowledge. This can be an ongoing training (workshop) for clinicians, carers and researchers. For example, we can also work together with hospitals to train workers to identify and be aware of items, equipment and procedures that have high carbon footprints, and how to monitor and reduce the carbon emissions. In the case of ocular surfaces, we can work together with TFOS to deliver information and training for eye researchers/clinicians.

Regions & Communities

Increasing the awareness and publishing solid findings on climate effects on ocular health will shed light on how effectively medical professionals and clinicians can work with NZI members to research how climate is affecting various diseases and how to prevent it. This increased awareness will further influence hospital and research institutes' decisions on what equipment/device to use based on clean energy/carbon footprints.

Investors & Companies

As pointed out in the earlier section, there may be opportunities for new devices. With increased climate awareness, investors and companies could prefer medical treatment/inventions/research that incorporate strategies for reducing CO_2 emissions.

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3. It is possible by analysing the risk to develop some adaptions on protecting health against the increased environmental challenge. E.g., developing new treatments and medical tools that include features that 1. help reduce climate related health risk, and 2. reduce carbon footprint.

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