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
There is no greater challenge than addressing climate change and the need for an urgent transition to net zero emissions. The World Economic Forum’s Global Risks Report 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.”

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.

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.
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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.

- **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 CO₂ 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.

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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.
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.

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 and the ongoing Australian Universities Accord process, 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.
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.

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Global achievements and challenges

In 1992, the United Nations introduced the United Nations Framework Convention on Climate Change (UNFCCC), 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. Subsequently, these gatherings led to the creation of two significant agreements, namely the Kyoto Protocol and the Paris Agreement.

Countries generally met their targets in the first commitment period. Shishlov, Morel and Bellassen 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 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. 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. 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 1990s 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. 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. The Paris Agreement requires all countries to establish commitments under the Kyoto Protocol. However, this has changed, and these nations are now required to pledge emissions reductions under the Paris Agreement. The new commitment targets under the Paris Agreement were established in 2015, and these nations are now required to pledge emissions reductions under the Paris Agreement.

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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 ensuring 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. The SGM requires large greenhouse gas emitters in Australia to reduce their emissions in line with the national target.

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

The latest Annual Climate Change Statement 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. 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 2050 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.
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.

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 systems23,24,25 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.

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The grand challenge

A simple equation defines the challenge:

\[ \text{Emissions} = \text{Emissions intensity (tCO2e/$ of GDP)} \times \text{GDP ($)} \]

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 accord of 2015, along with 25 conferences of the parties—over the same period the rate of decarbonisation has remained unchanged.”

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. 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.

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.

Global emissions in 2021 were also the highest ever. The transition is now constrained by the need for new infrastructure. We also see that clean energy systems are significantly more material intensive than their fossil-fuel based alternatives, 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.

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 to the supply of batteries are emerging.

While there are several organisations such as the International Energy Agency (IEA), which 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. 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 2050 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 2050 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:  

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<td>CO2/GDP</td>
<td>Technology deep dives</td>
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<td>Infrastructure deep dives</td>
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<tr>
<td>CO2/GDP (trend)</td>
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<td>Technology deep dives</td>
<td>Grid-scale storage</td>
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<tr>
<td>Trend = -1.8%/yr</td>
<td>renewables</td>
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<tr>
<td>1990</td>
<td>Coal-fired electricity</td>
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<td>1995</td>
<td>Gas-fired electricity</td>
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<td>2025</td>
<td>Solar PV</td>
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<td>2030</td>
<td>Solar PV</td>
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<td>2040</td>
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<td>2045</td>
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<td>2050</td>
<td>Solar PV</td>
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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. 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.

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.

<table>
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<th>Focus area</th>
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<td>Livestock</td>
<td>Optimising livestock data, breeding, health and disease management, improving manure management systems, and promoting anaerobic digestion ‘biogas’.</td>
<td>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. 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.</td>
</tr>
<tr>
<td>Reduction in crop and soil N&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>Reducing the quantity of nitrogen applied to soils, using low emission-spaying equipment, supporting organic farming and introducing organic fertilisers.</td>
<td>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. Carbon-auditing tools are not frequently mentioned, despite their high mitigation potential.</td>
</tr>
<tr>
<td>Carbon storage</td>
<td>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.</td>
<td>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).</td>
</tr>
<tr>
<td>Energy mitigation</td>
<td>Improving on-farm energy efficiency, excluding measures relating to biogas (this is covered as a manure management measure).</td>
<td></td>
</tr>
<tr>
<td>Wider food system</td>
<td>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.</td>
<td></td>
</tr>
</tbody>
</table>

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).
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). 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. 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.

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. 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. 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. 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 emissions reductions by 2050 will come from technologies that have been proven to work, but are not currently market ready. 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 performance 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 geostategic and economic benefits that support diverse, resilient and sustainable supply chains. 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.
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.

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 CO₂ 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 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.
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 consumption via a multi-energy system approach, essentially transforming these areas into energy hubs.

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

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.

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 Elektrolyse (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 electrolyzers 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.

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 Prof. Gregor Verbic (Electrical Engineering) and Prof. Ali Abbas (Chemical & Biomolecular Engineering)
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 2030.44 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.

The Community opposition is now impacting both new renewables projects and investment in transmission infrastructure. The Renewable Energy Alliance (RE-Alliance) 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.40

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.45 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.46

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 (NH3) or methane (CH4). 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 a hydrogen value chain that could 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 CO₂ 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 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.

Traditional concrete is notorious for its contribution to global CO₂ 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.
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)

Direct Air Capture

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 CO₂ 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. 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 CO₂. 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 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 CO₂.

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,14 and from the Climate Change Authority on Australia’s Carbon Sequestration Potential.15

DAC separates CO₂ 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 CO₂ 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 CO₂ from any source, including those that are mobile and dispersed. DAC can also provide CO₂ for various applications, such as synthetic fuels, carbon sequestration or utilisation. DAC can be deployed at any location and capture CO₂ from the air are more widely applicable for various separation applications beyond CO₂ capture.

There are different methods for DAC, but they generally involve a chemical process that binds CO₂ 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 CO₂ gas that can be stored or used. The energy required for DAC depends on the concentration of CO₂ in the air, the efficiency of the sorbent material and the purity of the CO₂ 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 CO₂ and $200/t CO₂ and even dropping below $60/t CO₂ by 2040 or 2050.16 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.

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 CO₂ from the air are more widely applicable for various separation applications beyond CO₂ 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 well-being. To date, our researchers have begun investigating effects of climate change on ocular 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 threatening coastal regions and leading to saltwater intrusion into freshwater resources, 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 US$9 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. They found that Australia must spend on the order of AU$9 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.

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 policies, 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

The University of Sydney

MAJOR SECTORS

PILLARS

SOLUTION

Manufacturing

Professional and technical services

Agriculture, forestry and fishing

Health care and social assistance

Construction

Accommodation and food services

Electricity, gas, water and waste services

Transport

Mining

Projects in the face of climate change

Net Zero Agriculture

Water security

Net Zero Health

1. Net Zero Agriculture. Use advanced carbon removal technology and practices as well as advanced sequestration measurement technologies in tandem with regenerative farming to maximise carbon sequestration.


3. Initiate a paradigm shift for project management in the face of the grand challenges for net zero transformation. 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.


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 CO₂ 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.

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 explore how this adaptation can contribute to supporting net zero strategies.

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)
Integrating NZI Solutions

The Net Zero Initiative represents a portfolio of solutions that are STEMM-enabled (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, the Federal Government has committed to a Nature Positive Plan (2022) 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.

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.
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 skilful 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 Activation 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 which are in strong alignment with the Australian government’s sectoral plans 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

Theme 4. Climate Change Risk

Appendix 2: NZI Solutions Requirements

Theme 1. Demand Reduction

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>Current TRL</th>
<th>Time to reach next TRL (years)</th>
<th>REQUIREMENTS</th>
<th>Funding to reach next TRL ($)</th>
<th>Time to reach TRL 7 (years)</th>
<th>Funding to reach TRL 7 ($)</th>
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<tbody>
<tr>
<td>Transport. Develop models for Plant removal.</td>
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<td>2.5</td>
<td>$1M - $50K</td>
<td>2.5</td>
<td>$1M - $50K</td>
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<tr>
<td>Sustainable sources.</td>
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<td>$1M - $50K</td>
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<tr>
<td>Rural Miners.</td>
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<td>$25K - $50K</td>
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<tr>
<td>Circular economy.</td>
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<td>$25K - $50K</td>
<td>2.5</td>
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Theme 2. Zero Emissions Energy and Industry

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>Current TRL</th>
<th>Time to reach next TRL (years)</th>
<th>REQUIREMENTS</th>
<th>Funding to reach next TRL ($)</th>
<th>Time to reach TRL 7 (years)</th>
<th>Funding to reach TRL 7 ($)</th>
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<tr>
<td>Carbon dioxide conversion.</td>
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<td>3</td>
<td>$1M - $50K</td>
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<td>$1M - $50K</td>
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<td>Carbon dioxide conversion.</td>
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<td>$25K - $50K</td>
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<tr>
<td>Powercool. (including hydro and anaerobic).</td>
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<td>$1M - $50K</td>
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<td>$1M - $50K</td>
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<td>Energy dehydration.</td>
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<td>$1M - $50K</td>
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<td>$1M - $50K</td>
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<tr>
<td>Renewable (solid).</td>
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<td>$1M - $50K</td>
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<td>$1M - $50K</td>
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</tbody>
</table>

Note: TRL refers to the technology readiness level, which indicates the level of development of a technology.
Appendix 2: NZI Solutions Requirements

**Theme 3. Greenhouse Gas Removals**

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>Current TRL</th>
<th>Time to reach next TRL (months)</th>
<th>REQUIREMENTS</th>
<th>Funding to reach next TRL (mil)</th>
<th>Time to reach TRL 1 (mil)</th>
<th>Funding to reach TRL 1 (mil)</th>
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<tbody>
<tr>
<td>Curved Carbon Capture</td>
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<td>12</td>
<td>Methods and equipment to accurately measure rates of carbon removal</td>
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<td>7.3</td>
<td>$4.9M</td>
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<tr>
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<td>Direct Air Capture</td>
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<td>Additional technology development</td>
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<td>$2M</td>
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<td>Development of a new material for Direct Air Capture</td>
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<td>$2M</td>
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<tr>
<td>Direct Air Capture</td>
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<td>Development of a new material for Direct Air Capture</td>
<td>$1M - $5M</td>
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<td>$2M</td>
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<tr>
<td>Direct Air Capture</td>
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<td>12</td>
<td>Development of a new material for Direct Air Capture</td>
<td>$1M - $5M</td>
<td>11</td>
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<tr>
<td>Enhanced Mineral Weathering</td>
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<td>Development of a new material for Enhanced Mineral Weathering</td>
<td>$1M - $5M</td>
<td>11</td>
<td>$2M</td>
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**Theme 4. Climate Change Risk**

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>Current TRL</th>
<th>Time to reach next TRL (months)</th>
<th>REQUIREMENTS</th>
<th>Funding to reach next TRL (mil)</th>
<th>Time to reach TRL 1 (mil)</th>
<th>Funding to reach TRL 1 (mil)</th>
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<td>12</td>
<td>Development of a new material for Enhanced Mineral Weathering</td>
<td>$1M - $5M</td>
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<td>$2M</td>
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<td>1.5</td>
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</tr>
<tr>
<td>Enhanced Mineral Weathering</td>
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<td>Development of a new material for Enhanced Mineral Weathering</td>
<td>$1M - $5M</td>
<td>11</td>
<td>$2M</td>
</tr>
</tbody>
</table>

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

**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**

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>CURRENT IMPACT</th>
<th>PROPOSED IMPACT</th>
<th>FACTORS AFFECTING IMPACT</th>
<th>COMMUNITY IMPACT</th>
<th>EMPIRICAL EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-carbon concrete production industry</td>
<td>New concrete production industry will open new opportunities for workers, investors, and companies</td>
<td>New green concrete production industry will open new opportunities for workers, investors, and companies</td>
<td>New green concrete production industry will open new opportunities for workers, investors, and companies</td>
<td>New green concrete production industry will open new opportunities for workers, investors, and companies</td>
<td>New green concrete production industry will open new opportunities for workers, investors, and companies</td>
</tr>
</tbody>
</table>

**Theme 2. Critical Minerals | Sustainable processing of minerals**

**Sustainable electrochemical processing of valuable metals from ores and electronic waste**

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

**REFERENCES**


**OTHER CRITICAL MINERALS & SOLUTIONS FROM THE 80s**

Our solutions are based on the exploration of microorganisms for the alternative extraction of metals from ores and metallic waste.

---

*Direct impacts: Workers & New Employment
Indirect impacts: Investors & Companies
Further solution impacts: Regions & Communities

IMPLICATIONS OF NET-ZERO TARGETS FOR INDUSTRY

FURTHER SOLUTION IMPACTS

SOLUTION IMPACTS

ALIGNMENT WITH GLOBAL/ NATIONWIDE DECARBONISATION STRATEGIES

CASE STUDY: The Waste Transformation Research Hub at USyd, led by Prof. Ali Abbas, has been instrumental in developing low-carbon engineered eco-pavements, their collaboration with Circrete has been a key factor in this success.
Theme 1. Demand Reduction

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

**SOLUTION IMPACT**

**DIRECT IMPACTS**
1. Reduced CO₂ emissions
2. Improved reliability of energy resources
3. Reduced cost of energy

**INDUSTRIES**
- 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

**BANKABILITY**
Depends on regulation and consumer decision making. This technology is new and needs to move to integration.

**INVESTMENT REQUIREMENTS**
- All the technology is ready, new needs to move to integration.

**IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY**
- Building development
- Technology adoption
- Business opportunities, especially for Small to Medium Enterprises (SMEs)

**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.

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

**HOW WILL THE SOLUTION SUPPORT...**
Workers & New Employment
- New jobs in EV service, distributed energy resources, EV mobility, and EV technology services and infrastructure.
- Electric vehicle charging infrastructure.

Investors & Companies
- Pivoting on the regulatory model for petrol stations and EV charging.

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.

**REFERENCES**

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

**SOLUTION IMPACT**

**DIRECT IMPACTS**
1. Understanding consumer demand for low-carbon travel
2. Multiple Equilibrium (ME) framework to understand the potential travel impacts of EVs

**INDUSTRIES**
-โดน user and demographics: there are already established models and tools in place.
- Travel planning and infrastructure development: requires new models and tools.

**CASE STUDY:**
The Institute for Transport and Logistics Studies at the University of Sydney and the NSW Department of Planning and Environment partnered to develop a model that can predict travel demand and infrastructure requirements for electric vehicles.

**HOW WILL THE SOLUTION SUPPORT...**
**Workers & New Employment**
- New jobs in EV service, distributed energy resources, EV mobility, and EV technology services and infrastructure.
- Electric vehicle charging infrastructure.

**Investors & Companies**
- Pivoting on the regulatory model for petrol stations and EV charging.

**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.

**NOTES**
This solution is developed in line with the Net Zero targets set by the government and aims to support the transition to low-carbon travel.

**REFERENCE**
### Appendix 3: NZI Solutions

#### Theme 1. Demand Reduction

Demand Reduction: Transport (including land and aviation)

<table>
<thead>
<tr>
<th>SOLUTION IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRECT IMPACTS</td>
</tr>
</tbody>
</table>
| 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. |

#### REFERENCES

Demand Reduction: Transport (aviation)

1. Development of models for Fleet renewal, Sustainable Aviation Fuel, electrification and hydrogen implementation in the aviation sector

### Appendix 3: NZI Solutions

#### Theme 2. Zero Emissions Energy and Industry

Zero Emissions Energy & Industry: Renewables (Solar)

<table>
<thead>
<tr>
<th>SOLUTION IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRECT IMPACTS</td>
</tr>
<tr>
<td>1. Enable financial cost of energy new developments from current to 50% lower.</td>
</tr>
<tr>
<td>2. Enable financial cost to reduce minimum amount of energy from renewable sources by 50%.</td>
</tr>
<tr>
<td>3. Enable global industry from advanced solar photovoltaic solutions</td>
</tr>
<tr>
<td>4. Turn carbon dioxide emissions into renewable and thereby renewable solar photovoltaics</td>
</tr>
</tbody>
</table>

#### REFERENCES


### Appendix 3: NZI Solutions

Zero Emissions Energy & Industry: Renewables (wind)

<table>
<thead>
<tr>
<th>SOLUTION IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRECT IMPACTS</td>
</tr>
<tr>
<td>1. Enable financial cost of energy new developments from current to 50% lower.</td>
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<td>2. Enable financial cost to reduce minimum amount of energy from renewable sources by 50%.</td>
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</tr>
<tr>
<td>4. Turn carbon dioxide emissions into renewable and thereby renewable solar photovoltaics</td>
</tr>
</tbody>
</table>

#### REFERENCES


### Appendix 3: NZI Solutions

Zero Emissions Energy & Industry: Transforming Wind Farms

<table>
<thead>
<tr>
<th>SOLUTION IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRECT IMPACTS</td>
</tr>
<tr>
<td>1. Enable financial cost of energy new developments from current to 50% lower.</td>
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<td>2. Enable financial cost to reduce minimum amount of energy from renewable sources by 50%.</td>
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<td>3. Enable global industry from advanced solar photovoltaic solutions</td>
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<tr>
<td>4. Turn carbon dioxide emissions into renewable and thereby renewable solar photovoltaics</td>
</tr>
</tbody>
</table>

#### REFERENCES

Appendix 3: NZI Solutions

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

HOW WILL THE SOLUTION SUPPORT...

Workers & New Employment
1. Employment creation
2. Skill development and upskilling
3. Local economic benefits

Infrastructure
1. Enhanced grid reliability
2. Increased energy storage capacity

DIRECT IMPACTS
1. Reduction in greenhouse gas emissions
2. Energy security enhancement
3. Economic benefits

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

REFERENCES

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.


HOW WILL THE SOLUTION SUPPORT...

Workers & New Employment
1. Employment creation
2. Skill development and upskilling
3. Local economic benefits

 Industries
1. Oil and gas
2. Chemicals
3. Transportation

DIRECT IMPACTS
1. Improved hydrogen safety
2. Reduced hydrogen leakage
3. Enhanced hydrogen storage infrastructure

INDIRECT IMPACTS
1. Reduced societal concern around hydrogen safety
2. Increased hydrogen infrastructure investment
3. Enhanced hydrogen infrastructure resilience

DIRECT IMPACTS
1. Improved hydrogen safety
2. Reduced hydrogen leakage
3. Enhanced hydrogen storage infrastructure

INDIRECT IMPACTS
1. Reduced societal concern around hydrogen safety
2. Increased hydrogen infrastructure investment
3. Enhanced hydrogen infrastructure resilience

REFERENCES
Appendix 3: NZI Solutions

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

SOLUTION IMPACTS

1. Disease green gases N2G and CO2
2. Jobs
3. Economic benefits

DIRECT IMPACTS

Workers & New Employment
New catalysts, reactor, and reactor systems for green gas production
New products and manufacturing
Innovations & Companies
New business and products

CUSTOMERS OF THE SOLUTION

Fertilisers

IMPLICATIONS OF NET-ZERO TARGETS FOR INDUSTRY

1. Policy: High standards for carbon emissions
2. Technology: Innovative solutions for carbon capture and storage
3. Economics: Market opportunities for green fertilisers

REFERENCES


Appendix 3: NZI Solutions

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 CO2 combined with air and water stability

SOLUTION IMPACTS

DIRECT IMPACTS

Workers & New Employment
New catalysts,-reactor, and reactor systems
New products and manufacturing
Innovations & Companies
New business and products

CUSTOMERS OF THE SOLUTION

Industries

IMPLICATIONS OF NET-ZERO TARGETS FOR INDUSTRY

1. Policy: High standards for carbon emissions
2. Technology: Innovative solutions for carbon capture and storage
3. Economics: Market opportunities for green fertilisers

REFERENCES

# Appendix 3: NZI Solutions

## Theme 3. Greenhouse Gas Removals

### Greenhouse Gas Removals: Direct Air Capture | Development of Membranes

<table>
<thead>
<tr>
<th>INDICATORS</th>
<th>CURRENT</th>
<th>FUTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
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<tr>
<td>Water</td>
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<tr>
<td>Technology</td>
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<tr>
<td>Policy</td>
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<td></td>
</tr>
<tr>
<td>Markets</td>
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</tbody>
</table>

**SOLUTION/IMPACT**
- Develop and test advanced membrane technologies for carbon capture and storage.
- Enhance the efficiency of current carbon capture systems.
- Facilitate the integration of carbon capture into industrial processes.

**HOW WILL THE SOLUTION SUPPORT...**
- Workers & firms: Education and training for new entrants.
- Industry: Development of new carbon capture technologies.

**REQUIREMENTS**
- Funding for research and development.
- Regulatory support for carbon capture initiatives.

**REFERENCES**
- [Reference 1](#).
- [Reference 2](#).
- [Reference 3](#).

### Greenhouse Gas Removals: Soil Carbon (Redesigning Soils) | Implementing methods to quantify soil carbon and thus verify increased CO₂ sequestration by soils

<table>
<thead>
<tr>
<th>INDICATORS</th>
<th>CURRENT</th>
<th>FUTURE</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Markets</td>
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</tbody>
</table>

**SOLUTION/IMPACT**
- Develop and test soil amendments for increased CO₂ sequestration.
- Implement soil carbon management practices at scale.
- Enhance the market for greenhouse gas credits.

**HOW WILL THE SOLUTION SUPPORT...**
- Workers & firms: Education and training for new entrants.
- Industry: Development of new soil carbon management technologies.

**REQUIREMENTS**
- Funding for research and development.
- Regulatory support for soil carbon measurement.

**REFERENCES**
- [Reference 1](#).
- [Reference 2](#).
- [Reference 3](#).

## Theme 3. Greenhouse Gas Removals

### Greenhouse Gas Removals: Coastal Carbon Capture | Enhanced Mineral weathering

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<tr>
<th>INDICATORS</th>
<th>CURRENT</th>
<th>FUTURE</th>
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**SOLUTION/IMPACT**
- Implement coastal carbon capture technologies to reduce CO₂ emissions.
- Enhance mineral weathering processes to sequester CO₂.

**HOW WILL THE SOLUTION SUPPORT...**
- Workers & firms: Education and training for new entrants.
- Industry: Development of new technologies.

**REQUIREMENTS**
- Funding for research and development.
- Regulatory support for carbon capture initiatives.

**REFERENCES**
- [Reference 1](#).
- [Reference 2](#).
- [Reference 3](#).
Appendix 3: NZI Solutions

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

<table>
<thead>
<tr>
<th>SOLUTION IMPACT</th>
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IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY
- Paradoxes for groups operating outside the paradigm
- Opportunities in paradigms that allow decision making, project design, epidemiology, resilience, risk management
- The value, valuation, and value of solutions

CUSTOMERS OF THE SOLUTION
- Project change, innovation - changing professional expectations and qualifications

ALIGNMENT WITH GLOBAL/NATIONAL DECARBONIZATION STRATEGIES
- Addressing ETCO₂ and ECO₂ carbon emission scenarios and setting revised financial targets for the health industry
- Opportunities for energy efficient principles and collaborations

REGIONS & COMMUNITIES
- The Universities and hospitals that require use of incubators can reduce their costs of CO₂ use.

OTHER:
- It could affect how CO₂ is being transported.

OTHER:
- It could affect how CO₂ is being transported.

REFERENCES
2. https://www.researchnester.com/reports/cell-and-tissue-culture-incubators-market/4050. Using different ways such as section doors to reduce the escape of CO₂ from incubators lessens usage of CO₂.

Theme 4. Climate Change Risk

Climate Change Risk: Net Zero Health | Eliminate carbon emissions in cell culture by recycling atmospheric CO₂

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REFERENCES
2. https://www.iiasa.ac.at/Research/Special-Reports/Climate/Emissions/2022-IAS_AR5_1.5°C.pdf

IMPLICATIONS OF NET ZERO TARGETS FOR INDUSTRY
- Lives of existing CO₂-based processes will be extended.
- Societal adaptation to a CO₂-free environment may require significant changes in how we live and work.

REQUIREMENTS
- As this is a decade used for scale-out, we will incorporate the regulatory path for pilot-implementation. As a final step in reducing CO₂, a network of closed-loop systems will be developed. The network will also be used to reduce the escape of CO₂ from incubators lessens usage of CO₂.

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