From Ambition to Reality 2:
Measuring change in the race to deliver net zero

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Foreword

Sue Brown

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Since the release of our first From Ambition to Reality paper in 2021, much has changed in the global order and in global energy markets. The dual challenges of energy security and climate change are exercising the minds of policy makers the world over.

Geopolitical events have elevated the need for energy independence and security of supply. In parallel, the impacts of climate change are increasingly being felt across the world and the stakes of decarbonization have never been higher.

Motivated by this nexus, it is time to shift the narrative from what we need to do, to how, and with urgency. Achieving mid-century net zero is in large part an infrastructure delivery challenge. One where the scale and pace of change has the potential to overwhelm us.

This paper showcases project examples where transformational project delivery thinking has been brought to bear to great effect. It builds on and brings to life the shifts defined in our first paper and goes on to propose a measurement and response path to support keeping the world on the mission to net zero by mid-century.

We value our partnership with the Princeton Andlinger Center for Energy and the Environment and believe that combining Worley's global project delivery expertise with Princeton's analysis of the pathways to mid-century net zero has the potential to produce an enduring legacy by changing the way the complex infrastructure of net zero is delivered.

Worley is committed to seeing the ambition of climate response driven to a practical reality. We will continue to explore and employ with our customers the shifts in practice we believe are necessary. We urge all of you to consider the magnitude of the task, and how radical our response needs to be, and to join us in what is the challenge of our lifetimes.

I hope what you discover in this paper inspires you to turn thinking into action and ambition into reality.

Andrea Goldsmith

Dean of Engineering and Applied Science, Princeton University
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Our collaboration with Worley represents exactly the kind of partnership between universities and companies that is needed to solve the enormous challenges facing humanity such as climate change.

Worley joined Princeton University's E-ffliates program in 2021, inspired by our influential Net-Zero America study, which provides one of the most comprehensive, detailed roadmaps for remaking the US infrastructure to stop the buildup of carbon in the atmosphere by 2050. The study, led by researchers at our Andlinger Center for Energy and the Environment, is not only driving climate discussions in the US but is inspiring similar studies around the world. Worley is supporting the first of these, in Australia, where Princeton researchers are collaborating with colleagues at the Universities of Queensland and Melbourne.

The Princeton E-ffiliates program, administered by the Andlinger Center, provides an excellent platform for this kind of partnership between universities and industry. This program offers corporations a unique opportunity to engage in bold impactful research and to find specific innovative solutions in energy and the environment.

With Worley, we are bridging the Andlinger Center's world-leading clean energy research and systems analysis with the real world of project delivery, in pursuit of a more sustainable net-zero world.

Our first collaborative publication, From Ambition to Reality – weaving the threads of net-zero delivery, identified five key shifts among project delivery practitioners and associated stakeholders if we are to achieve the massive infrastructure development implied by Net-Zero America. This new publication, From Ambition to Reality: Measuring to be net-zero ready by 2030, maps out processes to hold us to account in our adoption of the shifts.

I hope you enjoy reading this latest installment in the journey from ambition to net-zero reality.

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Clare is the Director of Sustainability Performance for Worley and is passionate about the decarbonization of the energy, chemical and resources industries. She stewards Worley to meet the commitments made in our Climate Change Position Statement, embedding sustainability in the way we operate our business and deliver services to our customers.

Clare has a PhD in Chemical Engineering, specifically relating to the adaptation of low-carbon technologies. She's worked in project and engineering management for more than two decades and is an experienced leader of large technical teams. Her experience spans all phases of project development from concept development through to detailed design, construction, and operation. She also has considerable experience working in Cooperative Research Centres (CRCs).

Clare has delivered major energy infrastructure projects in Europe, South Africa, and Australia. She is a former director of the Australian Institute of Energy and currently sits on the advisory panel for Net Zero Australia.

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Chris is the Theodora D. and William H. Walton III Senior Research Scientist at Princeton University's Andlinger Center for Energy and the Environment. He has a PhD in Chemical Engineering, is a fellow of the Australian Academy of Technology and Engineering (ATSE) and holds an adjunct professorial appointment at the University of Queensland in Australia.

His academic career follows almost three decades of international experience in the private sector, firstly as a company founder, and then in senior executive and non-executive director roles in major engineering, energy and resources companies.

At Princeton, Chris spearheads the Rapid Switch Initiative at the Andlinger Center and is an affiliated faculty member of the Princeton's High Meadows Environmental Institute. His research combines energy systems analysis, business and social sciences to explore the challenges of rapid decarbonization for different regions and sectors. He co-led Princeton's influential Net-Zero America (2021) study and is also leading Princeton's efforts on similar collaborative studies with universities in Australia, Asia and South America.

Dr Paul Ebert

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Paul is the Group Director Sustainability & Energy Transition Leadership for Worley and focuses on the company's external voice and influence across the critical sustainability challenges facing the world. This includes relationships with customers, research institutions and various industry stakeholders.

Paul has more than three decades experience working in clean energy and he's been responsible for projects across a wide range of technologies and industries. This has included enablers such as distributed energy, green hydrogen, various forms of energy storage and integration of such into industrial processes and markets. His focus is on large-scale sustainability impact, and he sees the heavy industries as a key focus area.

Paul is a mechanical engineer with a PhD in wind turbine aerodynamics. He sits on the Advisory Panel for Net Zero Australia and is a former advisory or steering committee member for the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australian National University and the University of Newcastle, Australia.

Acknowledgments

Many experts from around the world contributed to this paper. This has been a brilliant demonstration of the type of collaboration and partnership we outline within our key shifts. We thank everyone for their contribution and commitment to sharing ideas to uncover the solutions that will help us in delivering a more sustainable world.

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Front cover: Galileo thermometer

The UN Intergovernmental Panel on Climate Change (IPCC) estimates that human activities have already caused approximately 1.1°C of global warming, and its scientific work supports limiting further warming to 1.5°C to avoid the more severe impacts of climate change. Its modelling suggests that this would require reaching net-zero global emissions by around 2050.

The Galileo thermometer uses glass vials containing liquids of varying density that rise and fall depending on the ambient temperature. The ambient temperature is read as the temperature of the lowest floating vial.

We use the Galileo thermometer as a symbol of global temperature increase. With the long-term challenge being to stop the 1.5°C vial from sinking.

Contents

CHAPTER 1 Laying the foundation

Chapter 1: Laying the foundation

The science is clearer than ever and time is running out: avoiding the worst effects of climate change hinges on a world in which our greenhouse gas emissions are net zero.

In our first From Ambition to Reality paper, Worley and Princeton were explicit about what it will take to get there by 2050. To limit warming to 1.5°C, the world must fundamentally overhaul the speed and scale at which it develops energy infrastructure. We introduced five shifts in thinking the world needs to make for that ambition to become reality. But despite the best of intentions, increasing commitments, and some promising progress, we're still a long way from where we need to be.

In this paper, we use the five shifts to convert thinking into action. We describe how we'll track and drive the changes we need in the critical decade for climate action through to 2030. To complement this, we give examples of the remarkable success these shifts can bring across diverse industries and where they are being incorporated in new ways of doing things.

In addition to our core analysis, we've included an additional final section, New Numbers, Global Challenge, which examines a different economy and reminds us that the net-zero challenge is a global one.

We must face the energy crisis head on

The war in Ukraine, wider geopolitical tensions, and economic recovery from the pandemic have stretched supply chains and threatened energy security. No one could have anticipated that in 2022, sanctions on Russian-sourced energy and a lack of alternative, sustainable energy supply, would force Europe – a global leader on climate action – to increase its use of coal energy. As prices soar, winters loom, and the world prioritizes its response to these crises, we risk taking our eye off the climate challenge.

A collective imperative must drive our actions

To get to net zero, we must act with collective imperative. We must transcend the limits we put on ourselves – economics, processes, social differences – to change how we design, build, collaborate, and communicate. But we must not wait. Whatever the world might throw at us, however uncomfortable or vulnerable we may feel, we must act now to avoid the worst impacts of climate change. This is the critical decade for action.

Revisiting our first paper

In our first paper, we untangled the threads of the net-zero transition to weave a new delivery paradigm that unlocks speed and scale in infrastructure development. There, we:

- used Princeton's Net-Zero America work to size up the infrastructure challenge of decarbonizing the world's largest economy.
- broke the bigger challenge down to its smaller components so we could see what needed to be done differently.
- moved on from **what** we need to build, to **how** we should deliver infrastructure at speed and scale, regardless of the technology pathway.
- reflected on lessons from history, considered new insights, and brought all the latest project delivery thinking at our disposal to bear.
- introduced the five key shifts (Figure 1) needed to overhaul how we plan, develop, procure, and build the infrastructure needed to get to net zero by 2050.

Our first paper showed that while the path to net zero is possible, the challenge lies in the speed of development. This second paper outlines the indicators we'll use to measure and drive changes in practices.

The five shifts reveal indicators of change

We dissect the paradigm further to show how far we must push beyond our traditional limits and behaviors in the lead-up to 2030. To do this, we look at the foundations of the five shifts to ask:

- What does success look like?
- Where are we now?
- And what needs to change to get us on the right path?

This thinking leads to our **indicators of change**. They'll help us assess where we stand and give us the insight and confidence to adjust and correct our course.

Figure 1 – the five shifts of the net-zero delivery paradigm

Tracking the change we need to see

From next year, and for every year in the lead up to 2030, we'll measure the indicators of change across a representative and diverse cohort of stakeholders to track progress. A Princeton research team will design and roll-out a first-of-its-kind, independent survey to help identify patterns of behavior and practice.

We don't want to get to 2030 and find ourselves saying, "If only we knew." So we'll use this work to build a realistic picture of what we've achieved, to size up the change we need to see, and to drive better outcomes and more value for stakeholders and communities.

Industries, organizations, and communities are starting to change

We are starting to see some isolated examples that demonstrate what is possible from diverse industries, organizations and communities when the shifts are in play. There remains much to do, especially in the energy and industrial sectors, but we have included some examples to illustrate the transformative change in outcomes that become possible by using the shifts.

A shared sustainability focus powers our work

The Andlinger Center for Energy and the Environment (ACEE) at Princeton University is a multidisciplinary research and education center. Our singular mission is to develop technologies and solutions that secure a more sustainable future. We work with industry and governments to translate world-class research into practical solutions. Solutions that produce sustainable energy, and protect the environment and the global climate from the energy-related activities of human societies.

Worley's purpose is delivering a more sustainable world. Our global team of engineers, data scientists, consultants, construction workers, and innovators work with customers across the energy, chemicals, and resources sectors. We help to decarbonize and adapt to climate change and navigate the energy transition, and keep up with the digital transformation. And by doing that, we're helping to solve our planet's toughest issues.

For both organizations, net zero isn't a pipedream or lofty ambition. It's our collective imperative. We work to unravel the complexities and the scale of the challenge. We recognize the reality every country, industry, and community faces today. But we also believe the world can flip that reality. If we transform how we work together, if we hold ourselves accountable, if we're upfront and honest about what's working and what isn't, net zero by mid-century can become a reality.

CHAPTER

2 Triggering durable change

Chapter 2: Triggering durable change

The five shifts must immediately be translated from thinking into action. If we wait until 2030 to pinpoint what's not working, it'll be too late to set things right. But it's more than that: we'll miss the opportunity to share the big wins.

In this chapter, we assign each of the shifts three **indicators of change** that describe how rapid, scalable infrastructure development projects should be performing, and where we need to watch our step. We offer examples of companies using approaches consistent with the shifts for transformative outcomes. At the end of each shift, we unpack the indicators further to help stakeholders start evaluating their projects in the critical decade for action.

How we do things needs to change

Market-driven ideologies dominate how we measure the success and value of our energy infrastructure. We prioritize competitive advantage and profit, and engage communities – landholders, residents, First Nations people – just enough to avoid schedule disruption and regulatory scrutiny. Slow regulatory approvals, transactional relationships between service providers and developers, and bespoke, sequential design and construction processes constrain us. And we've barely tapped into the full potential of digital technology. These are limits we place on ourselves and it's slowing us down. The five shifts can flip this reality.

The five shifts are disruptive to traditional ways of doing business

If these shifts are applied, every stakeholder involved in the transition will be impacted. Asset owners, project developers, investors, service providers, contractors, regulators, communities, educators and policy makers will all be affected. Some companies, stakeholders, and individuals will probably feel vulnerable and at risk. The transformation will be uncomfortable, but we cannot let it stop us making the necessary change.

Leading indicators of change are our early warning system

We must measure the change we expect to see. We typically use lagging indicators to gauge progress. But in this instance we don't have time to rely on lagging indicators. They're important, but they only look back at what has already happened and don't give us the opportunity to make changes in real time. It's not enough – for example – to measure global emissions trends, after the damage has been done. We can use changes in the five shifts to detect patterns in our values, behavior, communication, relationships, and our practices.

We've identified a set of leading indicators for each shift that unlock accountability and transparency. They're an early warning system to flush out the traditional behaviors and practices that will inevitably persist among some stakeholders. They'll give us time to remove obstacles, get back on course, and deliver faster, fairer, and more sustainable infrastructure.

The five shifts can trigger tangible change

They reflect our collective imperative to get to net zero and tell us what we need to do before it's too late. We must:

- **Broaden our definition of value**
  Elevating environmental and social value will create more inclusion and social equity across a more diverse assembly of stakeholders.
- **Keep all technology options open**
  Attracting urgent, large-scale investment will bring a variety of new low-carbon technologies to market quickly.
- **Standardize how we design and build**
  Designing and building in parallel, and relying on the certainty of repeated design, will dramatically reduce development and delivery times.
- **Collaborate like our world depends on it**
  Communities will become much more important and collaboration across value chains much deeper, sharing risks fairly to meet the challenge of speed and scale.
- **Use digital technology to move faster and build bigger**
  Common digital platforms will enable transparency break down boundaries and ensure information flows around the world smoothly and securely.

1

Broadening value

Shift from 'economic' to 'social-economic-environmental'

Shift 1: Broadening our definition of value

Projects must deliver more than financial value. They must include social and environmental outcomes, accommodate the diversity of communities, and offer real benefits. Here's how we broaden value for everyone involved.

Empower projects with authentic ESG thinking

We must embed environmental, social and governance (ESG) practitioners into all elements of project development. And it must be authentic. We've got to empower them with real decision-making authority so they can move projects beyond a sole focus on economic value and make sure development delivers social and environmental benefits.

Design projects with real ESG objectives

ESG objectives must be on an equal footing with financial objectives. For projects aligned with the Paris Agreement, we should prioritize their funding and give them access to cheaper capital. Projects can use lifecycle assessments to evaluate and address the environmental and social impact needed for net-zero infrastructure.

Move beyond investor value

Communities must benefit from infrastructure, from the start (during project development) to the end (when the asset is up and running). Local contracts must offer training and skill development across the whole lifecycle including decommissioning.

Work out what matters to communities

Communities will view value differently. Some may prioritize the landscape, others the protection or integration of traditional ways of life. We must work to understand what matters to the communities our projects are working with and for. Benefits such as enhanced public health and education services, social infrastructure, better property values, and affordable housing are tangible and measurable. Even co-ownership of projects can be possible. If we don't get this right, we will in fact *erode* value to the community.

Leave no one behind

The speed and development of the COVID-19 vaccine was miraculous, but its distribution was far from ideal. Many of the world's poorest remain unvaccinated allowing the virus to mutate and its risk to both the vaccinated and unvaccinated to persist. But we can learn from this. If developed and developing countries work together on net-zero solutions, we can help all nations transition away from high emissions alternatives.

As we discussed in paper one, keeping the lights on during the transition is also an example of leaving no one behind. As an example, Schneider's smart technology (example shift success #1) has created energy security, stability, and reliability for communities in Australia, Egypt, and the UK.

Evaluate every project

Table 1 outlines three indicators of change and a framework to help evaluate how projects are broadening their definition of value, and shifting from economic towards social and environmental value.

Indicator of change	Assessment framework
Environmental and social representation	• The project team includes environmental and social sciences representatives • These representatives have the authority to make and strongly influence material project decisions • Communities and other interest groups have greater say in project design and delivery
ESG selection criteria	• Project development criteria includes ESG objectives • Projects weight ESG objectives and financial objectives equitably • Project key performance indicators (KPIs) reflect broader ESG goals • Projects use lifecycle assessment (LCA) techniques in development
Value shared across broader stakeholders	• Project stakeholders share value with impacted communities • Project contracts have built-in training and skill requirements • Local communities benefit from ownership opportunities • Solutions and expertise are freely shared globally

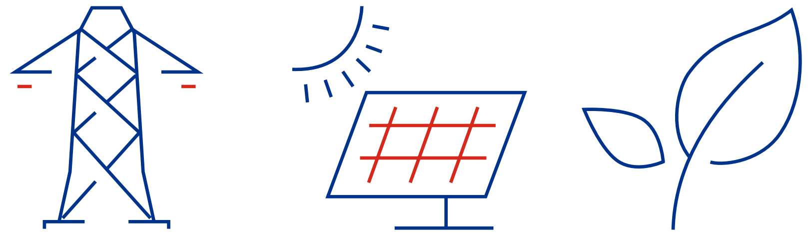
Table 1 - Our indicators of change and assessment framework for Shift 1: Broadening value

Example shift success #1

The grids of the future are green and digital

Schneider Electric

Electricity networks are facing power system stability and security challenges to meet the shift to renewables and the pressure to integrate electric vehicles (EV) and Distributed Energy Resources (DER), such as rooftop solar generation and urban energy storage. To be future ready, network companies across the world are deploying integrated modernization plants that includes smart technologies to ensure greater resiliency, security, flexibility and reliability.



Broadening value by keeping energy systems secure and stable, despite change

Schneider Electric has helped electricity networks in Australia, Egypt, and the UK to address these challenges with grid management systems, voltage control, and flexibility solutions.

For example, Egypt is investing in a new smart grid to provide 20 million+ people with electricity, while designing a power system that will include 40 percent+ renewables by 2035. This new smart grid enabled by Schneider Electric Advanced Distribution Management Systems (ADMS) will be able to manage and optimize DER and improve energy availability by detecting network faults and reconfiguring the network to ensure stability.

In the UK, the Electricity North West (ENW) network is using innovative voltage control solutions to manage electricity consumption at peak times, which could save customers £300 million over the next 25 years across Great Britain while improving grid stability. Here the CLASS (Customer Load Active System Services) is being used as a low-cost solution to balance supply and demand, maintain system stability, and ultimately ensure supply security.

In Australia, Schneider Electric has joined forces with Western Power in a pilot project to enable Western Australian businesses to manage DER through the electricity network. As renewable energy powers up to 70 percent of the south-west of Western Australia at times, Western Power’s pilot aims to demonstrate that with flexibility built into services, commercial and industrial costs will reduce helping address voltage issues while enabling grid flexibility and greater renewable penetration into the energy system.

1
2
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5

2

Enabling options

Address uncertainty through development of all technologies

Shift 2: Develop all possible low-carbon technology options

Governments and businesses must do two things: deploy the technology we've got and invest in the technology we need. To do that, they need to spread the effort, and the investment. These changes will put nations on the right path to net zero.

Invest in research and development

Investment in research, development and demonstration (RD&D) is critical for emerging technologies, and the solutions we're yet to commercialize. One way to check we're in the best position to develop technologies at the speed needed, is to measure the global RD&D investment effort and track the progress of technologies as they move through technology and commercial readiness levels (TRL and CRL).

We choose our speed of development

It took eight years from President John F. Kennedy setting the mission until we landed on the moon. And because we were up against the clock with COVID-19, researchers compressed the 10-year vaccine development cycle into one year (example shift success #2). In both scenarios, we chose to accelerate technology development and make the seemingly impossible, possible.

Invest in disruptive technologies early

Pumping capital into technologies that will disrupt the status quo – the early movers – well ahead of the greenlight decision, will unlock our capacity to get these projects off the ground quicker. This includes risk capital that gives designers the freedom to pilot new technologies, removing commercial obstacles that currently cause most financing to be reserved for only proven technologies.

Diversify the technology mix

There's no silver bullet solution to decarbonization. It'll be a tapestry of different technology approaches, each clashing with resource, geographic, market, and social/environmental/political constraints in different ways. How diverse our technology mix is will determine whether we can overcome these constraints, and if we can bounce back from the setbacks we'll inevitably encounter along the way.

Replace competition with collaboration

If organizations work together, share lessons and intellectual property, they can build, replicate, and distribute infrastructure faster and at scale. In short, everyone wins. COVID-19 vaccine RD&D teams shared DNA sequencing between labs and firms. In 2019, Volvo introduced an initiative to share crash-test data with other vehicle manufacturers – at no cost – to reduce car accident injuries and deaths. These are examples, where by working together and prioritizing global need over competitive advantage, thousands, if not millions, of lives were saved.

Evaluate every project

Table 2 summarizes the indicators of change that can ramp up the speed and scale of technology development.

Indicator of change	Assessment framework
Technology investment	• The total financial value of RD&D investment (public and private) • Suitable funding arrangements are allowing technologies to move through TRLs • Risk capital flows to early-mover pre-financial investment decision (FID) to allow the front-end work to proceed at pace
Breadth of technology options	• The technology mix on approved projects is diverse • Risks and uncertainties are well understood and accepted across the technology portfolio • Net-zero pragmatism is winning over ideology
Intellectual property	• Intellectual property is increasingly available in the public domain • Traditional competitors work together to solve technology problems • Projects manage first-of-a-kind technology risks and share lessons learned openly

Table 2 - Our indicators of change and assessment framework for Shift 2: Enabling options

Example shift success #2

2 Enabling options
3 Standardization
4 Creating partnerships

From 10 years to one

Oxford AstraZeneca

Saving time to save lives

The arrival in humans of the SARS-CoV-2 virus and then the COVID-19 disease in late 2019 led to a global pandemic not seen in the world for 100 years. As outlined in the book Vaxxers*, it can take 10 years to develop, test and then manufacture a vaccine, but such a timeframe was unacceptable in preventing enormous loss of life globally and resulting human suffering.

Streamlining steps in a development sequence

The Oxford University-led team managed to complete the process of developing the successful Oxford AstraZeneca vaccine (AZD1222, ChAdOx1-S, Covishield or Vaxzevria) in record time, having commercial product available for use in around one year. This included all the necessary testing and regulatory steps required by approval agencies, including the UK's Medicines and Healthcare products Regulatory Agency (MHRA) and the EU's European Medicines Agency (EMA).

Standardizing, replicating and running processes in parallel

Vaccine development was undertaken by Oxford in parallel with groups who were also working towards a vaccine using different technologies, keeping options open. Normally serial processes of development were run in parallel, building on enabling work previously undertaken. Changes in the way funding was allocated was critically important, as was co-operation with other researchers and vaccine manufacturers. COVID-19 vaccine development therefore also demonstrates the standardization and replication, and partnership and collaboration shifts.

**Gilbert, S. and Green, C. (2022) "Vaxxers", Hodder & Stoughton*

3

Standardization

Replicate designs and build in parallel

Shift 3: Design one, build many

Standard and modular designs save time, optimize resources, and speed up the supply chain. We'll need to see compromise right across the value chain. But we've done it before, and we can do it again. Here are the actions we need to take.

Learn from other industries

Several industries such as automotive and telecommunications use standardized parts and strategies to speed up delivery. In urban infrastructure, Laing O'Rourke (example shift success #3) has championed modularization to cut bridge design and assembly time down to a week – a remarkable outcome. In the energy industry (particularly in power), we've been standardizing reference designs for decades. But we've got some clear obstacles in our way.

Mandate standardization

Bespoke, project-by-project processes slow us down: regulatory differences, supply chain issues, community preferences, and designing to capital supply demands, can add years to a project.

We can scale, replicate and disseminate modular designs around the world far easier if we can reduce bespoke requirements. We must showcase and prioritize the utility and adaptability of standard designs. And our asset developments and regulators need to work with designers, suppliers, and construction companies to mandate that standardization.

Develop a global set of design standards

This is not just an infrastructure challenge. It's as much about the standards we use to design and build. For example, we won't achieve the speed and scale we need if we're designing the transmission lines, DC/AC converter stations, pylons, substations, pipelines and transformers to European standards, and then rejecting and redesigning them to be built in the US.

Energy supply and process industries will collide

We'll need standardized and modularized electrolyzers and synthetic chemistry facilities to align their expansion with that of large-scale renewable electricity plants. These new facilities will produce synthetic and e-fuels to meet our future demand for sustainable fuels.

Redeploy existing designs to new technologies

A lot of the technology researchers used to develop the COVID-19 vaccine already existed. We can do the same in energy and redeploy existing designs to new technologies. Of course, we can only do this if our business and political environment is open and collaborative, sharing data across teams, projects, and national and corporate boundaries.

Strengthen the supply chain

The supply chain doesn't need to wait until the engineer has finished the design to start getting ready. If they're told in advance, suppliers can stock up first on the standardized designs the project will need. Not only will the stock be ready to deliver, but once the design is complete and the build begins, the project isn't starting from scratch each time. Governments have a role to play, too. They can underwrite the supply chain to a point where suppliers will stock up if they're sure the order will come through.

Evaluate every project

Once the energy industry has standardized and modularized design, developed common standards, and stocked the supply chain, projects will deliver on time and within budget. Most importantly, the assets we need to get to net zero will be operational in record time. Table 3 captures these indicators of change.

Indicator of change	Assessment framework
Standard and modular designs	• Developers and regulators incentivize standard designs • Modularization is widespread across core project elements • Systems are (or are becoming more) modularized and common across regions/geographies • Shared platforms allow teams working within and across projects to easily access project specifications and data
Supply chain orders	• The supply chain works from standard orders to stockpile inventory in advance • Larger supply chain inventories are reducing delivery times
Project timelines	• Projects are meeting cost and schedule targets • Projects are improving against schedule targets • The usual escalations in project costs and schedules are becoming less common

Table 3 - Our indicators of change and assessment framework for Shift 3: Standardization

Example shift success #3

Assembling in a week

Laing O'Rourke

Using modular construction to speed up infrastructure delivery

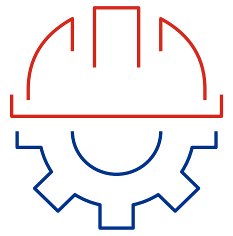
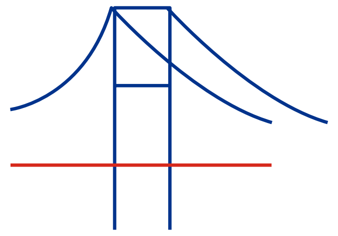
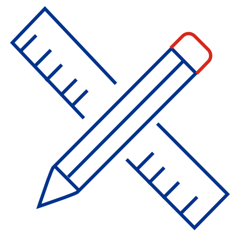
Increased need for transport connectivity, as well as aging assets create a significant need for a variety of new bridges to support vital economic infrastructure. However, the current approach of highly bespoke solutions developed for every single application is both time and resource intensive, and costly.

Using digital to pick up the pace of infrastructure delivery

Drawing on extensive experience in the sector, Laing O'Rourke has been progressively developing product-led modular bridge solutions that are both physically and digitally configurable. This allows manufactured elements to be rapidly assembled on site and designed in half current timescales. This has enabled the company to now assemble a bridge, from pile cap to bridge deck, in a week.

Shifts in action

The approach taken by Laing O'Rourke sees several shifts in action. The approach rethinks the value equation by going back to fundamental requirements to develop a better approach. Efficiency is driven by standardization and repetition, supporting the manufacturing-based delivery approach. Collaboration has been at the heart of the approach from the outset – through partnership with asset owners (Network Rail and National Highways), designers and delivery and manufacturing supply chain right from the Basis of Design stage onwards. And digital configuration underpins the solutions and unlocks faster more certain delivery.

4

Creating partnerships

Governments set the objectives and partnerships form

Shift 4: Communicate and collaborate

If governments, communities, and projects don't share goals and a collective imperative to get to net zero, the social challenge of decarbonization will likely be far greater than the technical challenge. Community groups must be central to new types of partnerships. Governments must lead from the front. And we must empower new coalitions to hit net-zero targets and deliver value to the communities they serve. Here's how we can make that happen.

Give the public full transparency

Projects can build trust with communities if they give them access to trusted project performance data. That might be through online access, or in a different way that works for the local community. Whatever the format, this is about making sure communities know what is happening, where and when.

Construct a 'no surprises' partnership approach

The composition of partnerships, the roles and responsibilities they assume, and the extent they feel they own a stake in the project, will make it easier to share risks and rewards more fairly. Partnership members will need to be included in project teams and decision-making bodies to guarantee early alignment, transparency, and confidence in the direction of travel. Partnerships will need to reach across the value chain, sharing data and intellectual property.

Override commercial instincts

The transition will be vastly more difficult if we don't bring the decarbonization of our energy systems together more effectively and efficiently. We can only do this if we share critical infrastructure like poles and wires, H_2 and CO_2 pipelines, water sources and desalination facilities. But this form of collaboration doesn't come naturally.

Our instinct is to act independently and protect our commercial interests. Microsoft is working with technology partners on a new, digitally based collaboration tool to help enable low-emissions clusters move forward in the UK (example shift development #1). They've unlocked new collaborative approaches between industries, increasing the speed of such collaboration, which in time is hoped will lead to the faster development of real, operating low-emissions assets on the ground.

Update work and education pathways

To drive sustainable outcomes and community value, companies and education providers must upskill the large workforces necessary for decarbonization. They must also work closely with governments to craft learning pathways for new technologies, and the design and construction practices used to create them.

Evaluate every project

Table 4 reinforces which indicators of collaboration will drive more transparency, better participation, and more inclusive outcomes.

Indicator of change	Assessment framework
Transparency	• The public knows what is happening on the project • Projects engage with communities to communicate changes and benefits • The public has access to a data center to track how the project is performing
Participation and collaboration	• A wider variety of stakeholders' needs are included in the project • Stakeholders are part of the project team and/or included in decision making • Stakeholder groups have financial ownership in the project • New types of partnerships are forming, including community groups, First Nations groups, and other impacted groups • Partnership models represent collaboration across the full value chain to include developers, contractors, suppliers, sectors and countries • The energy sector partners with education providers for training and development needs
Risk sharing	• Project partners share risks equitably • Projects share risks and rewards in new ways

Table 4 - Our indicators of change and assessment framework for Shift 4: Creating partnerships

Example shift development #1

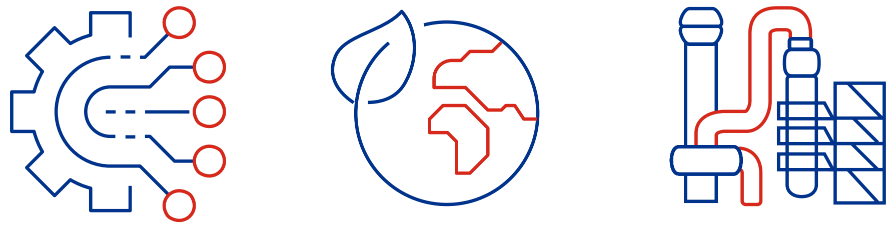
Fostering new models of collaboration

Microsoft, Advanced Manufacturing Research Centre (AMRC), Accenture and Avanade

A digital blueprint for faster, better net-zero collaboration

The UK has bold energy targets to decarbonize its energy systems. One such target is to deliver 10 GW of hydrogen by 2030 along with significant carbon capture and storage (CCS) infrastructure.

Given the scale of the task, the UK Government has formed six major industrial clusters to foster collaboration in the development of new, nationally important energy technologies.



Navigating uncharted territory together

These clusters require new levels of co-operation. Participants are overcoming traditional collaboration reticence to build improved collective innovation, commercial outcomes, and risk sharing, as well as better schedules, supply chains and emissions reduction performance.

A key enabler of this success is an industry blueprint for accelerated delivery, which is being applied to these clusters. Developed by Microsoft, AMRC, Accenture and Avanade, this uses a trusted data environment, combining digital twins, data governance, leading security, artificial intelligence (AI) and multi-user data sharing, across the asset lifecycles and industries involved. This is demonstrably improving the pace and performance of collaboration, helping to drive UK cluster ambitions forward.

Sharing for the greater decarbonization goal

This is an example of digital technology driving real collaboration outcomes and partnerships in new net-zero technology development and deployment. The case study demonstrates the digital accelerant as a broad enablement tool, which allows the power of partnerships and collaboration to drive better collective net-zero outcomes.

5

The digital accelerant

Digital platforms create the trust to move forward

Shift 5: Enable and monitor digitally

Unlocking the potential of digital technology will accelerate the transition and drive the speed and scale in net-zero infrastructure. Digital platforms will be the foundation of transparency, community trust and, ultimately, shared value. For many, it's a complex shift, so we've prioritized the critical actions.

Build digital environments that capture the whole system

Digital environments can incorporate data from all components of the energy infrastructure value chain. Trusted data that everyone can access will make decisions faster and push projects through to completion. For example, an evolving digital twin of a project could allow investors, suppliers, governments, off-takers – even the general public – to visualize the end result in advance of project phase completion.

Collaborate on digital platforms everyone can use

Data sharing within and across project portfolios will be enabled by common platforms. Teams of developers, suppliers and other stakeholders will be more inclined to utilize the platform if we build in a degree of standardization. And standardization irons out inconsistencies across data formats, security, and privacy. True, value chain digital platforms are more complex than the infiltration of digital technology we've seen across the other shifts. But development work has started: HSBC (example shift development #2) and partners are already developing digital platforms to build liquidity in energy infrastructure investment, hoping to unlock the trillions of dollars we need to deploy to get to net zero.

Build platforms communities can trust

Communities will rely on digital platforms to remain informed. But projects will need to be mindful. Over the years, data privacy breaches and manipulation have eroded trust. Giving impacted communities access to digital platforms to track a project's progress will start to rebuild that trust: what the project will look like, how much carbon it's saving, how many jobs it's created. This level of visibility needs to be there right from the start of the project. And if a community can't access project information digitally, the project will need to find another way to keep them up to speed.

Connect assets globally to improve performance

A digital information highway will connect assets around the world so they can learn from each other and optimize their performance. Real-time data will amplify this, and allow engineers, scientists and operators to learn, adapt, and improve.

Digital technology accelerated the COVID-19 vaccine rollout

Digital platforms tracked the delivery of the vaccine to billions of people. Contact tracing and digital vaccination certificates helped stop the virus spreading. And communities accessed data online, through media broadcasts, and through community health networks. It took time for people to trust the governments' numbers, but in the end, digital platforms and data were critical to explaining progress. We need to apply these digital learnings to mass infrastructure deployment.

Grow digital expertise *within* project teams

Digital specialists must be part of project teams, and not on the sidelines in standalone functions. Digital is how we'll supercharge the transition. And it's not enough to have the platforms, models, connectivity, if projects don't have the people making the most of them.

Evaluate every project

Table 5 brings these digital threads – models, platforms, people – into a simple framework that determines if a project's digital foundations are strong, or if they need to upgrade fast.

Indicator of change	Assessment framework

Digital modelling	• The digital environment represents the whole system from 'cradle to grave'
	• The digital environment integrates all value chain components
	• Digital highways connect assets to each other to:
	  – share performance
	  – learn from each other
	  – set performance benchmarks.
	• The public has access to project performance data

Digital systems	• Standardized, digital systems are being used across teams of developers, contractors, suppliers and regulators • Coalitions use common platforms • Projects are joining common platforms • Projects are sharing information through common platforms
Digital personnel	• Digital specialists are part of project leadership • Digital specialists make up a significant proportion of the project team

Table 5 - Our indicators of change and assessment framework for Shift 5: The Digital Accelerant

Example shift development #2

Digitizing net-zero capital allocation

FAST-Infra Consortium (HSBC, IBM, SIF, NowCM, TPICAP Group, Worley and SCALE.)

The right data at the right time

According to the International Energy Agency (IEA)*, the world needs US$4-5 trillion in clean energy investment per year to be on track to achieve net-zero CO_2 emissions by 2050. But it will be difficult to mobilize that amount of capital if we keep delivering projects the same way.

A key enabler of clean energy investment is transaction data, which helps investors to make informed decisions about whether projects meet their investment criteria. But poor visibility of data sources, weak data confidentiality, different data formats and complex data protection and privacy issues prevent the flow of trusted information to the parties that need it.

A standard approach for all assets

FAST-Infra is a consortium of parties that are building a new asset investment process, designed to make it easier to fund, build, operate and maintain sustainable assets.

Central to this will be the FAST-Infra platform. This is a joint initiative of HSBC, IBM, SIF, NowCM, TPICAP Group, Worley and SCALE. The platform encourages collaboration, using a common data standard and secure ledger that collects and manages trusted project data for all parties, from developers to investors.

This includes a standardized digital twin of each physical asset and its legal structure. It acquires all project data and authenticates and manages access to any party involved at that stage of a project. And it's useful from development and procurement through to construction and operation.

Speeding up low-carbon infrastructure development

The target of this collaboration is to increase trust in project information, reduce duplication in approach, and eliminate the need for continual hold points in the process for all stakeholders involved, including governments, developers, financiers and asset owners.

This consistent approach to project data is key to moving sustainable projects forward, and ultimately enabling the scale of change required in global energy systems over the coming decades.

**IEA (2021), Net Zero by 2050, IEA, Paris*

CHAPTER 3 Tracking durable change

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Chapter 3: Tracking durable change

In Chapter 2, we worked out **what** we need to track to overhaul infrastructure development by 2030. But this early warning system will be redundant if we don't measure **how** we're tracking. In this chapter, we describe the annual, independent survey that will do just that, and put the indicators of change into practice to work out where we are today, and where we need to be by 2030.

Princeton University will run an independent survey every year until 2030

This survey will be the first of its kind and will track the year-on-year progress of a representative cohort: how participants' values, behaviors, communications, relationships, and practices are changing, and whether the five shifts are transforming the delivery of energy infrastructure.

The survey will be:

- **Confidential** – the Princeton Institutional Review Board will review and guarantee participant privacy
- **Forward looking** – it will capture changes as they emerge. Including the good, the great, and the not so great
- **Inclusive** – participants will be from across the full energy chain, upstream and downstream, with representation across a diverse group of stakeholders
- **International** – participants will be from across the Americas, Europe, the Middle East, Africa, and Asia Pacific
- **Representative** – it will track a representative cohort of respondents to drive consistent, meaningful tracking across the next eight years.

Princeton will release the first set of results in 2023 and repeat the process every year through to 2030. We've provided more detail about the survey towards the end of this chapter.

Change has started, but there's a significant gap

This reflects our overall view on the behaviors we observe in 2022 and how they relate to the five shifts.

We've used a colour coded approach to reflect the size of the gap, shown in Figure 2.

- **Red** – the gap between where we are and where we need to be by 2030 is significant
- **Green** – the behaviors, systems and processes for accelerated delivery are in place

We think the gap today is **high**.

In Figure 3, we break that rating down further, unpacking where we think the gaps are for each of the five shifts. You'll see that some of the gaps are bigger than others. For example, in digital transformation we're seeing more of the change we need to see, but we're still anchored to measuring financial value and we're still working within a siloed, highly competitive world.

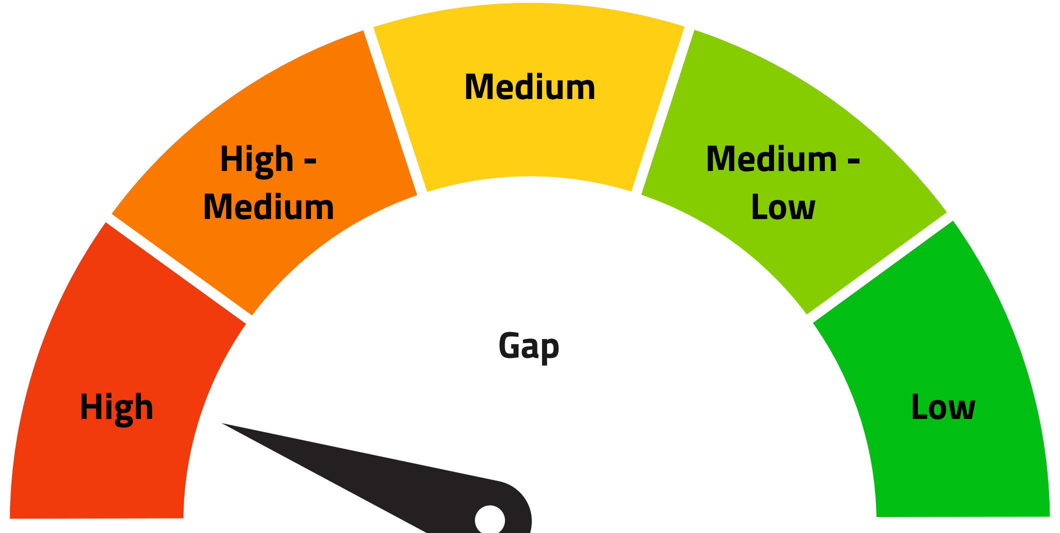

Figure 2 - The net-zero gap in 2022

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Where we see the gaps across the five shifts in 2022

Shift 1: Broadening value

The environmental and social science specialists embedded in projects are mainly there to meet regulatory requirements: they're not engaged in achieving broader ESG value. Financial objectives dominate and return on investment is the main measure of value. Projects sometimes include ESG criteria in go/no-go decisions, but regulatory risk is typically the primary driver.

The gap is **high** for this shift, which means our definition of value is significantly narrower than it needs to be for projects to unlock broader value from the transition.

Shift 2: Enabling options

Governments and large organizations are the primary funders of technology RD&D. It's difficult to attract capital investment until the technology has been de-risked and the business case has been established. And competitive advantage is preventing organizations and stakeholders from sharing intellectual property.

The gap for this shift is **high-medium** suggesting we cling to what we know, where we need to be funding all possible low-carbon technology options.

Shift 3: Standardization

There's a good degree of standardization across some technologies (solar PV, onshore wind). However, bespoke design is still commonplace for more complex technologies. The design process dictates when equipment orders can start. And bespoke designs cause significant lead times (>12 months) on some equipment. The bespoke 'design, then build' process makes it difficult for projects to stay on schedule.

The gap for this shift is **high-medium**, which indicates standardization has pockets of success, but traditional approaches to supply, design and build constrain speed and scale.

Shift 4: Communicate and collaborate

The lack of transparency surrounding projects makes it hard for the public to find project data – and trust in that data is low. Stakeholders often keep the public at arm's length, on a need-to-know basis and keep their interests in projects siloed, with little consolidation. Traditional power dynamics between stakeholders dominate. For example, service companies are subservient to a developer's wants and needs. Risk sharing models still aren't the norm.

The gap for this shift is **high** suggesting governments and organizations are not effectively collaborating with partners and communities who want to contribute to a successful and sustainable transition.

Shift 5: The digital accelerant

This is the shift that is arguably moving at the fastest pace. The creation and use of digital models across projects have increased. And we're starting to digitize our project value chains. But digital systems remain bespoke, operating on a project-by-project basis. We're yet to fully integrate digital specialists and expertise into projects, side-lining them to support functions.

The gap for this shift is **high-medium** which reflects the progress made so far.

Change needs to start now with a clear goal in mind

We can't turn up to 2030 and expect the world to have fundamentally changed. We need to monitor, report and adjust our behaviors and practices carefully and regularly on the way to 2030. The Princeton survey will be critical for this, but we can start to form tangible goals in our minds right now. In the following pages, and summarized in Figure 4, we give our view on the change we need to see in four years (2026) and in eight years (2030) across the five shifts.

		Current status of the gap
Broadening value	Environmental and social science personnel	Regulatory focus
	ESG selection criteria	Financial objectives only
	Value shared across broader stakeholders	Return on investment
Enabling options	Technology investment	Financed by governments and large organizations
	Breadth of technology options	Limited to those known to work and low risk
	Intellectual property	Not shared and litigious
Standardization	Standard and modular designs	Bespoke designs for complex industries
	Supply chain orders	Bespoke ordering, lead-times of >12 months for complex equipment
	Project timelines	Shared amongst collaborative partners
Creating partnerships	Transparency	Need to know basis
	Participation and collaboration	Project players act independently
	Risk sharing	Pushed into contracts
The digital accelerant	Digital modelling	Digital enablers emerging across value chain
	Digital systems	Bespoke digital systems
	Digital personnel	Digital personnel separate to core project teams

Figure 3 – the changes and gaps we're seeing against the five shifts in 2022

Shift	By 2026 (within four years)	By 2030 (within eight years)
1 Broadening value Shift from 'economic' to 'social-economic-environmental'	**We'll have a fairer, broader value definition** We'll integrate environmental and social science experts into projects, and they'll have a broader scope, contributing key performance indicators and scorecard results that will reverberate with authentic ESG thinking. Project development agreements will be more equitable and stakeholders, including communities, will enjoy a greater share of benefits.	**Our communities will be at the center of the transition** We'll equally weight authentic ESG objectives with financial ones. We'll guarantee co-ownership of the transition through project development agreements and reward sharing, and regulatory approvals that will also produce tangible co-benefits for communities such as: • upgraded public services (health, education) • social infrastructure • better property values • affordable housing • long-term skills training and employment opportunities.
2 Enabling options Address uncertainty through development of all technologies	**We'll leap over technology hurdles** Our risk appetite will grow, which means we'll fund technologies and projects in the early-stage development. We'll see a record amount of public and private spending on emerging technology. Of course, we'll still move technologies through the various stages of technology and commercial readiness levels (TRL/CRL). An increase in risk appetite will begin to see more early mover technologies deploying. We'll be beginning to share more intellectual property through collaborative partnerships. And because these partnerships will remove significant obstacles, we'll drastically speed up technology development.	**We'll have most of the technology we need for net-zero** A broad assembly of stakeholders will fund technology development. We'll push out first-of-a-kind technologies at record rates to match our net-zero expectations. We'll drastically ramp up the development of low-carbon options progressing through TRLs/CRLs. We'll have all of the technology we'll need – demonstrated at full scale – to get to net zero by 2050. We won't focus on protecting competitive advantage. Instead, we'll share our intellectual property publicly, speeding up technology development as a result.

Shift	By 2026 (within four years)	By 2030 (within eight years)
3 Standardization Replicate designs and build in parallel	**We'll shore up through standardization** For complex technologies like green hydrogen and carbon capture systems, standardized designs will emerge. Designs will be more modular and more often using equipment that already exists. We'll invest in supply chains, stockpiling them with materials and components, and set up standardized systems that will see us through the coming decades. And because of all of this, more projects will run to schedule. Some may even set new benchmarks on delivery times.	**The supply chain will be confident, ready, and efficient** Engineers – working to agreed global standards – will base their designs on equipment and modules already available in the supply chain. Governments and large private companies will underwrite those supply chains which will allow suppliers to pre-manufacture and stockpile the equipment and inventory projects need for construction. The lead time on complex machinery will be less than six months. And most projects will work to accelerated schedules because developers and service providers are working on multiple projects at the same time.
4 Creating partnerships Governments set the objectives and partnerships form	**We'll work better – together** Project teams will have their own data centers, and better access to data as a result. New, different types of partnerships will better represent stakeholders. Ownership of projects will broaden from one to many, contracts will proportion risk more fairly, and we'll be more aligned and transparent in how we work together. This means we'll share more of the risks and more of the rewards.	**We'll share. Everything.** The public will have full transparency of projects, operating assets, and performance, and our big wins and failures will be loud and clear. The stakeholders involved will be a vastly more diverse group than they are today. They'll all own a stake in the outcomes. In fact, sharing will become inherent to how we run projects: collaboration models, contracts, and infrastructure. Especially risks and rewards. We'll share these more equitably and appropriately between everyone involved.
5 The digital accelerant Digital platforms create the trust to move forward	**We'll have digital platforms, models, and teams** Digital models will exist for all new facilities. Digital platforms will start to connect assets and markets. Everything from environmental studies and assessments, to maps, surveys, testing sites and outcomes, regulatory decisions (and much more) will be available to stakeholders. This means project decision making will be increasingly digital, more transparent, and whole programs of projects will begin to work together on standard digital systems. The majority of new projects will feature strong digital strategies and will integrate digital specialists and expertise into project teams.	**Digital will hold it all together** Secure, digital platforms will connect all stakeholders – the lawyers, engineers, accountants, surveyors, investors - who'll access and make their decisions from the same project data. We'll connect all assets digitally, so they learn from each other, and performance improves. In fact, all projects and assets will run on common digital platforms and systems which will give the public – our communities – access to real-time performance data they can trust. We'll embed digital into all project strategies, and we'll have completed its shift from side-line to core discipline. Digital will keep the world connected as we progress into the next decade and towards net zero in 2050.

Shift	Area	2022	2026	2030
Broadening value	Environmental and social science personnel	Regulatory focus	Contributing to broader ESG goals	Accountable for project success
	ESG selection criteria	Financial objectives only	Scorecards with ESG goals	ESG equally weighted with financial objectives
	Value shared across broader stakeholders	Return on investment	Value added to communities, not subtracted	Community equity
Enabling options	Technology investment	Financed by governments and large organizations	Capital moving to early-stage technology development and first movers	First-of-a-kind technologies deployed at record rates required for net-zero transitions
	Breadth of technology options	Limited to those known to work and low risk	Increased number of diverse technologies in early development	Order of magnitude greater technologies at all technology commercial readiness levels
	Intellectual property	Not shared and litigious	Shared amongst collaborative partners	Shared publicly and between countries
Standardization	Standard and modular designs	Bespoke designs for complex industries	Modularization becoming more widely used	Standards and standardized designs are widespread even in complex industries
	Supply chain orders	Bespoke ordering, lead-times of >12 months for complex equipment	Investments made to ready supply chains	Governments underwriting supply chains for pre-manufacture, lead times <6 months for complex equipment
	Project timelines	Shared amongst collaborative partners	Projects meeting schedules and some setting new benchmarks	Continuous improvements on schedule benchmarks
Creating partnerships	Transparency	Need-to-know basis	Development of online performance data access platforms	Public access to the performance data
	Participation and collaboration	Project players act independently	New partnership models forming	Shared ownership and open collaboration
	Risk sharing	Pushed into contracts	New risk/reward models emerging	Risk/reward evenly and appropriately distributed
The digital accelerant	Digital modelling	Digital enablers emerging across value chain	Digital project progression cradle-to-grave has been achieved	Assets delivered and data openly available across trusted digital platforms
	Digital systems	Bespoke digital systems	Standard digital systems emerging	Assets connected through common systems
	Digital personnel	Digital personnel separate to core project teams	Digital strategies being implemented on projects	Digital considered a core integrated discipline

Figure 4 – The changes we need to see by 2026 and 2030 to plug the gaps across the five shifts we see today.

The ambition to reality survey

Who will be involved in the Princeton University study?

Professor Elke Weber and Dr Chris Greig will lead a research team at Princeton University's ACEE to design and conduct the survey. It'll take place every year and will involve a panel of respondents from the following stakeholder groups:

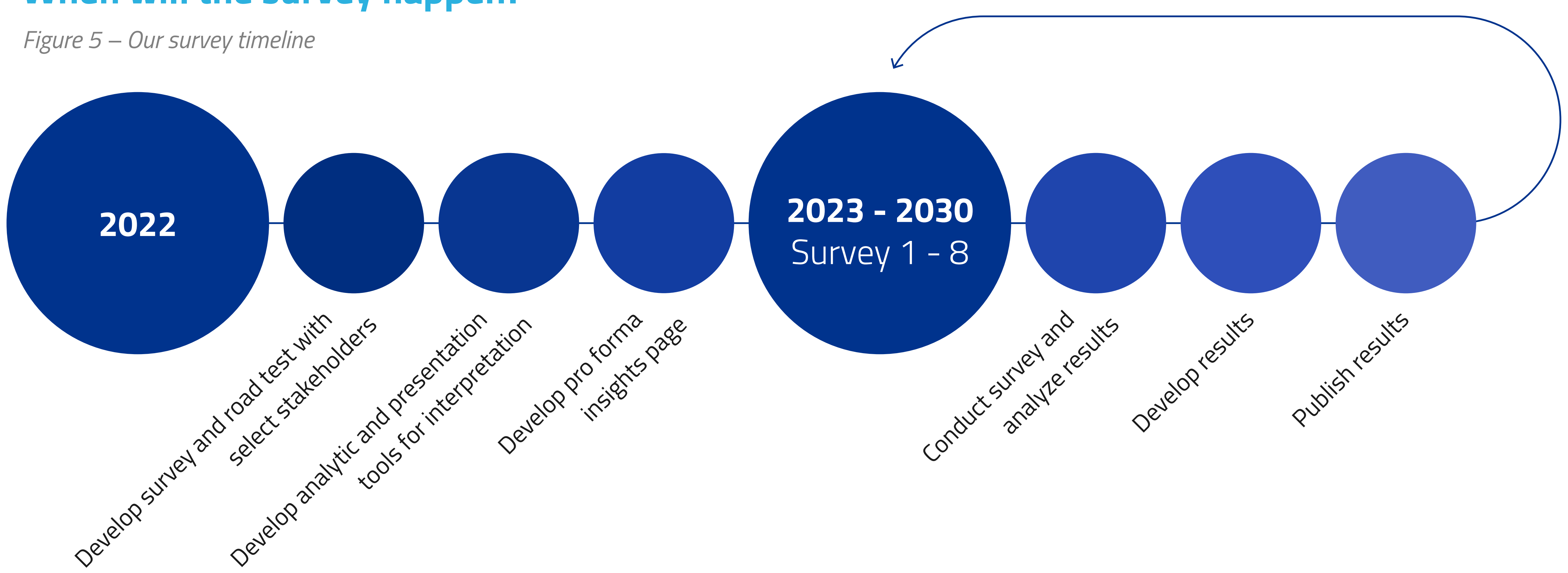
- asset owners
- project developers
- investors
- service providers
- contractors
- regulators
- communities
- educators
- policy makers
- unions.

Worley won't be involved in the survey, but will contribute funds to support the research

Details about the survey process can be found at the back of this paper.

When will the survey happen?

Figure 5 – Our survey timeline



CHAPTER 4

Act now in the critical decade for action

Chapter 4: Act now in the critical decade for action

The message is resounding: we must dramatically rethink the way we deliver infrastructure. If we work the way we always have, we won't get to net zero by 2050 and will fail to limit warming to 1.5°C.

The five shifts tell us what we need to do to succeed:

- Broaden our definition of value
- Keep all technology options open
- Standardize how we design and build
- Create partnerships like we never have before
- And use digital technology to move faster and build bigger.

The indicators of change – three for each shift – are our early warning system to detect changes and make adjustments. Princeton's annual survey will determine if change is happening across the five shifts. And we'll use the results to reroute our trajectory where it's needed, and to share the successes that are making a difference.

We've given our view on where we are in 2022. That despite the promising progress of the net-zero pioneers we've included in this paper, we're faced with a high gap across the five shifts. This is the critical decade for action, and time is running out.

By 2026, the paradigm shift must be well underway. By 2030, the paradigm shift must be complete.

And our simplified graphic in Figure 6 shows us the way from today's reality to success.

Authentic ESG-charged partnerships, standard designs, confident supply chains, fully immersed communities, a digital overhaul, honesty, transparency, and a collective imperative: that's how we scale up our infrastructure quickly and in a way that's lasting.

That's how we get to net zero and limit warming to 1.5°C. Holding ourselves accountable in the critical decade for action will make sure we get there by 2050.

Figure 6 – From today's reality to success in 2030

COUNTRY FOCUS

New numbers, global challenge

Country focus: New numbers, global challenge

To meet the net-zero challenge, virtually every country – and every economy – must move from years to weeks to develop and build its low-carbon energy infrastructure.

In the first paper we focused on the US – the world's second biggest emitter of greenhouse gases. Here, we revisit that work alongside a new country – a much smaller, less diversified economy where energy moves differently – to reinforce our thinking.

We find that the universality of the challenge is unmistakable: if we use the approaches of the past, if we don't proactively engage with the five transformative shifts and trigger the paradigm change we need, we'll fall well short.

We acknowledge there are differences: some countries are further advanced on their net-zero journeys; others are just starting. But our analysis suggests that for almost all economies, the net-zero infrastructure numbers are challenging.

Getting the US to net zero by 2050

In our first paper, we used Princeton's set of decarbonization pillars and five future pathways to 2050 to examine the US economy's net-zero challenge (Figure 7).

We focused on two pathways:

- constrained renewables
- 100 percent renewables.

Through these, Princeton showed it's possible to get the US economy to net zero by mid-century, and at a reasonable cost. We looked at the infrastructure development challenge this presents. What we found was monumental.

Princeton's pathways towards change

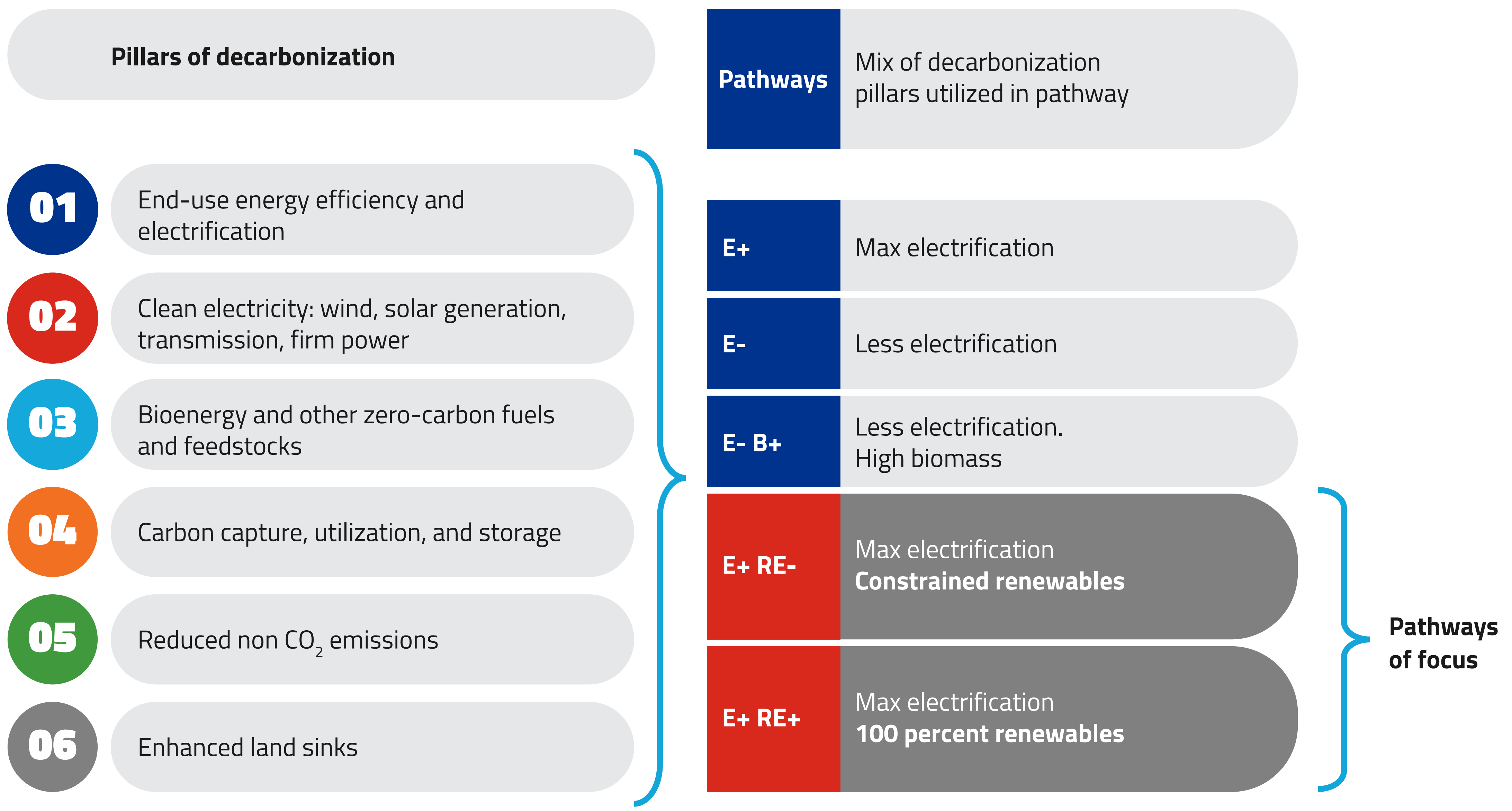


Figure 7 – Decarbonization pillars and focus pathways used in our first paper

The US transition must be big, fast, and fair

For the 100 percent renewables pathway, for example, the US would have to exceed the maximum renewable development rate ever achieved in any country – and by considerable margins – year after year, for decades.

We saw the same challenge across other pillars and pathways. Projects that would take decades to finish such as carbon capture use and storage (CCUS) and nuclear power – even enablers of energy flows like transmission lines and pipelines – must be done in years, and at a scale difficult to imagine.

Complex social negotiations emerged when projects were overlaid on infrastructure maps to show that as we alter landscapes and shift industries, we must empower and engage communities in the transition.

And the story is repeatable

Australia has abundant energy resources and roughly the same landmass as the US.

But there are some important distinctions. Australia has:

- a smaller, less diversified economy
- a much smaller population
- different political, cultural, and trading conditions.

These distinctions cause energy to move very differently in the economy. Australia uses about six percent of the energy the US consumes, but exports most (around 70 percent) of the energy it produces (Figure 8A). Its energy exports, dominated by fossil fuels, are growing (Figure 8B) and are a considerable component of the nation's economic production.

Year 2020 - circles to rough scale

Figure 8A – The US and Australia's primary energy consumption/export profile

Australia's energy balance 1980-2020

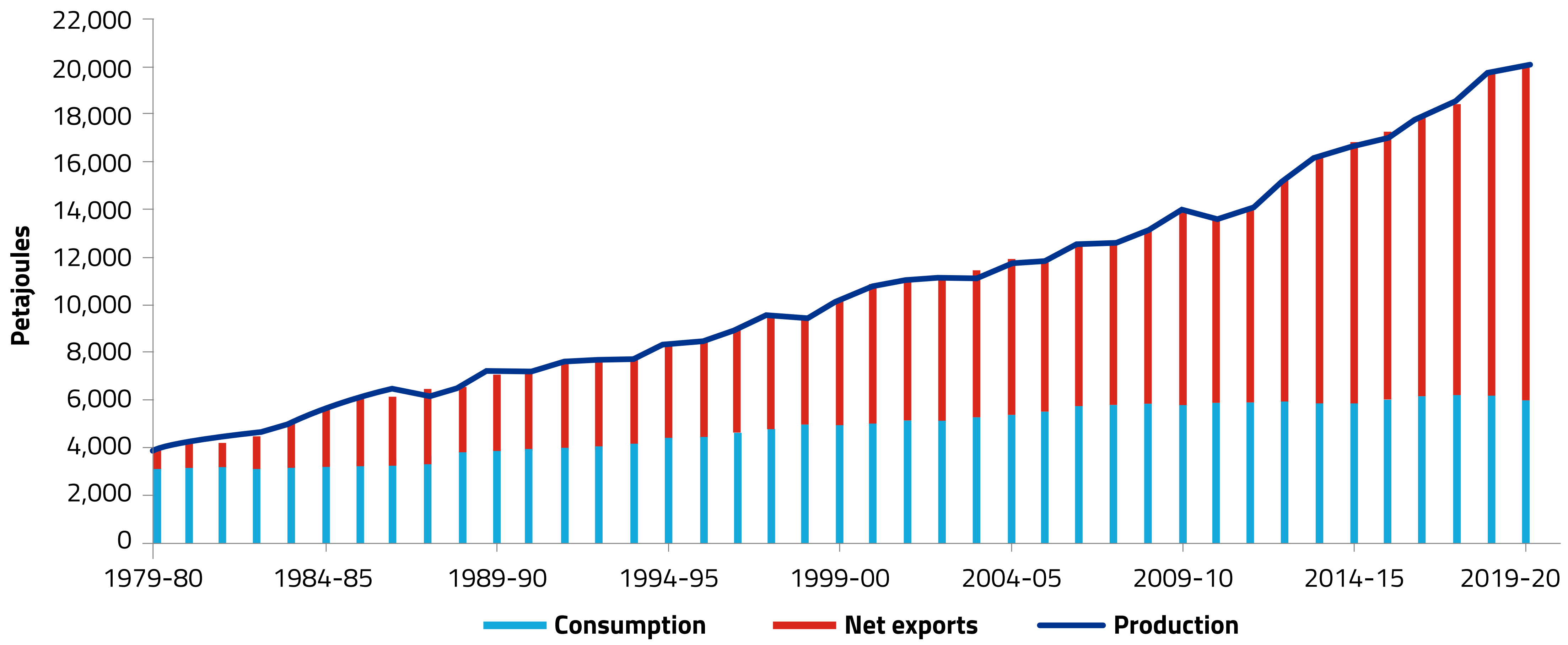


Figure 8B – Australia's energy balance, showing the increased dependency on exports over the years

Australia's domestic decarbonization journey is underway

Like the US, Australia's ambition is to shift its domestic energy use to net zero by 2050. And it's already making headway. For example, Australia's take-up rate of solar rooftop panels is the highest in the world. And its energy market operator has already recognized the primary electricity market is on a 'once in a century transformation' that requires market and regulatory reform, complex social dialogue, and enabling infrastructure to get to net zero. But the greatest challenge emerges when we shift to energy exports.

Exports dominate Australia's net-zero future

Given its current dependency on fossil fuel exports, a challenge for the Australian economy will be to consider their future in a net-zero world. This might include substituting fossil energy commodities with net-zero alternatives such as:

- blue or green hydrogen
- electrons through undersea cables into Asia
- importing the carbon emissions from its energy exports for geological sequestration in Australia.

The most likely outcome would be a combination of each alternative. Fortunately, Net-Zero Australia has completed its first stage analysis to reveal the scale of its infrastructure challenge.

Net Zero Australia used a similar approach to the US

Led by The University of Queensland and The University of Melbourne in partnership with Princeton University and Nous Group, the collaboration used the techniques and approach of Net-Zero America. Using the same decarbonization pillars as the US, they modelled four future scenarios (similar to US future pathways) with variations in the level of electrification and renewables. On the demand side, the core assumptions differ on the amount of electrification; on the supply side, on the amount of renewable energy development.

Each scenario produces an energy supply mix at the lowest cost available from the decarbonization pillars. Doing this creates technological pathways that reduce emissions to net zero, on a linear trajectory from 2022 through to 2050.

Scenarios	Mix of decarbonization pillars utilized in scenario	
E+	High electrification	
E-	Less electrification	
E+ RE+	High electrification with **100 percent renewables**	Scenarios of focus
E+ RE-	High electrification with **constrained renewables**	Scenarios of focus
E+ Onshore	High electrification with imposed onshoring of steel and aluminium production	

Figure 9 – Net Zero Australia has modeled five future scenarios in total. We're focusing on two.

The differences in the Australian model

Compared to the US, the net-zero options available to Australia demand a different approach. Australia is an arid country, with limited biomass resources, and Australian law doesn't allow nuclear energy.

Because exports dominate its energy balance they are looked at in detail, with the model pegging them to 2020 levels before following a linear net-zero trajectory from 2030 to 2060. This aligns broadly with export trading partners net-zero ambitions, and assumes they have limited alternative technology options.

A fifth scenario (E+ Onshore) investigates a different outcome: where a portion of the clean energy isn't exported but is used in new domestic downstream industries, such as steel and aluminium production, displacing offshore industries fulfilling that role today.

For Australia, we're focusing on two future scenarios

They're the same scenarios we used for the US in our first paper – although they were called future pathways.

E+ RE+: 100 percent renewables

- Australia will require large scale renewable infrastructure to end fossil fuels by 2050 domestically, and by 2060 for exports.
- Where carbon is unavoidable for processes like aviation fuel and chemical feedstocks, Australia will need direct air capture (DAC) or carbon capture use and storage (CCUS) for non-fossil sources such as calcining in cement production or bio-based processes.

E+ RE-: Constrained renewables

- Australia will limit its renewable energy infrastructure development to five -10 times its maximum historical achievement. This constraint is still a stretch, but considered plausible.
- Because nuclear and bioenergy can't make up the shortfall, Australia will need to expand natural gas production and use, and increase its carbon sequestration and circularity through CCUS and DAC to get to net zero.

Renewables will phase out fossil fuels and dominate

Under both scenarios, renewables will dominate the domestic energy mix as coal and crude oil are phased out by around 2040 (Figure 10A). Coal and liquefied natural gas (LNG) will no longer be exported by 2060, with blue and green hydrogen-based products taking over (Figure 10B).

Australia will also export electrons (see Figure 10C), at around 0.75EJ. Although this might appear trivial at first glance, it'll actually exceed the total yearly production of the country's current primary electricity market. For this small export component, this means almost *doubling* the country's electricity generation.

Green energy exports will dominate Australia's net-zero task

By 2060, primary energy demand for exports will outstrip domestic demand by a factor of five. And for as long as the scale of Australia's energy exports remain constant, the primary energy needed to fulfil its energy export market will rise. We call this the 'export penalty'. It's a consequence of inefficiencies in converting primary energy into transportable low-emissions options. By 2060, the export penalty will be around 50 percent, or roughly three times the total domestic primary energy demand. We think this will likely drive the price per delivered joule up for importers and may make onshoring downstream industries, such as steel and aluminium production, more attractive.

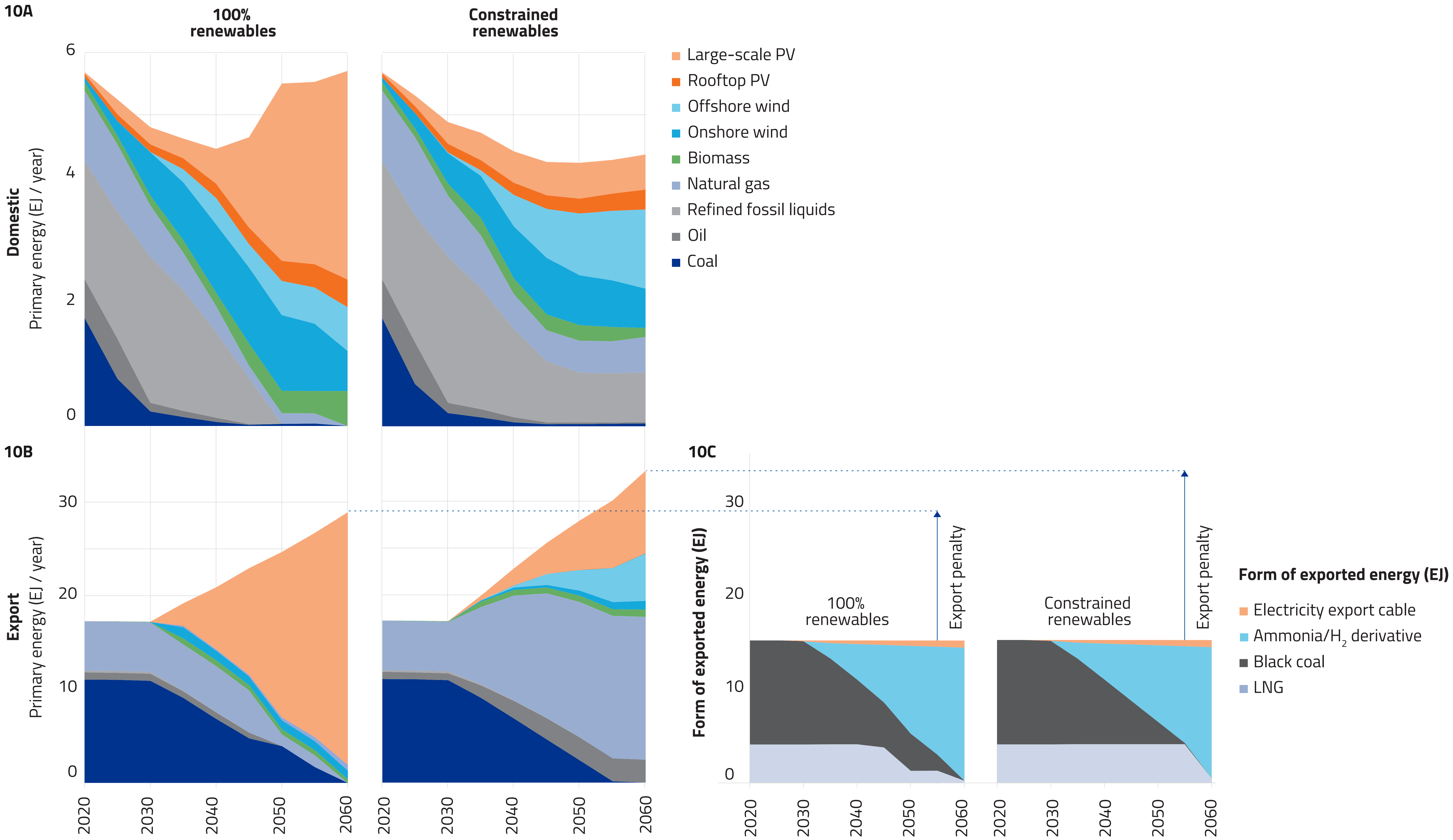


Figure 10A – Primary energy supplying Australia's domestic demand by future scenario. Note the scale difference between 10A and 10B/10C.
Figure 10B – Primary energy supplying Australia's energy exports by future scenario
Figure 10C – The final form that energy takes when exported, by future scenario

Carbon capture technologies will need to pick up the slack

Because Australia has limited biomass resources, it'll need to develop and deploy considerable DAC and other carbon capture (CC) technologies (Figure 11). In the 100 percent renewables scenario, DAC will provide captured carbon for aviation fuel and chemical production. In the constrained renewables scenario, DAC will offset the emissions Australia can't capture or store, mainly from using natural gas. Although it's a much smaller energy economy, zero-carbon exports result in a carbon capture, and transport and storage infrastructure challenge in Australia, similar in scale to the US, around 1GT/y.

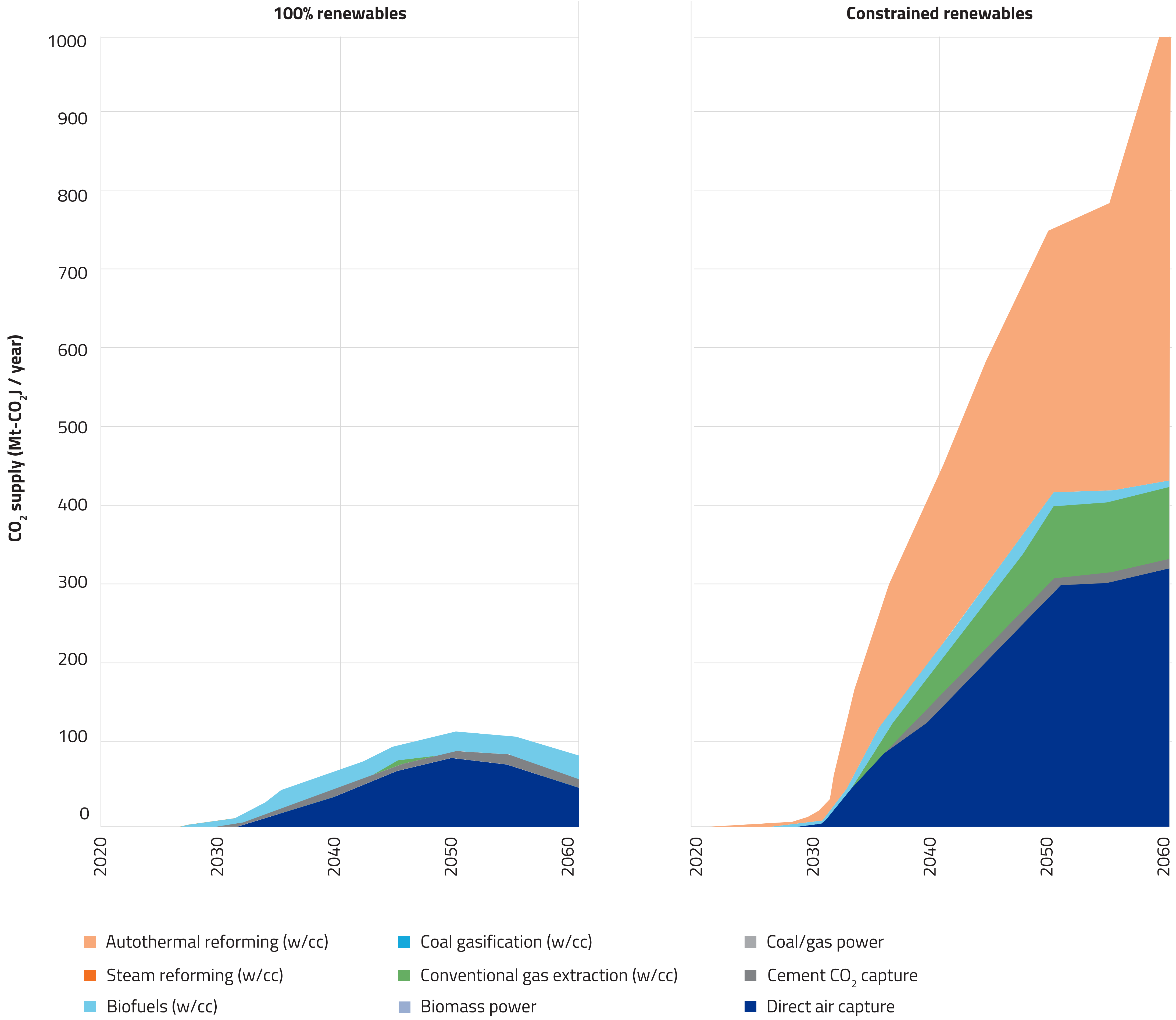


Figure 11 – Carbon captured by future scenario, and by source of capture

Australia will need an enormous amount of infrastructure

In 2023, Net-Zero Australia will publish downscaling maps to show where Australia could locate the physical infrastructure it needs to reach each future scenario. The magnitude involved can be seen in preliminary mapping results (Figure 12), which are subject to change as assumptions firm but these hint at vast inland renewable energy hubs and new continent-wide enabling infrastructure.

This coupled with our brief encounter with Australia's energy export dynamics tells us the task will be huge, but let's consider the actual numbers.

For three of the five scenarios, Australia will need to build around 3,000 GW of new renewables capacity – falling to about half that for the other two scenarios – between now and 2050.

This is a vast leap from where the world is today:

- 3,000 GW is about the same as the world's total installed renewables capacity right now.
- The most renewables infrastructure the world has collectively installed is around 300 GW year.

Australia has about 37 GW of renewables installed and working, and will need at least a 40-fold increase (and at most an 80-fold increase) in its renewables capacity.

Despite a well-developed and capable renewables sector, to get to net zero Australia will need to multiply that rate of installation drastically. Solar – for example – will need anywhere between 5-10 times the current rate. On the next page, in Figure 13, we show the installation rate Australia will need to hit every year to get to net zero by 2050 by future scenario and technology option. The dotted line marks Australia's previous best rate, and the bubbles compare Australia's target rate with a handful of large global projects.

The speed and scale attached to Australia's net-zero challenge is extraordinary. But it also provides clear evidence that the five transformative shifts that helped us understand the US challenge will be just as vital for Australia.

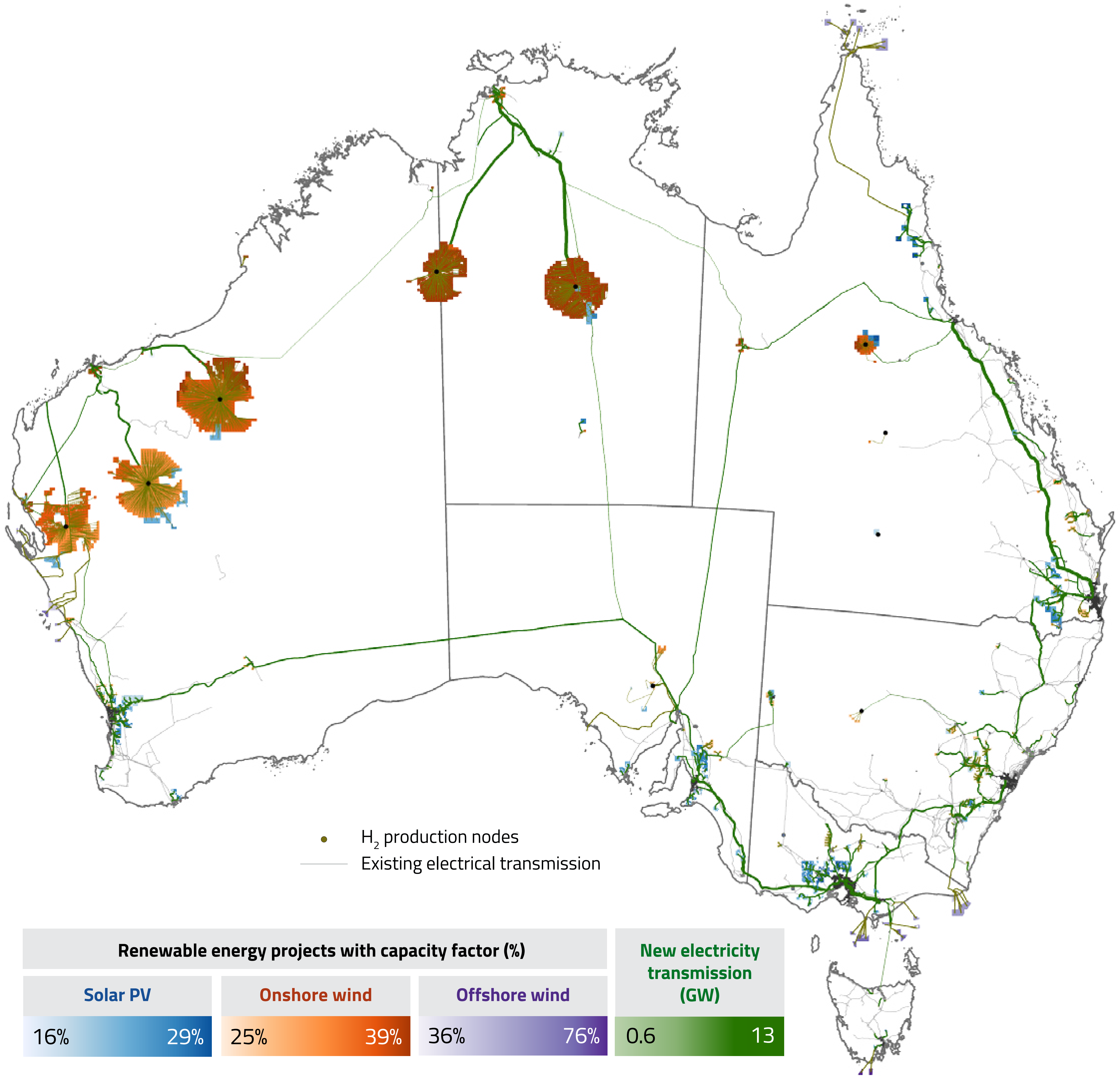


Figure 12 – Preliminary downscaling results for 2050, E+ pathway

The five shifts can get Australia there

Australia shares the same story with many other countries. And it brings us to the same conclusion: we must change global energy systems at rates we've never seen before. Assumptions and numbers may change. Demand for Australia's energy exports may increase, the need for Australia to capture its importers' carbon may decrease, or Australia may change its position on nuclear energy.

We developed the five shifts to show how countries like Australia and the US can build the scale and enable the speed they need to get to net zero by 2050. But the change will only happen if we hold ourselves accountable. To do that, we created three indicators of change for each shift as described in Chapter 2 that will not only measure change, but trigger interventions as early as possible in this critical decade for action.

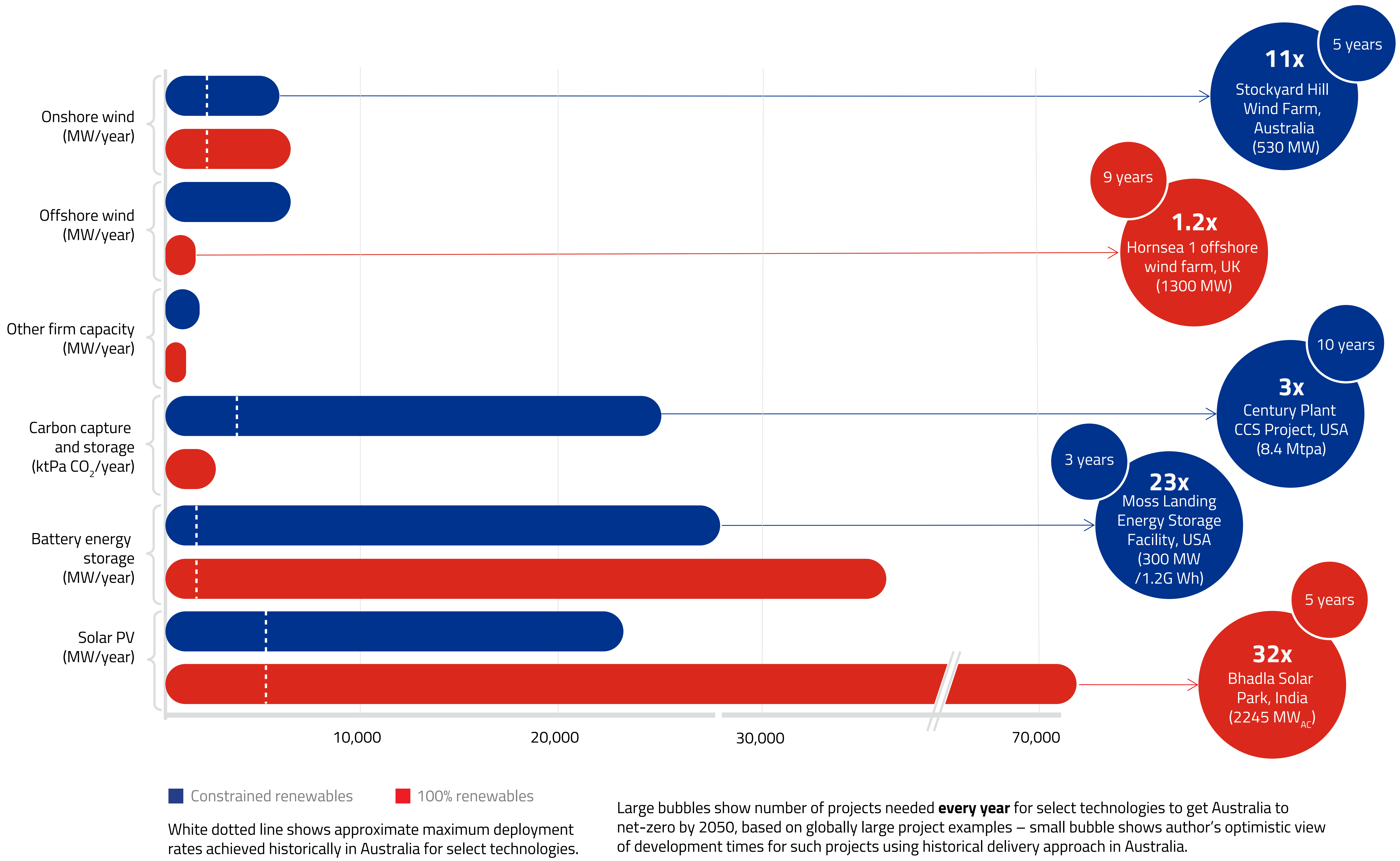


Figure 13 – Installation rates needed per year for certain technology solutions, and future scenario, and compared to large global projects.

Thank you for considering how to turn our net-zero ambitions into reality.

For more information on select ideas, follow these links:

Our first paper | Net Zero Australia | Net-Zero America

worley.com   acee.princeton.edu

1
2
3
4
5

How will Princeton run the survey?

The sample will be a minimum of 3,000 people formed from 30 cells: 100 participants from each of the 10 stakeholder groups, and from three geographic regions.

The sample is expected to grow through 'snowballing', as the initial panel invites more participants to join the study.

Recruitment →

Content and analysis →

The survey will ask two types of questions:

- **Questions common to all participants.** These questions cover each of the five shifts and will be the same for everyone. They're locked down so researchers can track changes in responses over time.
- **Questions specific to each stakeholder group.** These questions focus on the indicators of change and may evolve over time or vary by region.

To track progress over time, researchers will produce a rating derived primarily from the responses to common questions.

They'll also provide a status for each of the indicators of change and analyze differences and similarities across geographies and stakeholder groups.

Confidentiality →

The survey won't contain any personally identifiable information. Princeton's Institutional Review Board reviews and guarantees the privacy of all participants.

This extends to any documentation participants provide for further analysis (see below).

Additional activities

Princeton will bolster the self-reporting survey results in three ways:

- **Text analysis of climate action documents**
  Participants will have the opportunity to supply relevant documentation. Princeton will compare patterns of change between survey responses and participants' documents, and evaluate action relating to the five shifts.
- **Pulse check surveys**
  Researchers will use this type of interim survey method to understand the effect of:
  - Pre-identified events – new legislation, changes in political leadership, new sector policies
  - Post-identified events – wars, recessions.

  These events can be global, national, local, or within a stakeholder subgroup, but they must be relevant and have impacted the five shifts in some way.
- **Interventions**
  Researchers will work with stakeholders to design, deploy, and evaluate the impact of interventions to improve progress across the five shifts. They'll provide expert advice on how to implement and evaluate new pro-climate action initiatives, policies, and projects.

Acronyms

ACEE ....Andlinger Center for Energy and the Environment

ADMS ....Schneider Electric's Advanced Distribution Management Systems

AI ....Artificial Intelligence

AMRC ....Advanced Manufacturing Research Centre at The University of Sheffield

CCS ....Carbon Capture and Storage

CCUS ....Carbon Capture, Utilization and Storage

CLASS ....Customer Load Active System Services

CO_2 ....Carbon dioxide

COVID-19 ...Coronavirus Disease 2019

CRL ....Commercial Readiness Levels

DAC ....Direct Air Capture

DC/AC ....Direct Current / Alternating Current

DER ....Distributed energy resources

EJ ....Exajoule

EMA ....EU's European Medicines Agency

ESG ....Environmental, Social and Governance

EVs ....Electric Vehicles

FID ....Final Investment Decision

GDP ....Gross Domestic Product

GT ....Gigatons

GW ....Gigawatt

GWh ....Gigawatt hours

H_2 ....Hydrogen

IEA ....International Energy Agency

KPIs ....Key Performance Indicators

LCA ....Lifecycle Assessment

LNG ....Liquefied Natural Gas

MHRA ....UK's Medicines and Healthcare products Regulatory Agency

Mtpa ....Million Tons per annum

MW ....Megawatt

MWac ....Megawatt, alternating current

MWh ....Megawatt hours

PJ ....Petajoule

PV ....Photovoltaic

R&D ....Research and Development

SMR ....Small Modular Reactor

TRL ....Technology Readiness Level

UK ....United Kingdom

US ....United States