Australian Energy Transition Research Plan

A strategic research agenda to enable Australia's sustainable, reliable, affordable, and fair energy transition.

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AUSTRALIAN COUNCIL OF LEARNED ACADEMIES

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GOVERNANCE OF THE RESEARCH PLAN

The overall governance and monitoring of the Research Plan is led by ACOLA, an independent, not-for-profit research organisation. The ACOLA project is led by a Steering Committee consisting of experts and Fellows from Australia's Learned Academies that bring their multidisciplinary expertise across the energy and research sector.

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ACKNOWLEDGEMENT OF COUNTRY

ACOLA acknowledges all Aboriginal and Torres Strait Islander Traditional Custodians of Country and recognises their continuing connection to land, sea, culture and community. We pay our respect to the Elders both past and present.

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Funding Partners for the Australian Energy Transition Research Plan

NERA NATIONAL ENERGY RESOURCES AUSTRALIA

CSIRO

ARENA Australian Government Australian Renewable Energy Agency

Executive summary

Australia's energy system is embarking on a transformation at a scale and rate that is unparalleled. Nations, leaders, industries and communities acknowledge the imperative to address global climate change through an "energy transition".[1] The goal is to reach 'net zero emissions' (nominally by 2050 or earlier) to halt further global greenhouse gas emissions, which are contributing to rising global temperatures and causing potentially irreversible damage to our societies, physical infrastructure and ecosystems.

A 'business as usual' trajectory is no longer feasible; the window for the transition is narrowing fast, and the cost of inaction on our economy, communities, businesses and environment continues to compound. The global momentum towards net zero emissions is also rapidly accelerating, which will impact global trade in commodities, technology and services.

In Australia, governments, industries, citizens and researchers are bracing for the challenge ahead, with growing momentum and support for a rapid and low carbon energy transition. The trajectory to reach net zero emissions, however, will be challenging: as of 2020, fossil fuels provided 94 per cent of Australia's total energy needs.[i]

Australian governments are currently implementing a suite of reforms to address Australia's electricity infrastructure and energy market. However, much work remains to transform our industries (particularly mining, transport, manufacturing and agriculture), which are still mostly dependent on fossil fuels for their energy requirements, and also contribute substantially to emissions.

Australia also has substantial opportunities to grow our clean energy sector and to become a renewable energy superpower, buoyed by the current success of our solar and wind industries. However, realising these opportunities will require national strategic alignment, innovation and regulation.

Australia must be efficient, responsive and forward-looking if our transition to net zero emissions is to succeed, with as minimal disruption to our economy and society as possible. This also applies to the research sector, which must respond with appropriate research and translation on a time scale reflective of this critical need. A successful energy transition will be one that addresses the energy trilemma: reliable, affordable and reaching net zero emissions, while also placing the wellbeing of society at its centre.

Following extensive engagement with the energy and research sector, four critical challenges have been identified.

i This represents total energy consumption in 2018-19, which includes industrial and transport uses. Australian Government (2021) *Australian Energy Update 2020*, p 8. Available at https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202020%20Energy%20Update%20Report_0.pdf

1 While Australian researchers are undertaking critical and valuable research across all disciplines, **there is an absence of a scalable and cohesive research agenda** to focus efforts on priority issues to guide Australia on the trajectory of transition over the next 10-20 years. Ongoing, strategic and coordinated research activities, in all relevant disciplines, will be critical to achieving a successful and just transition.

2 Secondly, while international developments will undoubtedly inform our national pathway, **we cannot rely solely on international research to address uniquely Australian problems and needs**, including our dispersed and diverse populations and geography, our present reliance on fossil fuel resources and our energy infrastructure. Australia must continue to strengthen its domestic research capabilities to find local solutions and strategies that correspond to our local needs and are fair to our society. A strong local research capability will also give us a seat at the international research table, and enable the adaptation of international knowledge to Australian circumstances.

3 Thirdly, the energy transition is an interdisciplinary challenge. Australia performs well in science, engineering and technology-related energy research, and ongoing developments in these fields will be critical to ending our reliance on fossil fuels. However, **a successful transition must also encompass the perspectives and wellbeing of people, in the context of their lives, communities, economy and employment, in a way that is fair**. Consultations highlighted significant gaps in research on the social aspects of the energy transition, particularly in the Australian context. For example, there is currently little research on how best to provide assistance to communities to effect their own transitions, especially those whose livelihoods depend on high emission industries or live in rural and remote regions. Further, it is vital to ensure Aboriginal and Torres Strait Islander people have a say and lead the energy transitions in their communities.

4 Finally, all sectors involved in the energy transition, from **government, industry, research funders and research organisations, need to respond in a time scale that is reflective of the urgency and enormity of this issue**. The translation of research takes time, and we need to continue to look at efficiencies in the way research is funded and undertaken to ensure that outputs are available within the necessary timescales.

As a response to these challenges, the Australian Council of Learned Academies (ACOLA) has developed an Australian Energy Transition Research Plan (Research Plan).

In presenting the Research Plan, ACOLA considers that practical social applications of the energy transition, including equity and justice, should be considered at the *outset* and *in partnership* with technical research. The Research Plan aims to shift the current research paradigm by highlighting the Research Priorities (specifically, key research gaps, opportunities and subsequent research questions) that need to be addressed for Australia to transition successfully and rapidly.

Developed by ACOLA, in consultation with stakeholders, the Research Plan's research priorities are organised into three themes: energy system dynamics; social engagement dynamics and transition dynamics, with three topics under each as shown in Diagram 1.

While the Research Priorities are presented in a static, one-dimensional structure, the order of the list merely provides a structure to communicate a dynamic multi-dimensional proposition. It is not representative of the order of the importance of priorities.

Diagram 1: Australian Energy Transition Research Priorities Themes and Topics

Under each topic identified in the Research Plan, three high-level key research questions have been initially identified that will require research and funding over the next decade (see Appendix 1). The questions are classified as either *urgent* (where robust answers are needed in the near future) or *strategic* (where robust answers are required in the longer term). While research needs to begin now on all the questions, the Research Plan recognises that research for 'strategic' questions may take longer to have an impact. In total, these 27 questions represent the key questions requiring research now; they are likely to change in further iterations of the Research Plan as the transition progresses.

The Research Plan will be an ongoing program of work with periodic review cycles of the equal and complementary Research Priorities. ACOLA will also monitor current and emerging energy research across all disciplines. Regular review cycles will identify current research, emerging research gaps, and, importantly, whether the critical research priorities identified are being pursued. It is expected that new questions will emerge in this iterative process.

The purpose of the Research Plan is to offer those in the research ecosystem (researchers, funders and users), guidance on where and what research is being undertaken and what critical research is *not* being done. This will enable the research ecosystem to direct research efforts and funding to the highest priority areas to accelerate efforts, and avoid duplication.

Note, however, that ACOLA is not a funding body and will not be commissioning research through the Research Plan.

The shift to a net-zero emission energy system will require large-scale innovation and effort, and inevitably, there will be both successes and failures given the enormity of this task. Australia can minimise unintended impacts or harm by being proactive and engaging end users from the start, through fostering ongoing technological innovation, ensuring that policy and regulatory frameworks are agile to adapt to the changing energy landscape, engaging with communities to gain acceptance and trust, and continuing to fund and make use of interdisciplinary research for Australian solutions and strategies.

ACOLA is pleased to present the first iteration of the Research Plan, which was made possible by the extensive contributions provided by the Learned Academies, research scholars and practical policy makers in academia, government, industry, community groups, and other key stakeholders. We also acknowledge the financial contributions by National Energy Resources Australia (NERA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Renewable Energy Agency (ARENA) for this project. We look forward to the next steps in an ongoing conversation that enables the full range of relevant research organisations across government, industry and the philanthropic sector to support the urgent task of Australia's energy transition.

1. The energy transition context

Key points

- The energy transition has already commenced in Australia, but further work is required to transform our industries and support the broader socio-economic change required for a successful transition.
- As a major energy resources exporter, Australia will need to ensure that our future transition pathway (and exports) aligns with international demand and overseas transition trajectories.
- The opportunities, impacts and risks of Australia's energy transition will vary depending on the actions and pathways taken; but in all scenarios, business as usual is not a viable option.

Australia is a major energy powerhouse that exports energy to the rest of the world. At the same time, given our unique geography, climate, widely dispersed populations and federated political structure, we have a difficult energy transition to net zero emissions ahead of us. Nevertheless, continuing a business-as-usual trajectory is no longer a viable option, and there are strong economic, social and environmental reasons to pursue an energy transition to net zero emissions with great urgency by 2050 at the latest.

The energy transition is already occurring across Australia, and unique challenges are emerging. A mix of strategic, urgent, Australian-specific and international research is required to address these challenges.

International research will be important to the Australian energy transition. However, we cannot rely solely on this to support our transition. We must continue to build our research capabilities to find local solutions and strategies to solve local problems. Our unique energy environment will give rise to distinct energy transition research considerations over the coming decade.

Australia must also continue to play its part in the international research community, to continue to have direct access to innovations across the globe; better understand how to translate global innovations into the Australian context; and be able to share our knowledge with the rest of the world. Internationally, the academic community is beginning to call for enhanced interdisciplinary research to support national energy transitions, recognising the social, technical and economic forces behind this complex societal challenge.[ii]

As a response to these issues, ACOLA commenced work on the Research Plan in mid-2020 following strong stakeholder support and extensive engagement across the energy sector in 2019 as part of scoping work. The Research Plan is presented at Section 2.

What do we mean by energy?

For this project, 'energy' encompasses electricity (all sources), natural gas, liquid fuels, coal and hydrogen, and as used in stationary energy, transport and industry sectors. This includes the generation, transport, storage, use and export of energy, and includes energy efficiency and productivity.

ii See for example, The Future of Electric Power in the United States. The National Academies of Science, Engineering and Medicine. (2021). Washington, DC: The National Academies Press. https://doi.org/10.17226/25968.

Energy and the energy transition

Energy production, storage and use profoundly shape the way people, economies and ecological systems function. Energy transitions are complex processes, historically unfolding over long periods of time.[2] The current transition, however, is urgent: demanding a transition from fossil fuels to zero or low emissions alternatives under very different policy, social and technological conditions, which require nuanced management and governance. Cross-cutting research will draw on the expertise of the whole research sector, as well as engagement with industry, community and government on all levels.

Australia has been heavily dependent on large reserves of fossil fuels to fulfil domestic energy requirements, and as a major global energy exporter. As other countries transition their domestic economies away from fossil-fuel based systems of energy consumption and production to renewable energy sources, Australia must move adroitly to capture different economic and social opportunities, and to avoid stranded assets.

International context

The trajectory of Australia's transition will need to align with the current global geopolitical landscape and global policy action on energy and climate change. The baseline for global climate cooperation was established in 2015 through the Paris Agreement; with the central goal of limiting global temperature rises this century to below 2°C above pre-industrial levels, and to pursue limiting temperature increase even further to 1.5°C.[3] Nearly 200 countries have signed up to and ratified the Paris Agreement.[4]

> **Over the last 35 years, there has been significant progress in global energy policy to decrease global carbon emissions and achieve the target of net zero emissions by 2050. Global efforts have been largely driven by the UN's climate change efforts through the UNFCCC.**

International action to ameliorate climate change, including emissions targets, is coordinated through the United Nations Framework Convention on Climate Change (UNFCCC). In 2018, the International Panel on Climate Change, which reports to the UNFCCC, released a key report outlining that major and immediate global transformation would be required to limit warming to 1.5°C. This has rapidly accelerated global policy and industry efforts to curb emissions and drive research and development (R&D) in clean energy technologies. Various forms of climate activism are also playing an important role.

As of December 2020, more than 20 countries and the European Union (EU) have set net zero emission targets for 2030-2050, and more than 100 others are considering adopting targets through the Climate Ambition Alliance. Sweden, the UK, France, Denmark and New Zealand have adopted legislation enshrining their net zero targets,[5] as have Australia's key Asian energy trading partners Korea and Japan. China also recently announced that it will achieve net zero emissions by 2060. A growing number of companies are also committing to net zero and interim targets through the Business Ambition for 1.5°C campaign.[6]

In February 2021, the US re-joined the Paris Agreement, aligning global climate policy for the first time in recent years. Every member of the G7 and the EU is now committed to net zero emissions by 2050, and China by 2060. Signalling the US's renewed leadership on global climate issues, President Biden convened a Climate Summit in April 2021, calling on 40 world leaders to increase their greenhouse gas emissions targets ahead of the UN Climate Change Conference, COP26, scheduled for November 2021.

Australia's current international obligations on climate change are ratified in the 2016 Paris Agreement, committing Australia to a 26-28 per cent reduction in emissions below 2005 levels by 2030, and transitioning to achieving net zero emissions in the second half of the century.

The global pathway to net zero emissions by 2050 is narrow, but still achievable

The International Energy Agency (IEA) has outlined the essential priority actions for the global energy sector to reach net zero emissions by 2050.[7] Importantly, the technologies needed to achieve substantial decarbonisation by 2030 already exist, and the policies to drive deployment have been proven. Post 2030, reaching net zero by 2050 will require further innovation and R&D, rapid deployment of current technologies, and accelerating emerging technologies to market.

Australia in the geopolitical landscape

National energy systems have become increasingly integrated in a larger global energy landscape through the sharing of energy resources, production, transmission and use. Domestic energy resources, such as oil, gas or coal contribute to a nation's economy, stability and geopolitical influence through trade. The global energy transition will likely lead to a geopolitical and strategic reshuffle with the emergence of new winners and losers.

Geopolitical considerations will play a substantial part in Australia's energy transition, given our role as a key global energy exporter of coal, liquified natural gas (LNG) and other critical minerals to meet global energy needs. Global demand for net zero emissions energy and products, such as hydrogen, is increasing, and Australia is already working closely to capture these markets in Germany, Japan and Korea. Australia must continue to adapt to changing market forces and national transition trajectories, to capture new export markets and avoid being excluded from international supply chains. Exclusion from international supply chains may weaken our economy and nullify our regional and international geopolitical influence. Conversely, pursuing new growth markets and emerging as industry leaders is likely to accrue greater international diplomacy, prestige, employment opportunities and GDP.[8]

Over the course of this transition, it will be important to consider factors on Australia's evolving transition trajectory, including international market forces; the role of renewables in international diplomacy and peace; potential geopolitical tensions around the use and extraction of critical materials; cybersecurity; security of supply; and global investment trends.[9]

Australia has strong research and industry capabilities, as well as significant mineral resources required for manufacturing and developing renewable technologies. However, energy leaders such as the US, China, UK and the EU continue to invest substantially in their technological and research capabilities and will play a key role in shaping market forces in the new energy economy. Australia should continue to focus on building research competencies in areas where we have a comparative advantage, in addition to solving our unique domestic challenges.

Current Australian developments

Australia is unique in terms of its urbanised coastal settlements and sparsely populated interior, its highly variable climate (high solar intensity and extreme weather events), and distance from international markets. Our current energy system is a product of these characteristics. The energy transition has already commenced, both for domestic users and for industries, but there is still a long way to go. While the transformation of the energy market and policy considerations are progressing rapidly, the implications of these for communities and industries require urgent assessment.

A successful energy transition is one where Australia's future energy system is on a pathway to net zero emissions and importantly is reliable, affordable, sustainable, and places the wellbeing of society at its centre.

In terms of the national electricity grid, affordability has remained a consistent challenge and policy focus. The 2016 state-wide black out in South Australia, and power reliability issues under severe weather conditions in Victoria and South Australia in 2017-18 has also placed security and reliability at the forefront of the energy policy agenda.

Residential use has benefited from the installation of rooftop solar photovoltaic (PV) systems, as well as the adoption of more energy efficient practices, appliances and housing.[10] Australia is currently the world leader in the annual rate of installed solar and wind capacity per capita; an order of magnitude greater than the world average.[11] Investment by ARENA, state and territory-based incentive schemes, and the prevalence of single-storey housing across Australia, have accelerated the uptake of wind and solar energy technologies. However, the distribution and benefits from these schemes are varied, with many low-income households unable to afford the adoption of solar energy technologies.[12]

Energy policy and governance remains complex, subject to major changes in national policy direction as governments navigate the challenges of reducing Australia's carbon emissions. In 2021, the Prime Minister of Australia, Scott Morrison, stated that Australia's goal is 'to reach net zero emissions as soon as possible, and preferably by 2050',[13] and may not need to use its carryover credits from its commitments under the Kyoto Protocol to meet targets.[14] In September 2020, the Australian Government released its Technology Investment Roadmap: First Low Emissions Technology Statement, to drive innovation and investment in the clean technology sector. The Statement outlines the Australian Government's plan to drive the development of five key priority technologies, to make these cost-competitive with existing technologies and capture new export markets.[iii] This includes an investment of $18 billion and a forecast of 130,000 jobs added to the workforce over the next decade.[15]

The Australian government, states and territories have signalled a commitment to reach net zero emissions by 2050.

iii These are clean hydrogen, energy storage, low carbon materials, carbon capture storage and soil carbon measurement.

States and territories have established their own net zero energy policies, committing to substantial investment and policy to support the development of renewable energy technologies to meet these targets.

Several key structural challenges for the transition remain. While other global economies can employ a multitude of energy sources to undertake an energy transition, Australia has a high legacy of fossil fuel use; one of the longest and skinniest energy networks in the world; ageing transmission infrastructure; no neighbouring nations with surplus energy; no legacy nuclear power; no very-cheap domestic gas; and limited hydroelectric infrastructure. It does, however, have abundant wind and solar resources, potential for pumped-hydro development, and extensive low-cost land. Citizen engagement and uptake of rooftop solar is also exceptionally high.

> **Compared to the rest of the world, Australia faces one of most difficult energy transitions.**

A net-zero emissions electricity system is a critical component of the transition. Australia's transition will require a shift from a largely centralised system, where electricity is supplied by energy companies to users via a linear supply-demand model, to a more decentralised, reciprocal system, which provides multiple renewable options for generation and supply. This new system will enable users to not only be consumers but also 'prosumers', as both producers and consumers of energy. While individuals may have greater control and participation over their energy needs, this could create new issues around access, equity and fairness. The management and governance of this transition will therefore be complex, given that pathways will be dynamic and responsive to technological developments, as well as user needs, values and perceptions.

> **Australia's domestic energy consumption was 6,196 petajoules in 2018-19, and 94 per cent dependent on fossil fuels.**
>
> **Industry accounts for substantial energy use: transport, (28.2 per cent), manufacturing (16.9 per cent) and mining (13.1 per cent).**
>
> **Transport, particularly road and air, is predominantly reliant on the use of oil and oil imports, and will play substantive role in Australia's transition to net zero emissions.**
>
> **Renewables currently account for only 6.4 per cent of Australia's total energy consumption.**[16]

While the transformation of our electricity system is progressing, complementary work to transition our industries and economy towards net zero emissions is urgently required. As the largest contributors to Australia's total emissions, the transport, mining and manufacturing sectors will need to make the most substantive changes to their business models.

A range of solutions are already known and are underway: primarily through the substitution away from fossil fuels to a mix of alternative renewable sources (with current viable pathways expected to be based largely on electrification and hydrogen); developing and implementing carbon capture and storage technologies; considering carbon offset markets; and developing pricing mechanisms and incentives to encourage industry and consumer behaviour change. Commitment by industry leaders and businesses to transition towards net zero pathways is steadily growing: ClimateWorks' Net Zero Momentum Tracker, which monitors progress towards net zero emissions across key sectors (including transport, resources, banking, property) has assessed nearly 200 organisations, with 52 committed to net zero emissions by 2050.[17]

While the technological aspects of the transition are rapidly progressing, communities are still in the early stages of the transition. Genuine participatory processes and communication are crucial elements in achieving social licence and acceptance in the development and implementation of large infrastructure or industrial projects in communities. There have already been instances of community frustration, anger and distrust around the construction of major transmission infrastructure to accommodate large-scale renewable energy projects.[18] This can be a stressful and costly exercise for all parties, especially when community engagement or mediation occur near the end of the process. Past experiences and learnings will assist, such as those arising from a consideration of community concerns associated with the health impacts of wind turbines during increased industry developments in the early 2000s.[19] In these engagements, it is vital that the consultation processes are cognisant of the ways in which disadvantage will affect community participation in the transition.

Aboriginal and Torres Strait Islander communities need to be more involved as active decision makers and partners in energy transition efforts, to share the benefits of the transition, and to support reconciliation efforts acknowledging their role as Traditional Owners of Australian lands. Significant solar and wind resources are found on Aboriginal and Torres Strait Islander estates across Northern and Central Australia, and have great potential to support large-scale renewable energy developments. However, Aboriginal and Torres Strait Islander communities have largely been left out of critical decision-making processes and policy development. Where engagement does take place, this often occurs after regulatory processes for energy projects have been greenlighted, entrenching community distrust and disenfranchisement. Collaboration and engagement at the outset will be critical for strengthening greater participation, equity and fairness. In addition, Indigenous land management and practices represent some of the oldest, in-depth ecological understanding in the world[20] and could assist in ongoing land and ecological management to support the transition.

Urgent research is therefore needed to support broader social and equity implications of energy transitions in Australia.

Risks, opportunities and costs

The opportunities, impacts and risks of Australia's energy transition will vary depending on the actions and pathways taken; but in all scenarios, business as usual will be disrupted.

There will be impacts and opportunities across the full energy sector. Current efforts on the transition are occurring rapidly but unevenly, with various actions being progressed by state and territory governments and communities. This poses a risk that the future energy system will be disjointed.

The risk of negative impacts, such as insecure, unreliable or expensive energy, will need to be carefully managed. Additionally, Australian emission-intensive industries are likely to face major disruption as global demand transitions. This has significant implications for Australia's economy and society as the fossil fuel assets, and the associated infrastructure, may become 'stranded'.

> There may be a disproportionate impact on regional communities, given that 20 to 60 per cent of total regional employment is in emission-intensive industries.[21]

As noted in a recent Australian Academy of Science report, the environmental impacts of a changing climate without global mitigation include more intense and frequent rainfall flooding, cyclones, drought, extreme fire events and sea level rises.[22] These conditions have widespread implications for Australia's economy, environment and society: hotter temperatures impacting on labour productivity and population health; lost productive arable land due to drought and rising sea levels; capital damage resulting from destruction of infrastructure damaged by extreme weather events; the devastation to ecosystems caused by heat, drought and bushfires; and lower air quality (and associated increased mortality rates) due to increased smoke from bushfires.

Workforce impacts will also need to be carefully considered. Currently, 23 per cent of the Australian workforce are employed in emissions-intensive industries and will need to transition or upskill as those industries evolve.[23]

Modelling by Deloitte Access Economics (DAE) estimates that the economic cost to Australia of staying on its current economic trajectory, from unmitigated climate change would be losses of $3.4 trillion in present value terms, or 6 per cent of GDP. This will result in the loss of 880,000 jobs in 2070. Even with earlier projections on impact by 2050, the 'pathway of inaction or mis-action leads to economic losses of $1.1 trillion in present value terms by 2050 or 3.6 per cent of GDP. This sees the loss of almost 330,000 jobs by 2050.'[24] While the results of such models are approximations, the critical point outlined in the DAE analysis is that Australia does not have a 'no change, no cost' future available to it. At the minimum, it will have to deal with the growing damage done by climate change. Australia must therefore act swiftly and smartly, to minimise the disruptive impact on our society, the environment and economy, and to have the best chance of an optimistic future.

> A "business as usual approach" to the energy system will likely lead to significant losses in jobs and national output.[25]

On the other hand, the opportunities to benefit from Australia's energy transition are substantial, and well documented. Emerging evidence suggests that it is possible for Australia to reduce its emissions without substantial negative economic impacts – a 2019 assessment of 19 recent national reports modelling higher emission reduction targets by 2030, including three Treasury reports, concluded that various actions on emissions reductions would not have disastrous effects on the economy and, in fact, that deep reductions would likely lead to growth across the economy.[26]

DAE has forecast that a growth recovery pathway towards a zero-emissions scenario could increase GDP by 2.6 per cent and add $680 billion (in present value terms) to the economy in 2070. This pathway would also add over 250,000 jobs by 2070.[27] Additionally, modelling by PriceWaterhouse Coopers (PwC) has found that investing in renewables could add $13.2 billion to Australia's GDP and an additional $5.6 billion in consumption by 2040.

> A focused and strategic trajectory towards net zero emissions can build investor confidence and lead to economic prosperity and jobs.

Australia's ambitious Hydrogen Strategy also offers opportunities to carve out a hydrogen export market with Japan, South Korea and Germany. Two major renewable energy export projects have recently been granted Australian Government major project status: the Asian Renewable Energy Hub (hydrogen and ammonia) and the Australian-ASEAN Power Link (electricity). Additionally, Australia is continuing to demonstrate world-leading research capabilities in solar PV, which is likely to continue to grow and develop as global demand for renewables increases.

As demonstrated by the 'learning rates' model, technical advances and manufacturing improvements drive down the capital cost of production of new technologies. It is likely that concerted investment and focus on export opportunities for renewable technologies will have a positive impact on the pace and scale of the domestic transition in Australia, by driving down costs and increasing uptake of technologies such as hydrogen. The increased uptake of domestic solar PV in Australia has been driven in part by the dramatic learning rate, which has caused the solar module cost per watt in 2019 to fall to 1/500th of the cost in 1976.[28]

Recognising that markets can most effectively deliver desired investments and outcomes when investors have clear visibility of government direction,[29] the alignment of national, state and territory energy policies would facilitate greater confidence by investors and industry. Managing the risks and seizing the opportunities of the Australian energy transition will be greatly assisted by a focused research program.

Impact of COVID-19

The impact and scale of the COVID-19 pandemic on global economies and societies have been extensive. Comparative to the global experience, Australia has been largely successful in its management of the pandemic, and is recovering well from the economic and social impacts. Globally, COVID-19 is likely to influence government policy and stimulus measures over the next few years, which may impact the scale and rate of national energy transitions around the world. The IEA's 2021 Global Energy Review noted the resurgence of coal use for electricity generation, estimating that CO_2 emissions are heading for their second-largest annual increase in recorded history, as economies recover from the pandemic. This will reverse most of the decline caused by the pandemic last year. Global energy demand is also estimated to increase by 4.6 per cent, led by emerging markets and developing economies.[30] Australia will need to assess the long-term impact of the pandemic on its transition pathway, as well as its impacts on global markets and trading partners.

While global impacts have been substantial, COVID-19 has also demonstrated that there is an extraordinary capacity for societies to cope with change and adversity, presenting an opportunity to 'build back better', with an energy system that anticipates and contributes to a net zero emissions future.

2. The Research Plan

Key points

- The objective of this Research Plan and future releases, is to identify major research needs and gaps, and subsequently promote research priorities for a successful Australian energy transition to net zero carbon emissions.
- The Research Plan and Priorities will be annually updated to ensure it remains relevant over the course of the energy transition.

Recognising the challenges in the energy and wider research sector, the objective of the Research Plan is to identify major research gaps and subsequently promote research priorities for a successful Australian energy transition to net zero carbon emissions (by 2050 or earlier), with the purpose of helping to inform and influence the direction, allocation and quantum of research funding in Australia.

This will: 1) guide research funders, industry and researchers' activities related to the national energy transition; 2) encourage research activities that complement existing strengths and avoid duplicative efforts and 3) facilitate the required research to support evidence-based decision-making by research users (e.g. government and industry).

In addition, the Research Plan will contribute to broader transition research, which assesses the technological, organisational, economic, institutional and political impacts of large-scale socio-economic transitions through a multidisciplinary lens. Nationally and internationally, the energy transition is happening at a rapid pace and scale, and insights and research derived from this project and the Research Plan will likely provide important knowledge for future global transitions.

In parallel to developing the research priorities, ACOLA will also undertake research and consultation to examine the quantum and allocation of Australian energy research funding in the global context. International data on publicly funded energy research from comparable nations will be reviewed and compared with Australian data to better understand Australia's research position and trajectory in the global energy transition.

The Research Plan will be a dynamic document with annual updates and will be developed in consultation with stakeholders, to ensure it remains relevant over the course of the energy transition. Additionally, the Research Plan will include periodic reviews to comprehensively map out the state of current energy research in Australia. This will provide a clearer picture of which areas are being progressed, and where the largest gaps exist. The Plan will help prevent unnecessary duplication of effort so that funding and research can be directed towards the most critical issues to support the transition, including the most difficult issues that may require extended research investment, focus and time.

The Research Plan has received initial funding for the next three years. Regular updates will be provided, potentially through the annual State-of-Energy-Research Conference (SoERC) organised by the Energy Research Institutes Council for Australia (ERICA).

Timeline

ACOLA has developed an initial three-year timeline for ongoing development and update of the Research Plan outlined below.

Year 1

Development of initial research priorities and plan
September 2020 – June 2021

ACOLA will begin drafting briefing papers for each of the three Research Priority themes identified in this document. These papers will include a more detailed discussion exploring the research priorities and gaps for each theme including:

- rationale for each topic
- synthesis of current relevant research (in Australia and overseas)
- further elaboration on the research questions posed and how they might be best addressed, and
- key specific translation questions.

Year 2

Data collection and development
July 2021 – June 2022

ACOLA will continue to produce the briefing papers, which will be published by end of 2021. Early insights and findings will be presented at the annual ERICA SoERC subject to timing.

In the second half of Year 2, ACOLA will audit current national energy transition research and data gaps (both research and translation) against the research priorities. ACOLA will undertake consultation with the energy sector to ensure that audit results are consistent with the energy sector's understanding of the research landscape. Findings and insights will be presented at the 2022 ERICA SoERC.

The Research Plan's research priorities will be assessed at the end of 2022 to ensure that they remain consistent with the pace and direction of the energy transition as it evolves.

ACOLA will also develop an evaluation framework to measure the impact of the Research Plan.

Year 3+

Maintenance and evaluation
July 2022 – June 2023

ACOLA will reassess the state of the energy research landscape, building upon the audit from the previous year. As with previous years, ACOLA will use the ERICA SoERC to provide an annual update.

From Year 4 onwards, subject to ongoing funding, ACOLA will annually monitor and reassess the national energy research landscape, track progress against the research priorities and maintain the online energy research database. A triannual review of this initiative is proposed in Year 6.

3. Research priorities

Key points

- The Research Plan identifies the *urgent* and *strategic* research priorities (and critical gaps) that require assessment for a successful Australian energy transition.
- Three themes for priorities are identified: energy system dynamics; social engagement dynamics and transition dynamics, with three topics under each.
- In considering the identified gaps and highest priority areas, researchers and research funders can direct research efforts and funding to accelerate national efforts.
- We encourage funders to utilise the priorities in their funding guidelines and assessment of applications, to help ensure funding has the most impact or benefit.

ACOLA is grateful for the contributions and submissions made during extensive consultation on the draft research priorities. Experts across the sector provided their considerable expertise which has helped further refine the development of these research priorities.

The initial research priorities, as developed by ACOLA in consultation with stakeholders, are listed in the Diagram 1. They are organised into three themes: energy system dynamics; social engagement dynamics and transition dynamics.

Diagram 1: Research Priorities Themes and Topics

Themes

Energy System Dynamics

encompassing the technologies that we will need, how they will be integrated, and the pathways for their deployment and the associated retirement of legacy energy systems.

Topics

1. Technology

Technological innovation in renewables, energy efficiency and storage will be essential in facilitating the rate and scale of the energy transition. Mature technologies should be continually improved to increase efficiencies, while emerging technologies require sustained R&D to drive down production costs and encourage uptake. The Australian Government has identified priority technologies (and several emerging, enabling and 'watching brief' technologies) for government and industry support, with an annual review cycle. International innovation and market forces will also play a decisive role in the technology options and innovation pathways that Australia pursues. A close watch needs to be kept on emerging technologies, that are not currently on the radar.

Social engagement dynamics

encompassing the policy and regulatory settings that will be required for the transition, how people (individuals, communities, regions etc) will be engaged, and how principles of equity, justice and fairness throughout the course of the transition will be developed and applied.

4. Policy and regulation

Government (Commonwealth, state/territory and local) policy and regulation can facilitate or impede a successful energy transition. We need research to support best-practice energy-related policy and regulatory architecture within the context of the Australian political economy. Electricity markets are currently being re-designed; while this is essential, further work will be required.

Transition Dynamics

encompassing the governance structures that we will need, how we will manage the economic, health and social risks, and how industries and employment will be transformed.

7. Governance

Government, regulatory bodies, research, industry, NGO and community energy-related institutions all have important and distinct roles in the governance and management of the transition. Many, however, were established before the energy transition commenced at scale. We need to consider how current energy-related governance structures and institutions can be optimised to enhance governance, collaboration and decision-making. Evaluation of research translation into policy will also be important.

2. Transition pathways

There will be multiple, dynamic social, techno-economic pathways to reach a net zero emissions energy system by 2050 or earlier (most assuming massive renewable electrification with storage and a new hydrogen industry, to replace coal, oil and gas). The actual pathway and technology mix will evolve, with the extent and timing of sectoral coupling, clean energy exports and scaling issues being significant uncertainties. These pathways should be explored in an interdisciplinary manner; considering the social, cultural, technical, geo-political and economic dynamics of these pathways; how they will evolve; and the roles that the various actors need to adopt to optimise national outcomes.

3. Systems integration

The energy ecosystem is a complex system of systems with multiple interdependencies (supply chains, physical infrastructure, markets and the regulatory system and end user impacts), all now being disrupted. We need to understand how these systems interact with each other and with other sectors across the disciplines, as well as wider impacts and linkages for significant co-benefits (such as the impact of the transition on population health). Further research on the data and tools to support the transition will also be required.

5. Communication and engagement

Effective engagement on the impacts of the transition to diverse audiences is essential. Political ambition for the energy transition remains a complex and divisive issue in Australia. We need to better understand why this issue has been so divisive, and the values, impacts and perspectives of different communities and individuals in the transition towards a net-zero economy and society. A successful transition will need effective communication, genuine engagement, community support, and consumer, prosumer and investor confidence.

6. Social licence and participation

National and local support will be critical to a successful transition, but cannot be taken for granted. The new energy system is shifting to a more decentralised system with greater choice for users in the production, storage, and use of energy. Justice, equity, fairness, health and wellbeing should apply across social and geographic contexts, with particular consideration of the impacts on disadvantaged communities or households. For an inclusive transition, we need to better understand perspectives and values to facilitate genuine engagement with, and participation of, communities, at all scales and across all sectors.

8. Risks

There will be risks associated with the transition, particularly as dynamic, alternate pathways continue to evolve and new risk scenarios inevitably arise. Interdisciplinary research will help us navigate the unintended or negative impacts of the transition (across areas such as health, environment, economy and society). However, the transition also represents numerous opportunities to transform our society, economy and industries. Growing a successful renewable/low emissions industry will maintain Australia's position as a global energy exporter and encourage domestic economic growth and stability.

9. Industry

A strong, evolving Australian industry sector to support a net zero emissions economy will be underpinned by a mix of skills, capabilities, stable and strategic investment flows, collaboration across the innovation chain, and an understanding of Australia's role in the global energy market. We will need to consider whether Australia has the necessary skills and capabilities, self-reliance, and export potential, to develop these in the required volumes, and how these might be enhanced.

Under each of the topics, three high-level research sub-topics and initial high-level questions identify the critical research gaps and priorities that will require research and funding over the next decade (see Table 1 below). **The detailed Research Priorities and high-level questions can be found at Appendix 1**. These are not exhaustive, and, in many cases, there will be research already underway to help address them. The intent of these questions is to identify the priorities to help develop a more intensive and integrated framework for the Research Plan.

While research needs to begin now on all questions, questions are classified as either *urgent* (where robust answers are needed in the near future) or *strategic* (where robust answers are required in the longer term). These 27 questions represent the key questions requiring research at this point in time; but are likely to change in further iterations of the Research Plan as the transition progresses.

While the Research Priorities are presented in a static one-dimensional structure, the order of the list merely provides a structure to communicate a dynamic multi-dimensional proposition. It is not representative of the order or importance of priorities.

Themes	Topics and sub-topics		
Energy System Dynamics	**1. Technology**	**2. Transition Pathways**	**3. Systems Integration**
	1.1 Policy framework	2.1 Scenarios	3.1 Integration
	1.2 National advantages	2.2 Pathway Implications	3.2 Infrastructure
	1.3 Research focus	2.3 Scaling conditions	3.3 Digital
Social Engagement Dynamics	**4. Policy and Regulation**	**5. Communication and Engagement**	**6. Social Licence and Participation**
	4.1 Stocktake	5.1 Socio-political environment	6.1 Acceptance and support
	4.2 Markets and governments	5.2 Engagement	6.2 Community considerations
	4.3 Decision-making	5.3 Confidence	6.3 Benefits
Transition Dynamics	**7. Governance**	**8. Risks**	**9. Industry**
	7.1 Institutional models	8.1 Risks	9.1 Education and Skills
	7.2 Research community	8.2 Resilience	9.2 Capabilities
	7.3 Roles and practices	8.3 Global Trust	9.3 Export

Table 1: Australian Energy Research Priorities

The initial questions have been broadly framed; however this is not to suggest that more granular research questions are less important. For example, the initial technology research questions have a policy focus, but Australia will also require research on specific ways to reduce the cost of producing hydrogen to compete in a global market, and technologies to integrate weather-dependent renewable generation into the electricity system. Similarly, some of the initial questions related to the social elements of the transition have a broad focus, but these issues will also require investigation in the context of local communities. More granular research questions will be further developed in the next stage of the Research Plan. There were many other suggestions for research priorities during the consultations, both high-level and granular. These can be found online at www.acola.org.

Similarly, the structure of the priorities table is not intended to suggest the optimum structure for any particular research program, be it undertaken by universities, industry or government. Some research programs may be highly focused, addressing only a part of one of the research questions, while others may integrate elements from many of the themes and topics. While research should be driven by the interests of the research-funder and the capabilities of the researcher or research team, the Research Plan should help guide researchers, drawing attention to research that is already being undertaken and where research is not being done and thus requires attention. We encourage researchers to engage in interdisciplinary research where possible as this will yield particularly insightful knowledge.

ACOLA also encourages funding organisations across industry, the philanthropic sector and government (including the Australian Research Council (ARC), the National Health and Medical Research Council (NHMRC) and ARENA), to draw on the Research Plan and Priorities in their assessment of research grant applications, to help fund research that will have the most impact or provide the greatest benefit. Where possible, it will be important for funding assessors to familiarise themselves with the Research Plan to assist with enhanced funding assessment processes.

4. Australian energy research

Key points

- Australia has a diverse and flourishing research ecosystem, with energy transition research being progressed and supported by government, industry and philanthropic organisations.
- However, research activity needs to reflect the scale, speed and urgency of the transition.
- While strong progress is being made in science and technology aspects of Australia's transition, it must continue to support rapid transition towards net zero emissions.
- However, research on the social and human elements is lacking. Social and human research gaps include transitioning communities built around high-emissions industries, and issues of access and equity of the future distributed energy system.

Research landscape and funding

Accelerating energy research and innovation is complex, requiring coordination between public and private sectors, and the ability to react and respond to regular adjustments to new developments, especially in a time of rapid change. Australia's energy research reflects this complexity, consisting of numerous agencies, bodies and institutions in government, industry and the philanthropic sector across the research and innovation pipeline.

The Australian Government has historically taken a 'technology-neutral' stance in the support and development of energy research, with the notable exception of the creation of ARENA. The ARC and NHMRC are responsible for administering national funding to support basic and applied research in the sector. In 2021, the NHMRC created a Special Initiative in Human Health and Environmental Change to strengthen Australia's current capability and capacity in human health and environmental change research with a multidisciplinary focus, suggesting an appetite for energy-related research given the potential health impacts. The Medical Research Futures Fund was also established as part of the Australian Government's 2019-2020 Budget to support innovation and research translation in the medical sector over the next decade. The 2020-21 Federal Budget signalled a welcome injection of funding into the energy research sector including $1.9 billion in new funding for low-emissions and renewable technologies over the next 12 years with $1.62 billion earmarked for ARENA to finance research aligned with the Australian Government's Technology Investment Roadmap: First Low Emissions Technology Statement. States and territories are also heavily invested in R&D to support local projects. In the 2021-2022 Federal budget, the Australian government announced it will invest over $1.8 billion in Australia's future energy system. Of this, $1.2 billion will go towards positioning Australia at the forefront of low emissions technology innovation and commercialisation, including $275.5 million to develop four additional clean hydrogen production hubs in regional areas and $263.7 million towards carbon capture and storage projects.

In the research sector, many Australian universities have an energy research institute, and 12 of these are collectively represented by the Energy Research Institutes Council for Australia (ERICA) to provide specialised and interdisciplinary energy research. CSIRO, as the national science agency, continues to progress important energy research to assist government, industry and the community.

Not-for-profits and the philanthropic sector play an important role to strengthen the links between science and society, and to raise the profile of societal and economic responses in energy transition research.[31] In Australia, these include ACOLA, the Grattan Institute and ClimateWorks who conduct disciplinary and multidisciplinary energy-related research. In an assessment of the top five IEA countries in energy-related research for the period of 1981-2017 (Australia, UK, Canada, US and Germany), Australia showed the highest increase (908 per cent) in the publication of energy-related[iv] papers.[32]

Industry plays a critical role in translating applied research to demonstration, commercialisation and deployment. Through co-led industry and national funding, Cooperative Research Centres (CRCs) support industry-led research in deployment and commercialisation to solve industry identified issues. Energy-related industry associations including the Australian Energy Council, the Energy Networks Association and the Clean Energy Council importantly support industry collaboration and network linkages in the sector.

ARENA has provided a substantial investment into the commercialisation of energy research, with $1.58 billion in funding grants since 2012 to support R&D, market demonstration and early-stage commercialisation in renewable energy technologies. Additionally, the Clean Energy Finance Corporation (CEFC) supports the deployment and commercialisation of clean energy technologies at the latter end of the innovation chain, through mechanisms such as the Clean Energy Innovation Fund and the Advancing Hydrogen Fund.

Industry has contributed substantially to energy R&D, particularly in the mining and resource sector.[33] Private investment in large-scale renewable energy projects has increased significantly between 2016-2019, driving strong growth in private sector electricity related investment. It is estimated that the direct investment by ARENA and CEFC (of over $8.5 billion in clean energy related projects since their inceptions) has encouraged additional private sector investment of $25 to $30 billion.[34] A 2019 study on Australian R&D has also indicated that the R&D intensity of large Australian firms in the energy sector is higher than peers globally, with large Australian firms spending 4 per cent of revenue on R&D expenditure compared to the global average of 1 per cent.[35]

However, Australia has typically performed poorly in global innovation comparisons, ranking 22 in the WIPO 2019 Global Innovation Index. There are several key structural challenges to the translation of research into commercialisation, including financial and reputational risks, uncertain policy environments, intellectual property concerns, and academic culture and overcoming the 'valley of death' (see Box below). More direct policy interventions by the government, such as co-investment schemes to reduce risk, incentives for industry collaboration, government procurement schemes to support new technologies and direct investment have been implemented internationally to encourage industry-led R&D, and may assist in supporting broader institutional behaviour change in Australia.

The Australian Government has assessed the overall R&D landscape with a recent review of federal investment and system performance of innovation, science and research. The report recommended better alignment of investment to priorities, stronger evaluative measures to measure impact and performance, intentional sustained funding to provide certainty to the industry and research sectors and greater coordination across R&D ecosystems, and strategically balanced investment.[36]

iv Energy-related research fields are Ecology, Energy & Fuels, Environmental Studies, Water resources.

Australia has a diverse funding ecosystem, recognising that resources from multiple sectors across government, industry and philanthropy will be needed to address the energy transition as an issue of societal responsibility. Acknowledging the work that is already underway, a non-exhaustive list of recent reports and initiatives that contributed to the foundation and guidance for the Research Priorities is outlined in Appendix 2. While these are current at the time of drafting, the list will be updated as the Research Plan is further developed.

Research gaps and priorities

Our scientific and technological energy research is generally acknowledged as being globally competitive.[v] The strong economic incentives to develop Australia's significant natural energy resources has facilitated investment in consistent energy R&D over the past 35 years. In particular, we have world-leading expertise in the mining sector, as well as in the development of conventional and unconventional gas.[39] There have also been targeted

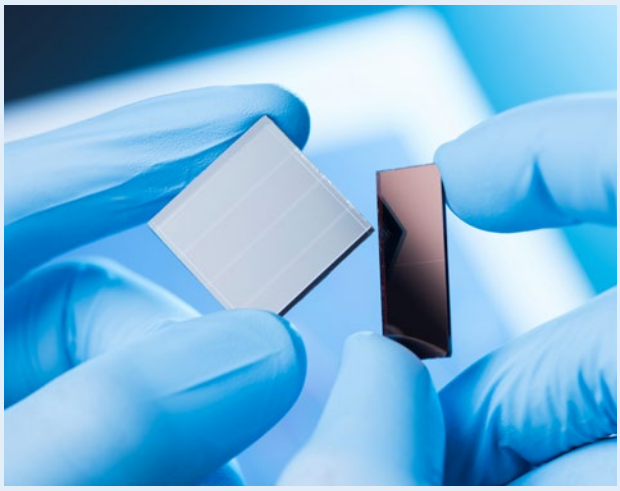
Challenges for Australia's Research Landscape

Valuing local and domestic research

Well-documented challenges in Australia's broader research landscape may also impede energy transition research, and the integration between sub-sections of this research. For example, universities often place greater value on research published in international journals compared to national journals, as these metrics can be used to inform a university's international ranking. A reframing of the value and importance of local research is required so that Australian researchers are funded and well supported to assess and solve local problems and what is needed to achieve a successful domestic transition.

Research translation into commercialisation

The 'valley of death' representing the gap between scientific research and commercial application of a technology has often been cited as a key institutional challenge for the Australian research landscape. The OECD suggests the valley of death occurs in the commercialisation of low emission technologies because of high risk/return, higher initial capital requirements, longer market lead times and a lack of entrepreneurial experience discouraging investors from funding start-ups.[37] A holistic understanding of demand and supply is required, as is strengthening industry ecosystems and linkages. In Australia, this may be a result of research capacity in universities evolving independently of innovation needs for the economy.[38] This impedes translation impact: while Australia may perform strongly in basic and applied research output, there may not be the sufficient scale or intensity to meet potential industry demand. In a dynamically changing energy sector, Australia could benefit from more deliberate policy interventions and/or incentives to encourage collaboration and reduce risks for the academic and industry sectors.



v For example, in the areas of solar and wind technologies, carbon capture storage, conventional and unconventional gas. International Energy Agency (2018). *Energy Policies of IEA Countries: Australia 2018 Review.*

investment in clean energy technologies, including hydrogen, large scale solar, grid scale battery, pumped hydro, bioenergy, and distributed energy technologies. As previously noted, Australia has become a world leader in the development of solar renewable energy systems and domestic appetite for cleaner alternatives to high emission energy sources.[40]

Continuing to progress Australian science and technology research efforts will be important to ensure Australia has the appropriate technological solutions to achieve long-term net zero emissions, including, for example, the decarbonisation of industries that rely heavily on fossil fuels as well as developing our domestic hydrogen capabilities. Additionally, novel research gaps and priorities will emerge and need to be addressed as technologies and pathways evolve.

However, ACOLA's research and consultation to date has demonstrated a particularly critical and urgent gap in energy research in the humanities, arts and social sciences disciplines. In particular, there is relatively little research that considers the social, cultural and economic impact of the transition for local communities and end-users. Transition efforts, especially in regional areas, will have a tangible impact on people in the context of their lives and wellbeing, including their employment, lifestyle and social interactions. While broader lessons can be learned from international research, these will not be always applicable in the Australian context.

> More Australian research is needed to develop locally-relevant strategies and solutions to domestic challenges.

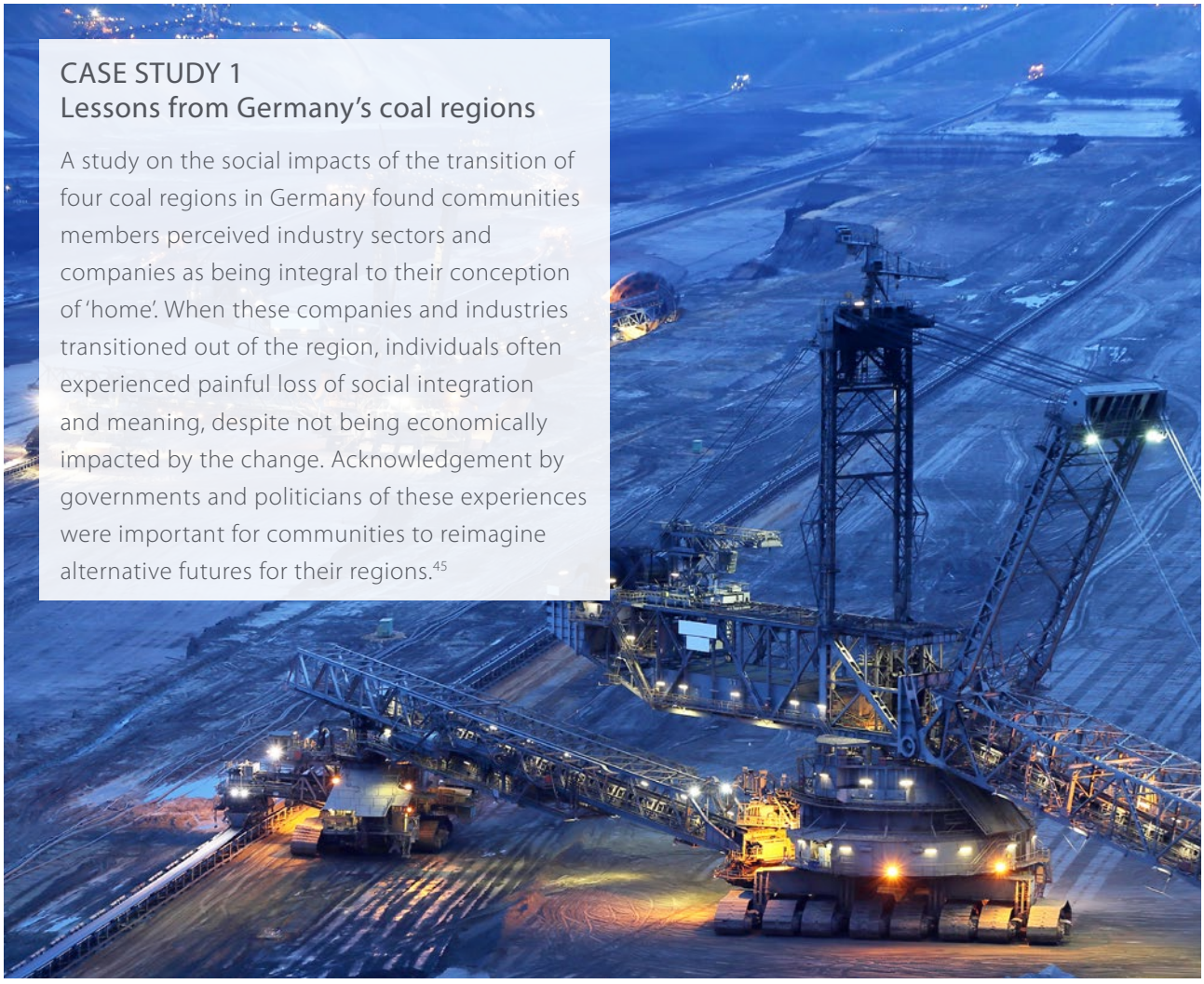
Furthermore, in a future decentralised system that includes users as producers, citizens and community members may be more interested in benefits such as wellbeing, cultural values, enhanced social capital, energy autonomy, ethical usage, indoor comfort or property value increase, rather than just 'traditional' considerations such as emissions reductions, energy efficiency or cost savings.[41] How they choose to connect, use and contribute to the future national energy system may have various effects or unintended impacts, including disruptions to system resilience and reliability, or limiting equitable participation and access.

Another distinctive and important dimension of Australia's energy transition is the impacts on communities traditionally built around fossil fuel industries, such as mining or coal-fired electricity generation. There is little local research on the social, cultural, behavioural, and geographical context of the energy transition on communities, such as the underlying connection and values associated with individuals' employment by these industries. Without understanding these dynamics, top-down energy policies to transition communities to a green energy future may be unsuccessful or met with resistance or mistrust.

Research that appropriately considers the social and economic challenges of the energy transition can help develop relevant policy measures such as upskilling or reskilling workers or attracting new industries and investment into a region. It is important to note that measures will not be universally appropriate: the transition for the Pilbara region, WA will be very different to the Surat Basin, Queensland and in the Hunter Valley, NSW. While many Australian social and community experiences will be unique, there will be instances where we can draw on international research to develop supportive and meaningful policies to help communities and individuals through this transition (see for example, case study 1).

Other gaps identified in the consultation include economic considerations of the various trajectories of the transition; the governance considerations required to facilitate the transition; downstream effects of renewables and low emission technologies, such as the use of hydrogen in appliances; the impact of large-scale energy projects in renewable energy zones (as outlined in the Australian Energy Market Operator's (AEMO) Integrated System Plan); the social, cultural, legal and regulatory impact of energy projects on Indigenous estates or land held under the Native Title Act; and the geo-political dimensions of Australia's transition, such as the impact of global partners on domestic industry incumbents. This list is by no means exhaustive but demonstrates the breadth of questions that will underpin a successful transition.

People exist at the centre of the transition as the users and beneficiaries of the energy system. However, social science research and human perspectives are often treated as an afterthought. They may be limited to focus groups testing the feasibility of a scientific or technological innovation prior to market deployment. Technological solutions are required for the transition, but they have little value if they do not incur trust and confidence by users, or correspond with people's lives, jobs and communities. As such, interdisciplinary perspectives and research agendas will continue to be essential as we progress through the energy transition.



CASE STUDY 1
Lessons from Germany's coal regions

A study on the social impacts of the transition of four coal regions in Germany found communities members perceived industry sectors and companies as being integral to their conception of 'home'. When these companies and industries transitioned out of the region, individuals often experienced painful loss of social integration and meaning, despite not being economically impacted by the change. Acknowledgement by governments and politicians of these experiences were important for communities to reimagine alternative futures for their regions.[45]

Social licence and community acceptance

The concept of 'social licence' or 'social licence to operate' refers to the process taken by industries to engage with communities on the costs and benefits of industrial development.[42] In Australia, the term has been popularised over the last 20 years through its usage by the resource sector to describe engagement with communities impacted by large-scale projects, such as mineral extraction and forestry. However, its usage has been problematic, having been associated with perceived opportunistic corporate agendas to 'extract' acceptance rather than to achieve it with communities through joint negotiation and collaboration.[43] The term has continued to be commonly used in the course of the energy transition to describe engagement with communities in the development of innovative technologies and large-scale energy projects. The Research Plan recognises the utility of the term, and uses it to include community leadership and participation in the interdisciplinary research mix.

The success of the transition should be synonymous with an acceptable level of social acceptance and support across Australia, where acceptance (behaviour that promotes or enables the use of a technology and support (proclaiming or using technology) is achieved, rather than resistance (deliberate actions to protest or not use a technology) or tolerance (in favour but inaction).

Factors such as perceived costs, risks and benefits, issues of procedural and distributive fairness, outcome efficacy and awareness of adverse consequences have been determined as impacting overall acceptance and support in several empirical technology acceptance studies. In addition, communities may have different attitudes depending on their interactions with a technology. Citizen acceptance, where the public is faced with the placement of a technology close to their home, will require different levels of engagement and trust-building, compared to consumer acceptance, which is associated with the purchase and use of technologies. Drawing on learnings from past corporate engagements with communities, and understanding psychological factors that motivate values, attitudes and behaviour will be crucial for furthering broader public engagement, acceptance and understanding of the transition.[44] Consultation with leading experts in this field has also underscored the importance of associating social licence with genuine participatory processes, underpinned by ongoing behaviour and sentiment monitoring.

ACOLA understands that important research efforts and deliberative community engagement processes are currently occurring across Australia, however, more research on broader community impacts and attitudes will be necessary as our transition trajectory evolves.

5. Conclusion

The energy transition to net zero emissions is one of the most profound societal challenges that Australia and the world has faced. We already know that a business-as-usual trajectory is no longer possible, and that the impacts of climate change on our cities, regions, unique natural systems and physical infrastructure can no longer be ignored. The evolving transition of our energy systems, environment and climate will impact societal well-being in the years and decades ahead.

ACOLA's Research Plan addresses the fragmentation and lack of focus in our research activity to solve uniquely Australian problems, including ensuring that social and human perspectives are considered in conjunction with scientific and technological developments. Implementing its deliberately coordinated and strategic research priorities will help ensure our future energy system is sustainable, reliable, affordable and fair.

In acting on the research priorities outlined in this Research Plan, we particularly encourage funders of research (government, industry and the philanthropic sector) and research institutions to continue to facilitate, undertake and support interdisciplinary research and research that are focused on timely, practical and applied outcomes for communities, government and industry. Our climate and our nation cannot wait for research that takes a decade to be translated.

We thank NERA, ARENA and CSIRO for their contributions to the Research Plan, and we trust that this and future iterations of the Research Plan will be a vital tool to support the progress on strategic and critical energy transition research efforts in the years ahead.

Appendix 1

Research Priorities: themes and high-level questions

Theme: Energy System Dynamics

Topic	Scope	Time
1. Technology	Low, zero and negative emission technologies are essential for the energy transition. The Australian Government has identified priority technologies (and several emerging, enabling and 'watching brief' technologies) for government and industry support, with an annual review cycle. It will be important to ensure that Australia has the appropriate energy mix to meet its future domestic needs, and to grow a clean energy export market.	
	1.1 **Policy framework**: How might technology policies in Australia be further developed (additional or alternative energy technologies, energy efficient mechanisms R&D programs, industry participation, deployment support mechanisms) as our transition pathway evolves over time?	Urgent
	1.2 **National advantage**: Where does Australia have a competitive or comparative advantage in clean energy technology research and development, and how can this be exploited to support the energy transition?	Urgent
	1.3 **Research focus**: What are the specific core, niche or enabling technologies where Australia should make a concentrated research effort (should our energy technology research effort be more specialised)? How can this adapt to consider international developments?	Strategic
2. Transition pathways	There are multiple techno-economic pathways to a net zero emission energy system by 2050 (most assuming massive renewable electrification with storage, and a new hydrogen industry, to replace coal, oil and gas). The actual pathway and technology mix will evolve, with the extent and timing of sectoral coupling and clean energy exports being significant uncertainties.	
	2.1 **Scenarios**: What are the main feasible transition pathways, and where are the greatest uncertainties, based on current knowledge and forecasts?	Urgent
	2.2 **Pathway implications**: What are the costs, benefits, impacts and risks to the Australian economy, society and environment of these pathways (what parts are most difficult, how important are clean energy exports, do we have comparative advantages)?	Urgent
	2.3 **Scaling conditions**: How will we reach the social, technical and economic conditions required for a successful transition of this scale? What are the scaling, economic adjustment and capital mobilisation issues?	Strategic
3. Systems integration	The energy economy is a complex system of systems with multiple interdependencies, all now being disrupted. There are interdisciplinary issues (technical, economic, regulatory, market design, equity and fairness) that must be addressed.	
	3.1 **Integration**: What are the critical system integration issues for low/zero/negative emission energy technologies across sectors (including social, economic and technical considerations), and do we have the necessary interdisciplinary capabilities to address them?	Urgent
	3.2 **Infrastructure**: What national energy-related infrastructure changes are required, what investment is needed to support these changes, how can this investment best be funded?	Urgent
	3.3 **Digital**: How can emerging digital technologies be leveraged in energy systems integration; and are we well-placed to utilise these technologies (do all stakeholders, including local communities, have the necessary data and analytical tools)?	Strategic

Theme: Social Engagement Dynamics

Topic	Scope	Time
4. Policy and regulation	Government (Commonwealth, state/territory, local) policy and regulation can facilitate or impede a successful transition and will need to be dynamic, integrated and agile over the course of the transition. Electricity markets are currently being re-designed; while this is essential, further policy and regulatory work is required.	
	4.1 **Stocktake**: Which policies and regulations are supporting, impeding or missing for the transition (what can we learn from overseas experience in these areas)?	Urgent
	4.2 **Markets and governments**: What is the optimum mix (over time) of market forces and government planning and intervention over the course of the transition?	Urgent
	4.3 **Decision-making**: How can we integrate multi-factorial policy-making and regulatory tools to better consider the complexity of the energy transition across social, technical, and economic dimensions?	Strategic
5. Communication and engagement	A successful transition will need effective communication, genuine engagement, community support, and consumer and investor confidence. This would be assisted by a greater political consensus.	
	5.1 **Socio-Political Environment**: How is Australian energy politics and our political economy different or similar to that in other developed nations (what can we learn from the overseas experience)?	Urgent
	5.2 **Citizen engagement**: How can communication platforms and messaging be used to best engage the breadth of Australian audiences, from national to local; what are the community (place-based) engagement issues and how does this relate to their identity, values, lived experiences, history and willingness to participate in the transition?	Strategic
	5.3 **Confidence**: What are the drivers of consumer, prosumers and investor confidence? To what extent are consumers and investors leading or following the transition, and how can their preferences and engagement be leveraged?	Strategic
6. Social licence and participation	National and local support will be critical to a successful transition, but cannot be taken for granted. Social justice, particularly for households and communities living in disadvantaged circumstances, could be enhanced or diminished by the energy transition.	
	6.1 **Acceptance and support**: What are the current social attitudes towards the transition, by location, technology and sector (what is working, what isn't, why, and what could be changed)? How do consumers want to participate in the new energy market? How can it be made equitable for all sections of the community?	Urgent
	6.2 **Community considerations**: What are the broader implications of the energy transition on different communities (such as cultural, social, economic, health), including vulnerable populations? As traditional owners, how can we integrate Aboriginal and Torres Strait Islander perspectives, participation and leadership in the transition?	Strategic
	6.3 **Benefits**: How can the benefits of the energy transition in general, and a potential renewable energy export boom in particular, best be captured for the wider community? What are the health and wellbeing impacts of a successful transition likely to be? How can they be enhanced?	Strategic

Theme: Transition Dynamics

Topic	Scope	Time
7. Governance	Governance during a transition is more complex and sensitive than during periods of incremental change. Governments, research, industry, NGO and community institutions all have important roles in the transition.	
	7.1 **Institutional models**: What institutional governance models are best suited for the Australian energy transition and are there learnings from international experience?	Urgent
	7.2 **Research community**: How can the Australian energy research community (funders, researchers and research users) be structured to optimise their contribution to the transition, including the effective translation of research into impact?	Urgent
	7.3 **Roles and practices**: How should the roles, structures and practices of governments, regulators, researchers, industry, NGOs and communities adapt to most effectively facilitate the transition?	Strategic
8. Risks	There will be risks associated with the transition, particularly as dynamic, alternate pathways continue to evolve and new issues arise.	
	8.1 **Risks**: What are the technical, economic, environmental, geo-political and social risk scenarios (including social justice) that could impede successful transition to net zero-emission systems, and how can these best be mitigated?	Urgent
	8.2 **Resilience**: How do we build and maintain energy system resilience against natural disasters, climate change, cyberthreats and power system changes?	Strategic
	8.3 **Global trust**: How do we ensure that Australia remains a 'trusted partner' in global energy supply chains?	Strategic
9. Industry	The Australian net zero emission energy economy will require a different mix of skills, capabilities and supply chains. This has both commercial (business) and strategic (national) implications.	
	9.1 **Education and Skills**: What are the critical new skills that will be needed for the transition, are there any structural barriers to them being met (time, place, quantity) and, if so, what are the appropriate policy responses?	Urgent
	9.2 **Capabilities**: To what extent should Australia be self-reliant in clean energy industry capability (both manufacturing and services)? What are the costs, benefits and potential policy responses to a range of self-reliant scenarios?	Strategic
	9.3 **Export**: What opportunities are there for Australia to export clean energy industry capabilities and skills?	Strategic

Appendix 2

Notable reports

Independent Review into the Future Security of the National Electricity Market – Blueprint for the Future (Finkel Review).[46] This 2017 independent review chaired by Australia's Chief Scientist Dr Alan Finkel AO delivered a roadmap to the COAG Energy Council for the future security and reliability of the National Electricity Market (NEM) enabled by system planning, stronger governance and an orderly transition.

Data Strategy Consultation Paper.[47] The Energy Security Board (ESB) has released a public consultation paper on a new data strategy for the NEM, which was one of the recommendations from the Independent Review into the Future Security of the National Electricity Market – Blueprint for the Future.

2020 Integrated System Plan.[48] The Australian Energy Market Operator (AEMO) Integrated System Plan (ISP) is a whole of system actionable roadmap to guide the efficient development of Australia's NEM over the next 20 years. Its primary objective is to facilitate an energy system that is low-cost, secure and reliable, and incorporates Australia's ongoing emissions trajectory within an acceptable level of risk. It serves the regulatory purpose of identifying actionable and future ISP projects, as well as informing market participants, investors, policy decision makers and consumers.

NEM Engineering Framework.[49] This 2021 AEMO Report describes the changing physical characteristics of the NEM (attributes, operability, integration) and the work underway to adapt the system for the energy transition. Attributes include resource adequacy, frequency management, voltage control, system strength and system restoration. Operability incudes control room, support and system analysis. Integration includes resilience, performance standards and distributed energy resources.

Technology Investment Roadmap: First Low Emissions Technology Statement – 2020.[50] Released in 2020, this document outlines the Australian Government's plan to invest in low emission technologies across five key priority areas, and to make them market-competitive with current higher-emission technologies.

Australia's National Hydrogen Strategy.[51] The strategy outlines an approach to scale up a national hydrogen industry with a set of national coordinated actions for government, industry and the community to position Australia as a major global export by 2030.

Hydrogen for Australia's Future: A briefing paper for the COAG Energy Council.[52] This briefing paper was developed by the Hydrogen Strategy Group for the COAG Energy Council to support the national strategy and discusses the scope of the potential for an Australian hydrogen industry.

State of the Energy Market 2020.[53] This annual report from the Australian Energy Regulator highlights trends and issues across the energy industry, covering wholesale electricity and gas markets, the transmission and distribution networks and energy retail markets. The 2020 report features a new chapter on the rapid transformations across the electricity sector.

Energy Security Board: Post 2025 Market Design Options – A paper for consultation.[54] The ESB has been tasked to develop advice on reforms to the NEM to meet the needs of the transition and beyond 2025. This paper builds on existing work, setting out a suite of potential reform pathways for consultation.

Australian Industry Energy Transitions Initiative.[55] Established by ClimateWorks Australia, the initiative seeks to support Australian 'hard to abate' industries (steel, aluminium, LNG, selected metals and chemicals) to develop pathways and actions towards net zero. The initiative will focus on creating a platform for industry learning and experimentation to achieve this goal.

Australia's energy transition: a blueprint for success.[56] This report from the Grattan Institute provides a number of recommendations for key policy and institutional reforms to support Australia's energy transition.

Go for net zero: A practical plan for reliable, affordable, low-emissions electricity.[57] This Grattan report provides modelling and analysis demonstrating that Australia's NEM can achieve net-zero emissions without threatening reliability or affordability.

A new choice: Australia's climate for growth.[58] This 2020 Deloitte Access Economics report provides a recent economic analysis on the pathway of Australia's economic transition, and the potential damage to the economy and the environment of unconstrained climate change.

Clean Energy Australia Report 2020.[59] This report from the Clean Energy Council covers the latest key figures and statistics on the national energy market for 2020 and includes analysis across the NEM, and other major grids across the country including WA and NT.

Future Electricity Market Summit. Co-organised by the ESB, the IEA and the Australian National University Energy Change Institute (in collaboration with ERICA), this summit captured the key issues that need to be addressed for a future zero-emissions electricity market. The outcomes were published in a series of eight papers corresponding to the Summit Themes in the November 2020 issue of the Electricity Journal.[60]

Community Engagement and Benefit Sharing in Renewable Energy Development: A Guide for Applicants to the Victorian Renewable Energy Target Auction.[61] Commissioned by the Victorian Government, this is a best practice guide for developers delivering low-emissions technologies projects for community engagement and benefit sharing across all renewable energy technologies. This includes case studies and practical information to deliver projects to benefit project hosts, neighbours and communities.

Collie's Just Transition Plan.[62] Developed collaboratively by representatives from the Collie community, employers, unions, and state and local governments, the Plan outlines the first phase to facilitate the just transition of workers and communities in the town of Collie, the site of WA's only productive coalfield.

Best Practice for Community Engagement: Determining who is Affected and what is at Stake.[63] This paper was developed by Peta Ashworth, who is a recognised expert in her work in building energy literacy and supporting community and stakeholder engagement in the energy sector.

The Clean Jobs Plan.[64] Developed by AlphaBeta for the Climate Council, this Plan identifies 12 major policy opportunities to kick-start economic growth and deliver 76,000 jobs in the clean energy sector, following the bushfire crisis of 2019 and COVID-19.

Just Transition: Implications for the Corporate Sector and Financial Institutions.[65] This report by Global Compact Network Australia, examines practical ways for the corporate and financial sector to manage their interests, customers and shareholders to plan and prepare for transition to a low-carbon economy.

Healthy, Regenerative and Just: Our vision for a better future.[66] In response to climate change events and Covid-19, the Climate and Health Alliance brought together over 100 thought leaders across sectors to imagine a new collective future that is healthy, regenerative and just. Eight key areas of policy actions are recommended to help achieve this goal.

Net Zero by 2050: A Roadmap for the Global Energy Sector.[67] This special report by the IEA sets out a global pathway to transition to net zero emissions by 2050 through the uses of renewables. It also assesses some key uncertainties on this trajectory including the role of bioenergy, carbon capture technologies and behavioural changes in reaching net zero.

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