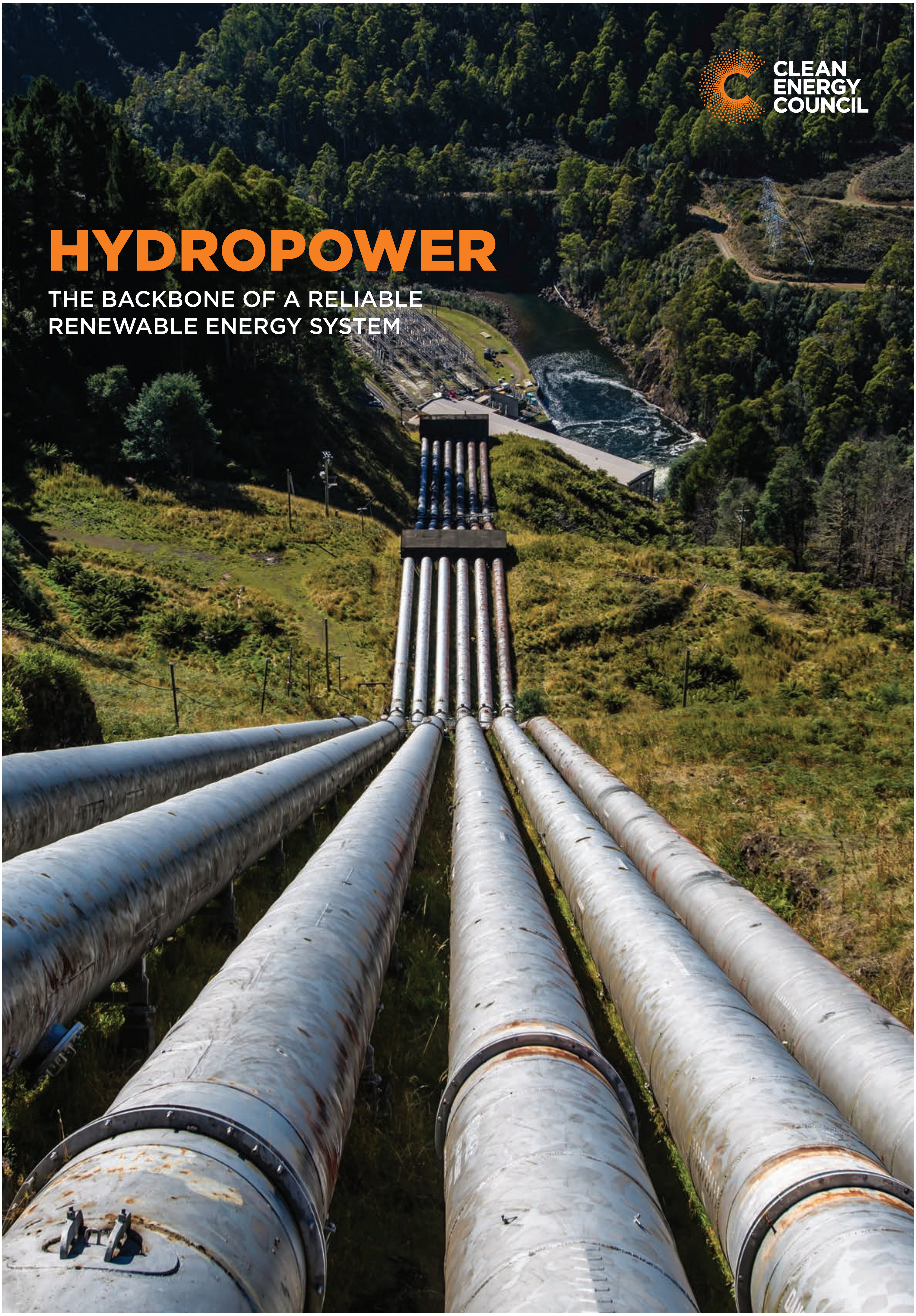
CLEAN ENERGY COUNCIL

HYDROPOWER

THE BACKBONE OF A RELIABLE RENEWABLE ENERGY SYSTEM



Hydropower capacity across Australia

Operating and proposed

WESTERN AUSTRALIA

1 OPERATING PROJECT
Capacity: 30 MW
Operations/maintenance jobs: 30

1 PROPOSED PROJECT
Capacity: 400 MW
Construction jobs: 576
Operations/maintenance jobs: 32

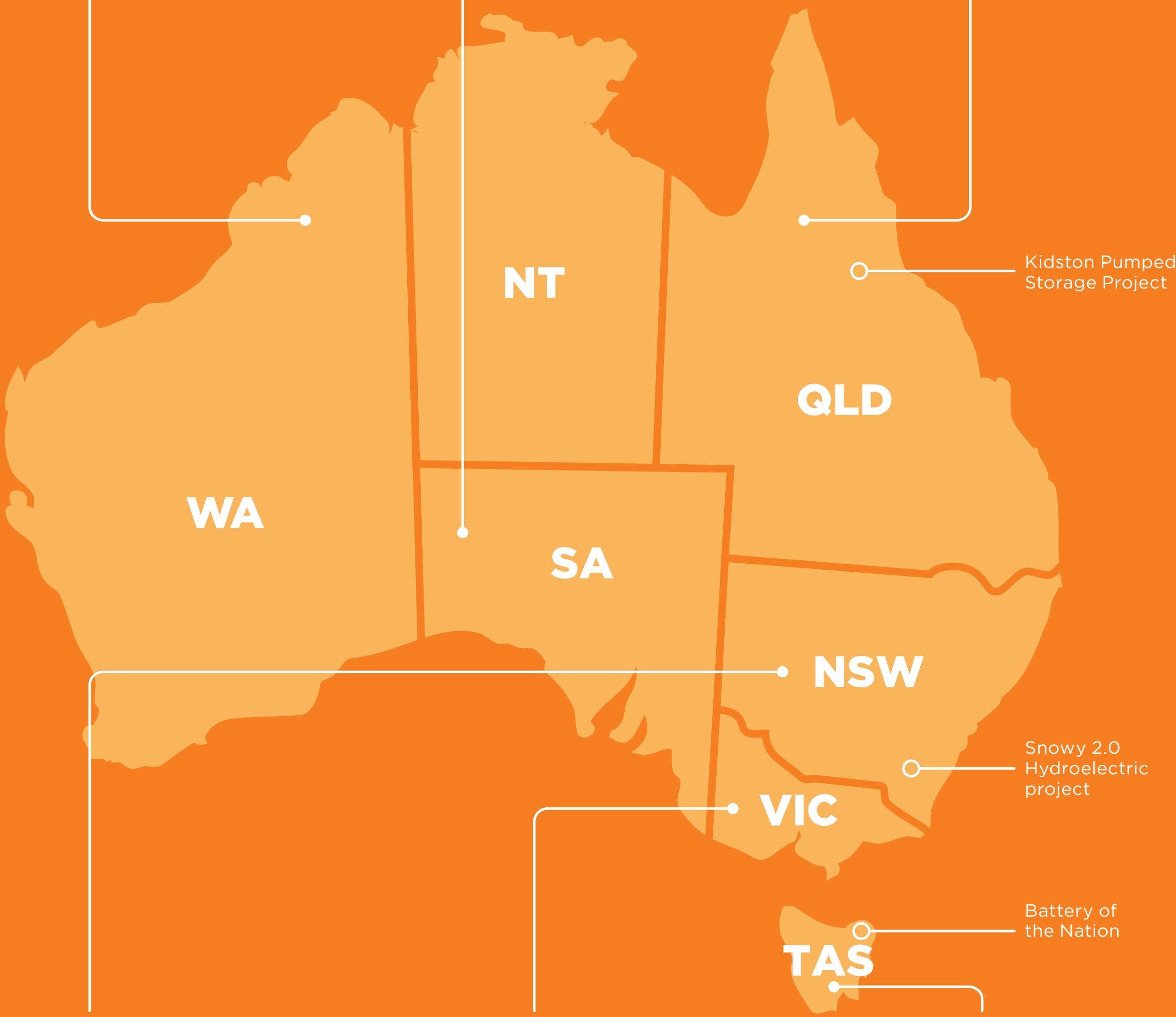
SOUTH AUSTRALIA

5 PROPOSED PROJECTS
Capacity: 920 MW
Construction jobs: 1325
Operations/maintenance jobs: 74

QUEENSLAND

4 OPERATING PROJECTS
Capacity: 729 MW
Operations/maintenance jobs: 102

6 PROPOSED PROJECTS
Capacity: 3800 MW
Construction jobs: 6937
Operations/maintenance jobs: 344



NEW SOUTH WALES

19 OPERATING PROJECTS
Capacity: 4533 MW
Operations/maintenance jobs: 617

9 PROPOSED PROJECTS
Capacity: 5245 MW
Construction jobs: 7553
Operations/maintenance jobs: 421

VICTORIA

10 OPERATING PROJECTS
Capacity: 733 MW
Operations/maintenance jobs: 102

1 PROPOSED PROJECT
Capacity: 30 MW
Construction jobs: 43
Operations/maintenance jobs: 2

TASMANIA

30 OPERATING PROJECTS
Capacity: 2290 MW
Operations/maintenance jobs: 331

6 PROPOSED PROJECTS
Capacity: 3550 MW
Construction jobs: 1800*
Operations/maintenance jobs: 427

Note: All jobs figures in proposed projects are expected jobs.
Proposed projects include those that are under construction, have reached financial close or are proposed/approved.
* Figures differ to those used in the Clean Energy at Work report, which were based on calculations of employment factors relevant at a national scale.

Foreword

Kane Thornton
Chief Executive,
Clean Energy Council

Hydropower has been the backbone of the Australian power system for the past 100 years. Today, hydropower is critical to a reliable, low-cost and decarbonised energy system in Australia.

Central to maintaining reliability and keeping the lights on, hydropower assets not only provide a low-cost and dependable supply of energy, they also deliver a wide range of crucial system services and flexibility that complement the wind and solar generation that is increasingly dominating the Australian energy mix. This proven technology will work alongside batteries and a stronger network to build the resilience of our energy system in the face of ageing coal-fired generators and increasing extreme weather events.

However, core investment challenges will need to be overcome if we are to reach the 19 GW of dispatchable energy that will be needed by 2040 to replace retiring coal-fired power stations.[1] Market signals are not only critical to support the development of new capacity, they also provide existing hydropower assets with the confidence to refurbish and modernise to ensure that they are fit-for-purpose in a high renewables future. With long lead times for the development and refurbishment of hydropower assets and the deployment of wind and solar outpacing even the most ambitious official assumptions, it is critical that policy makers work with the hydropower sector to design and implement policy approaches that can unlock new hydropower investment, including strategic transmission investment such as Marinus Link and HumeLink.

Hydropower has done a lot of heavy lifting over the last 100 years. With the right support, it can continue to do so for 100 more years, creating thousands of jobs today while underpinning the reliability of the grid for generations to come.

Kane Thornton
Chief Executive, Clean Energy Council

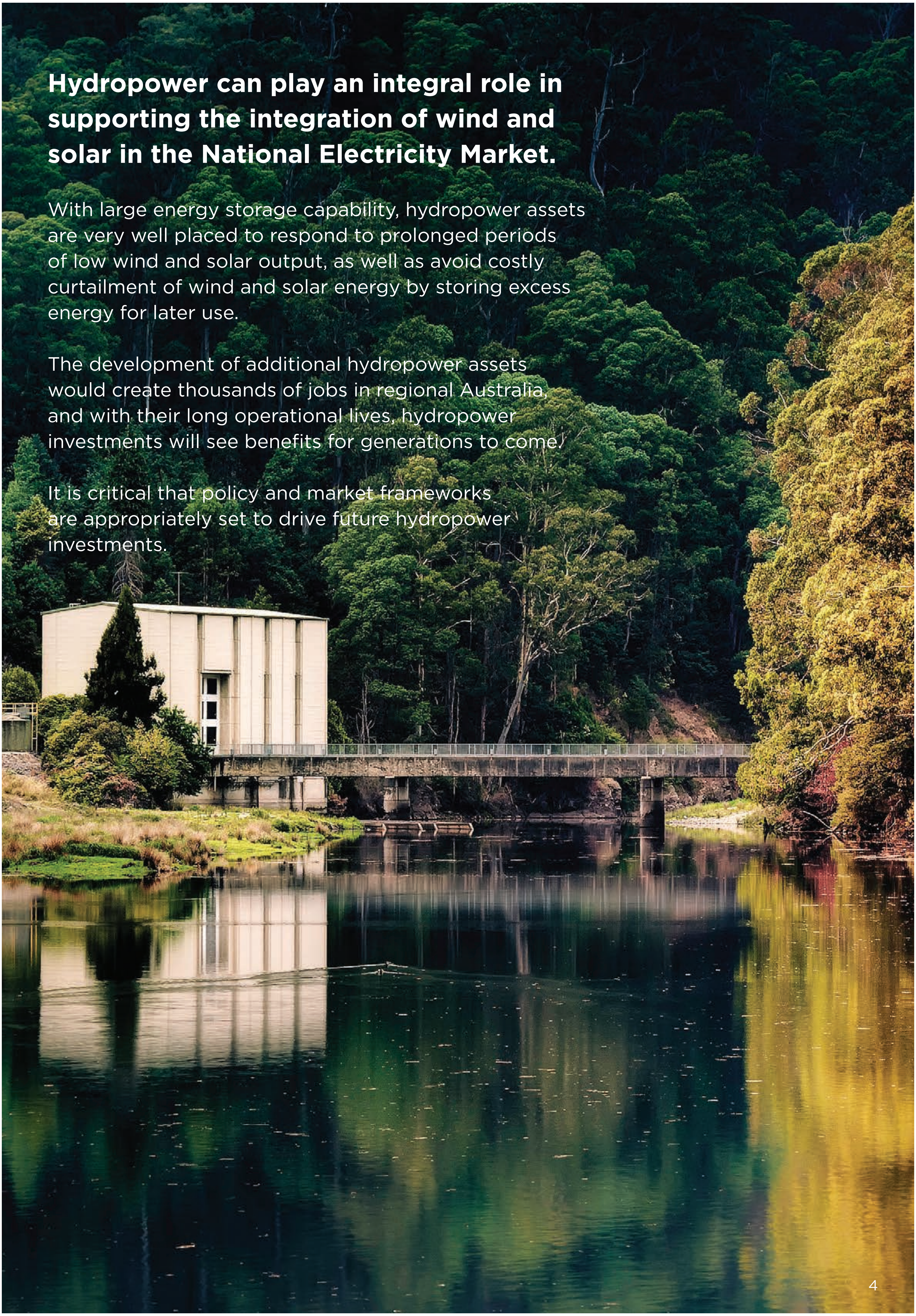
1 Australian Energy Market Operator, *2020 Integrated System Plan*, 30 July 2020, aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp

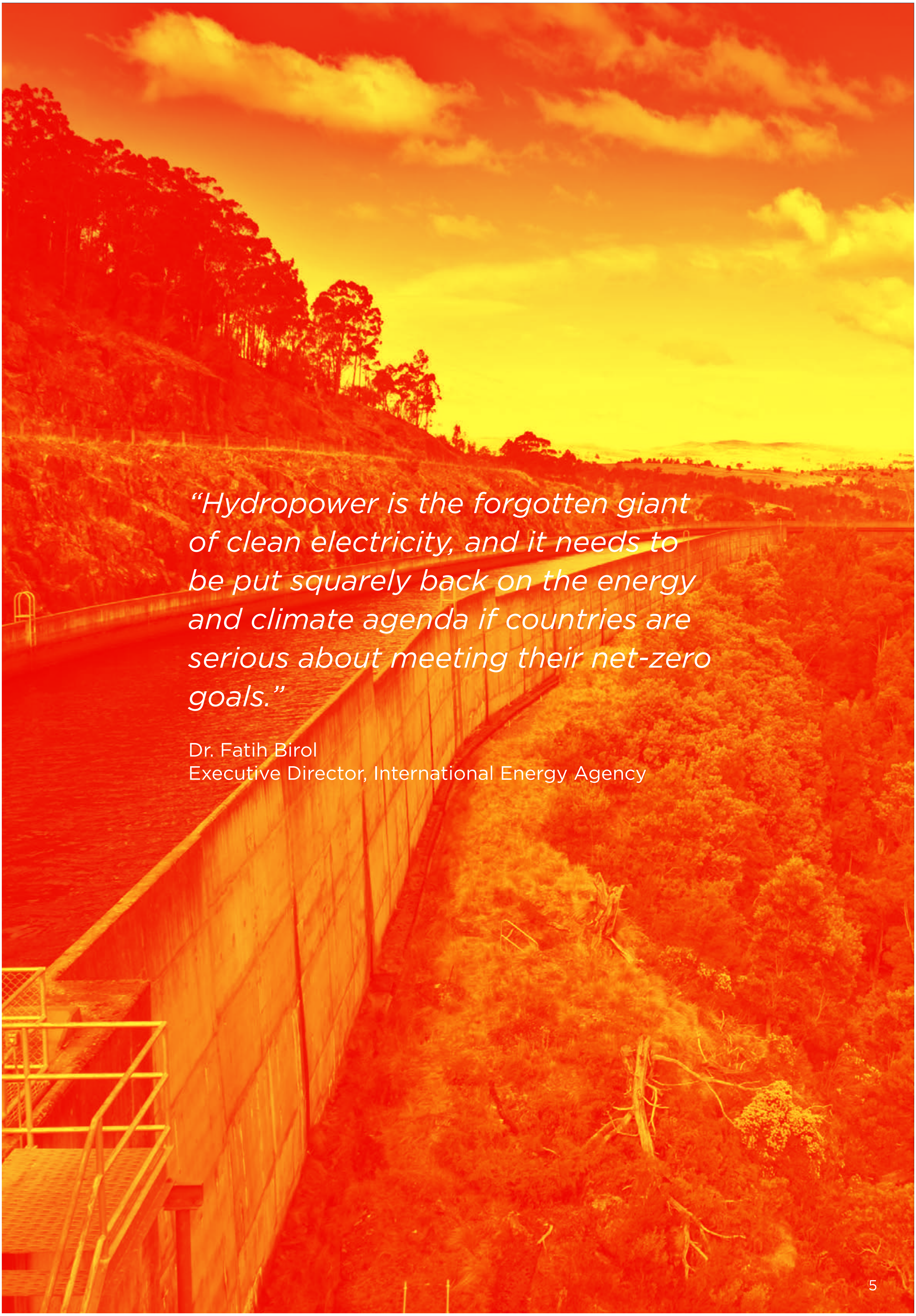
Hydropower can play an integral role in supporting the integration of wind and solar in the National Electricity Market.

With large energy storage capability, hydropower assets are very well placed to respond to prolonged periods of low wind and solar output, as well as avoid costly curtailment of wind and solar energy by storing excess energy for later use.

The development of additional hydropower assets would create thousands of jobs in regional Australia, and with their long operational lives, hydropower investments will see benefits for generations to come.

It is critical that policy and market frameworks are appropriately set to drive future hydropower investments.





"Hydropower is the forgotten giant of clean electricity, and it needs to be put squarely back on the energy and climate agenda if countries are serious about meeting their net-zero goals."

Dr. Fatih Birol
Executive Director, International Energy Agency

Executive summary

50 GW

of large-scale renewable generation needed in the National Electricity Market by 2040 to replace retiring coal-fired power

8.5 GW

of hydropower assets in operation across Australia today

Hydropower will play a central role in decarbonising the National Electricity Market (NEM). It will do this as a renewable form of generation itself, but also by supporting the rollout of more wind and solar. As the backbone of the power system, hydropower has long played a central role and will continue to do so into the future.

The rollout of renewable energy is the lowest cost way for Australia to decarbonise. This rollout is progressing ahead of official forecasts, with the Australian Energy Market Operator's (AEMO) Integrated System Plan (ISP) 'Central Scenario' forecast already exceeded through the rapid connection of solar PV and wind generation assets In fact, many market analysts now suggest that the market transition is tracking closer to the 2020 ISP's more ambitious 'Step Change Scenario'.

As a baseline, AEMO has forecast that up to 50 GW of large-scale renewable generation will be needed in the NEM by 2040 to replace retiring coal-fired power stations. To integrate increasing shares of renewables, up to 19 GW of new dispatchable resources, such as hydropower and battery storage, will also be required by 2040.

Hydropower is therefore central to NEM decarbonisation. Governments and policy makers must design markets and incentive mechanisms that properly reflect the full value that hydropower can provide. This is central to a smooth, stable and affordable transition to a decarbonised generation fleet.

This report explores the benefits of hydropower and demonstrates how it can provide the backbone necessary for our clean energy transition.

HYDROPOWER IS A MATURE AND ESTABLISHED SOURCE OF GENERATION

Hydropower has been the foundation of Australia's renewable energy sector since 1914. Today, there are 8.5 GW of hydropower assets in operation across Australia, which represented approximately 13 per cent of national capacity in October 2021[2] and 23 per cent of Australia's renewable generation in 2020.[3]

Major new projects, including Snowy 2.0 in NSW and Battery of the Nation in Tasmania, will include pumped storage hydro, enabling significant increases in the capacity and energy available through these storage facilities.

The falling costs of wind and solar has resulted in a significant increase in their deployment. However, rather than supplanting hydropower, this has made it an even more critical part of Australia's energy mix as a reliable and controllable source of clean energy that helps to support wind and solar and provides vital system strength and inertia to the grid.

2 Australian Energy Market Operator, *NEM Generation Information October 2021*, 15 October 2021, aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information
3 Clean Energy Council, *Clean Energy Australia Report 2021*, 31 March 2021, cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report

2500

people employed
in hydropower and
pumped storage hydro

HYDROPOWER PROVIDES A NUMBER OF SERVICES TO SUPPORT THE TRANSITION TO A ZERO EMISSIONS POWER SYSTEM

Hydropower units are like an anchor, or a backbone, which keeps the renewable energy system strong and stable. It already plays an important role in the operation of the NEM as a highly responsive or 'flexible' generation type that is often used to meet peak demand. It also complements other renewables by increasing and decreasing its energy production to match variations in wind and solar output as well as storing excess energy in times of plentiful renewable generation. Hydropower is well placed to step in during the kinds of low probability but high impact reliability events that may occur with a high renewables generation fleet, particularly prolonged periods of reduced solar and wind availability.

This flexibility is demonstrated in Figure 1. Hydropower can rapidly ramp-up its production to meet peak demand when the sun sets and solar output recedes. As the market continues to install higher shares of renewable energy, particularly solar, these kinds of fluctuations can be expected to increase in magnitude, with hydropower playing an increasingly important role in maintaining bulk energy supply reliability.

HYDROPOWER IS A SOURCE OF EMPLOYMENT AND OPPORTUNITY

Hydropower and pumped storage hydro can be an economic boon and creator of employment opportunities for regional communities. During construction phases for new plant, there are significant direct and indirect economic benefits for local communities, with ongoing opportunities during operation. Today, hydropower and pumped storage hydro together employ around 2500 people in Australia or 10 per cent of the renewable energy sector workforce.

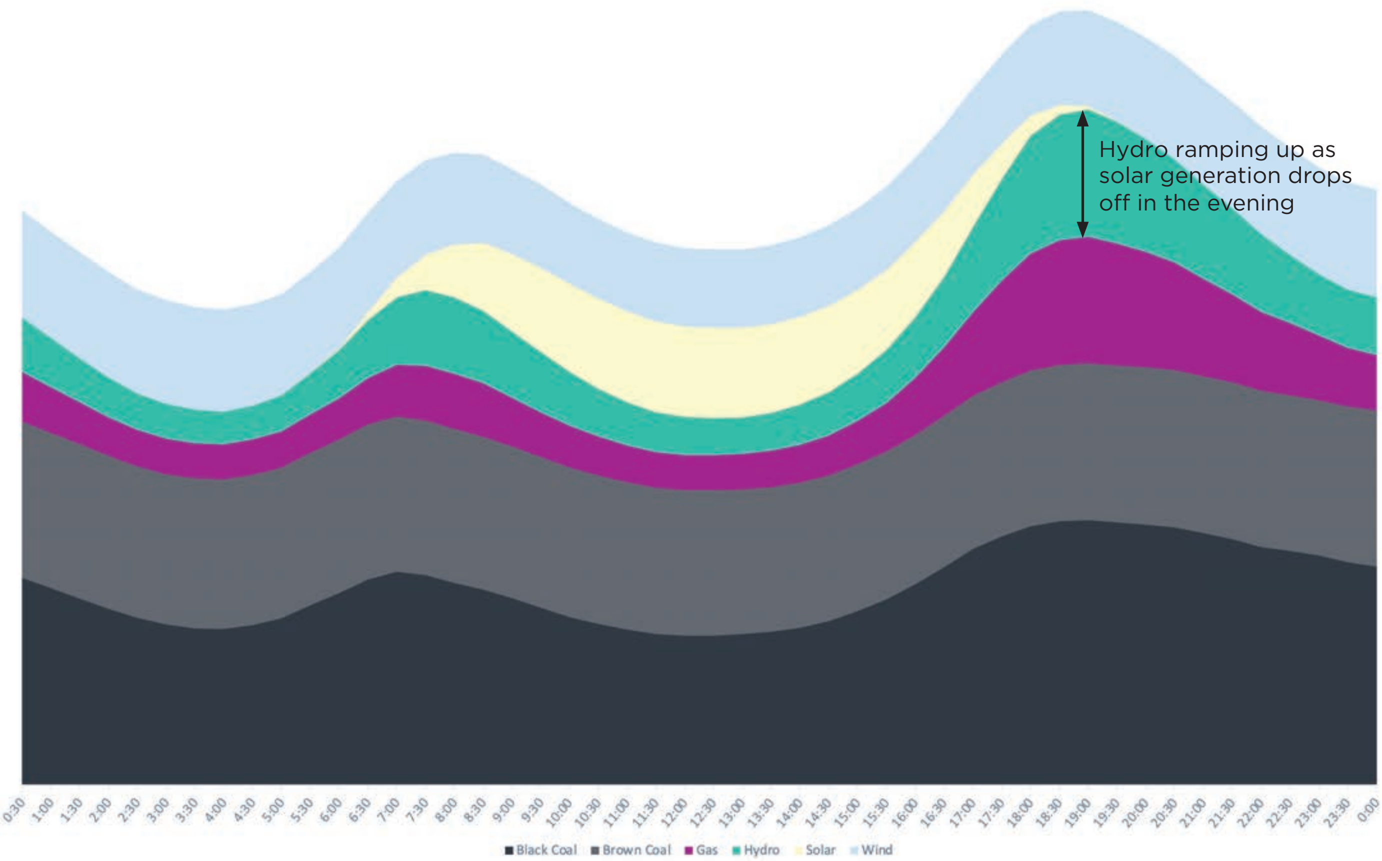


Figure 1: NEM average time of day generation

2.3 GW

capacity of hydropower projects that have progressed to financial commitment since the beginning of 2017

HYDROPOWER IS CAPITAL INTENSIVE AND NEEDS A STABLE INVESTMENT ENVIRONMENT TO FLOURISH

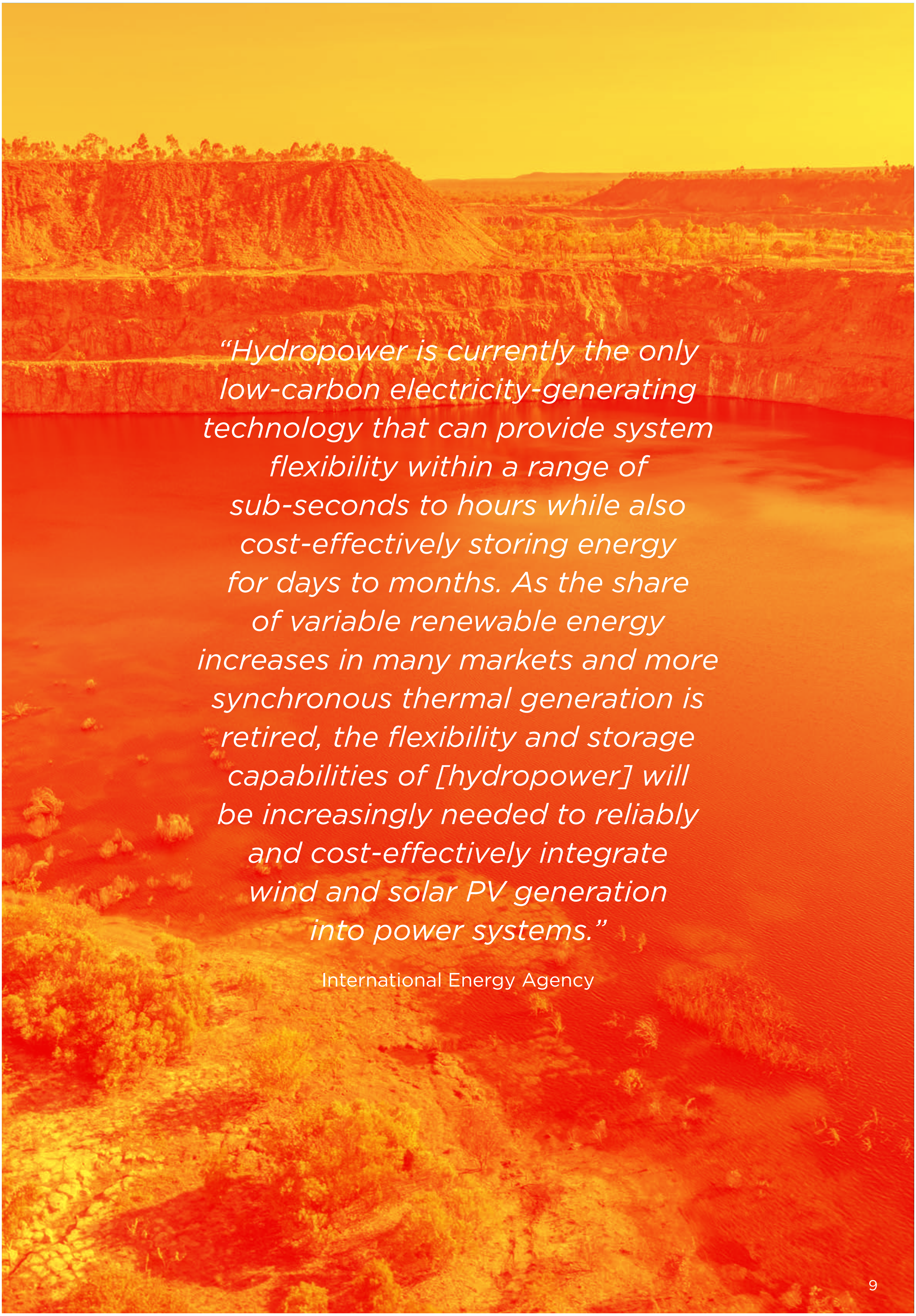
Despite a clear need for flexible and dispatchable energy generation and deep storage assets such as hydropower and pumped storage hydro, only two projects with a capacity of 2.3 GW have progressed to financial commitment since the beginning of 2017. In that same period of time, 27 battery storage projects with a capacity of 1.5 GW have progressed to financial commitment.

The difference in these deployment rates largely reflects the higher degree of complexity and costs of pumped storage hydro projects relative to battery storage projects. To date, there has been a shortage of clear market signals within the NEM to value the distinctive services that hydropower can provide, such as medium- to long-period energy reserves (storage) as well as certain critical system security services (e.g. inertia, system strength to support wind and solar, provision of fault current and voltage control).

Few, if any, hydropower projects have been developed in recent years without substantial government support. For example, while the Snowy 2.0 project will provide a major increase in available hydropower, it has required significant government support to get over the line. In addition to targeted government support, it is important to develop clear and consistent market price signals to support the development of these valuable projects.

There are some very positive developments in progress that should begin to address this lack of effective market signals. In particular, the Energy Security Board (ESB), working with the Australian Energy Market Commission, has developed new markets to value these services. System strength is one such service that hydropower can provide and which is now explicitly valued through the market frameworks.

However, more work is needed on this front. In particular, it is important to define the specific reliability issues that we may face in a grid with high wind and solar penetration. Although there are currently no reliability problems on the near horizon, this may change over the longer term. Hydropower can play a lead role in maintaining overall reliability by providing low-emissions, reliable capacity to make sure the lights stay on all year round. Any future development of mechanisms to maintain reliability must recognise the specific value of hydropower as a low-emissions, reliable source of bulk energy.



"Hydropower is currently the only low-carbon electricity-generating technology that can provide system flexibility within a range of sub-seconds to hours while also cost-effectively storing energy for days to months. As the share of variable renewable energy increases in many markets and more synchronous thermal generation is retired, the flexibility and storage capabilities of [hydropower] will be increasingly needed to reliably and cost-effectively integrate wind and solar PV generation into power systems."

International Energy Agency

The case for hydropower and pumped storage hydro

Hydropower assets are generational investments that can make an enduring contribution to the Australian energy system and underpin the deep decarbonisation of our energy sector.

FLEXIBILITY AND SUSTAINED PEAKING CAPABILITY

Hydropower can provide flexible 'peaking services' to meet rapid changes in energy demand as well as during peak periods. It can also help supply energy during less frequent, prolonged periods of energy supply shortfall due to reductions in wind and solar output. This capability is integral to managing the transition to a generation fleet that is dominated by wind and solar generation. With fast-start and fast-ramping characteristics, hydropower can also respond rapidly to dynamic changes in our energy system and maintain this service provision for as long as is necessary to 'keep the lights on'.

ENABLES RENEWABLES INTEGRATION

Hydropower is an ideal complement to variable renewable energy generation and can smooth the transition of our energy system as more wind and solar connects. The flexibility of hydropower assets allows them to operate in lockstep with wind and solar, essentially making renewables dispatchable and controllable, regardless of weather conditions. By helping to make wind and solar dispatchable, hydropower can also reduce wholesale price volatility, managing price impacts for customers.

EMISSIONS REDUCTION

Hydropower is a low-emissions energy resource that can enable increased uptake of other low- and zero-emissions energy resources. This will reduce our reliance on other, higher emitting peaking technologies. Hydropower will be a key tool in assisting Australia to achieve its emissions reductions targets, now and in the future. A recent study on energy stored and invested in Switzerland showed that pumped storage hydro returns 186 times the energy required to build it over its operating life.[4]

AN ESTABLISHED FLEET

With an existing hydropower fleet of 8.5 GW (second only to black coal), there is already a significant amount of pre-existing infrastructure, including dams, stations and network configurations. With advancements in hydropower technology, further efficiencies can be realised through refurbishment and modernisation.

50

LONG-LIVED AND GENERATIONAL INVESTMENTS

Hydropower assets can operate for up to 50 years without major refurbishment, while civil infrastructure of these assets can exist for more than 100 years. This makes hydropower the longest lasting and longest serving energy assets in the world, contributing to the provision of clean, reliable and affordable energy for today and generations to come.

100

MATURE TECHNOLOGY

Hydropower has been in operation globally for more than a century. In 2021, hydropower generated approximately 4330 TWh of electricity or 16 per cent of global generation. As markets around the world change (including in Australia) to incorporate higher shares of wind and solar, hydropower has demonstrated its unique capability to play a key supporting role in markets with high renewables penetration, reliably performing when needed.

INNOVATION, RESEARCH AND DEVELOPMENT

Hydropower assets are evolving to be fit-for-purpose in changing markets and power systems. Technological advancements such as the use of variable speed turbines or hybridised hydropower plants integrating floating solar PV or small battery applications can enhance plant flexibility and output. Often overlooked in this mature sector are significant innovations in artificial intelligence, machine learning, power electronics, materials science and optimisation, which all contribute to continued efficiency and performance. The ability to operate some hydropower units in 'synchronous condenser' mode will also be central to supporting the greater penetration of wind and solar while keeping the grid stable. New innovations are also being explored to enhance the sustainability of hydropower by continuing to minimise and mitigate ecological and hydrological impacts.

REGIONAL EMPLOYMENT AND ECONOMIC IMPACTS

Hydropower and pumped storage hydro can be an economic boon and creator of employment opportunities for regional communities. Not only are there direct and indirect economic benefits during construction phases for new plant, there are ongoing opportunities during operation. Today, hydropower and pumped storage hydro together employ around 2500 people or 10 per cent of the renewable energy sector workforce.

4 Swiss Academy of Engineering Sciences, *Current and future energy performance of power generation technologies in Switzerland*, November 2018, satw.ch/fileadmin/user_upload/documents/02_Themen/05_Energie/SATW-Energy-Performance-Switzerland-Report-EN.pdf

Hydropower is a mature and established renewable source of generation

4330

terrawatt hours of electricity generated globally by hydropower in 2021

100

billion tonnes of carbon dioxide emissions avoided globally through the use of hydropower

In Australia, hydropower typically consists of a number of traditional gravity-fed, reservoir-type generators, ranging from the largest capacity units and storages in the Snowy and Tasmania regions down to a number of smaller storages and units scattered across the country. Historically, only a small number of these generators have had pumping capability. Pumping capability is the ability to operate in reverse and pump water 'back up hill' for re-use later.

Hydropower has been in operation globally for more than a century. In 2021, hydropower generated approximately 4330 TWh of electricity or 16 per cent of global generation. This is enough to supply over 1 billion people with clean energy. As demonstrated in Figure 2, it is also the world's main form of low-carbon energy generation.

As markets around the world change to incorporate higher shares of wind and solar (including in Australia), hydropower has demonstrated its unique capability to play a key supporting role in markets with high renewables penetration, further contributing to emissions reduction.

With an existing hydropower fleet of 8.5 GW in Australia, there is already a significant amount of pre-existing infrastructure built to provide clean hydropower, including dams, stations and transmission networks. With increased network interconnection and market reform and development, along with advancements in hydropower technologies, further efficiencies can be realised through refurbishment and modernisation.

HYDROPOWER HELPS REDUCE EMISSIONS DIRECTLY

Hydropower is probably the oldest form of renewable generation. As a mature renewable technology, it is well suited to contributing to the overall decarbonisation of the Australian economy.

The International Hydropower Association estimates that the use of hydropower instead of fossil fuels for electricity generation has helped to avoid the emission of more than 100 billion tonnes of carbon dioxide in the past 50 years. It is estimated that without the existing international fleet of hydropower assets, global emissions from fossil fuels and industry would be at least 10 per cent higher.[6]

A concern sometimes raised is that hydropower assets may result in the emission of carbon dioxide. This can occur through the processes of building the asset, but also due to the decomposition of flooded organic material. While this can occur, there are several factors that can reduce these emissions, such as the design of the asset and the structure of storage ponds.

Hydropower provides a significant 'return on energy' in terms of the amount of energy expended in its construction relative to what it generates over its lifetime. For example, a recent study on energy stored relative to energy invested showed that pumped storage hydro returns 186 times the energy required to build it.[7]

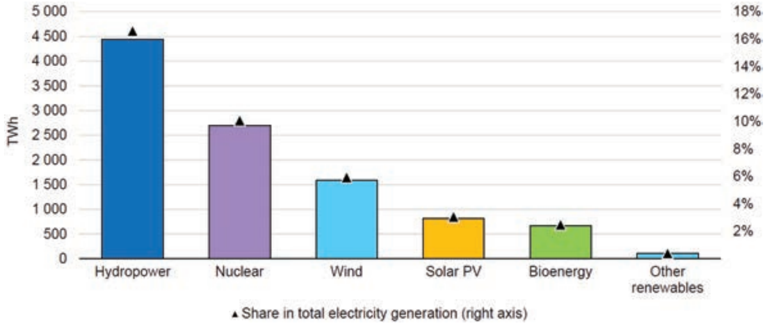


Figure 2: Low-carbon electricity generation by technology and shares in global electricity supply, 2020[5]

5 International Energy Agency, *Hydropower Special Market Report: Analysis and forecast to 2030*, 30 June 2021, iea.blob.core.windows.net/assets/4d2d4365-08c6-4171-9ea2-8549fabd1c8d/HydropowerSpecialMarketReport_corr.pdf
6 International Hydropower Association, *Hydropower's carbon footprint*, hydropower.org/factsheets/greenhouse-gas-emissions
7 Swiss Academy of Engineering Sciences, *Current and future energy performance of power generation technologies in Switzerland*, November 2018, satw.ch/fileadmin/user_upload/documents/02_Themen/05_Energie/SATW-Energy-Performance-Switzerland-Report-EN.pdf

1895

year the first hydropower plant was developed in Australia

6.4%

of Australia's total energy demands met by hydropower

AUSTRALIA HAS A WELL-ESTABLISHED FLEET OF HYDROPOWER GENERATION

Hydropower has long been the foundation of Australia's renewable energy sector. The first Australian hydropower plant was developed in 1895, with the majority of hydropower assets built between 1951 and 1996.

Today, there is around 8.5 GW of hydropower capacity in operation across Australia, providing approximately 6.4 per cent of total energy demand in 2020.

These generators have often played a role in helping to meet peak demand, such as during heatwaves in summer or cold snaps in winter. They can also help meet bulk supply, especially where they have large storages, such as those in Tasmania and in the Snowy region.

These established units have long lives. With the right market settings and targeted policy support, refurbishment and upgrade works can then be used to significantly extend their lives. As discussed in the rest of this paper, this means that hydropower can continue to form the backbone of a decarbonised generation fleet for many years to come.

PUMPED STORAGE HYDRO MAKES EXISTING ASSETS EVEN MORE VALUABLE

A small number of existing hydropower units have pumped storage hydro capability. Pumped storage hydro is where a hydropower generator effectively operates in reverse, pumping water back up hill for later use. A pumped storage hydropower station is effectively a massive battery that can store significant volumes of energy to support reliable supply for customers, complementing variable supply from wind and solar generation.

Historically, there have only been a few pumped storage hydro assets in Australia. However, several of these projects are currently being developed in the NEM. These include major retrofit and expansion projects such as Snowy 2.0 and Battery of the Nation. Both of these projects will include pumped storage hydro, enabling significant increases in the capacity and energy available through these storage facilities.

The Snowy 2.0 project will expand the existing Snowy Hydropower project to include a new underground power station with pumped storage hydro capacity. Battery of the Nation will include optimising existing hydropower assets and unlocking significant pumped storage hydro potential, enabled by an expansion of the interconnection between Tasmania and the mainland.

Another key project is the Kidston Pumped Storage Hydro Project. This project is currently being constructed in Queensland and will include a 250 MW generator coupled with an existing 50 MW solar farm. It will be capable of providing 2000 MWh of continuous power generation in a single cycle, or approximately 250 MW provided continuously over an eight-hour period.

Hydropower provides a number of services to support the transition to a zero-emissions power system

Hydropower is an ideal complement to other forms of variable renewable generation and can smooth the transition of our energy system as more wind and solar connects. The flexibility of hydropower assets allows them to operate in lockstep with wind and solar, essentially making renewables dispatchable and controllable, regardless of weather conditions. By helping to make wind and solar dispatchable, hydropower can also reduce wholesale price volatility, managing price impacts for customers.

HYDROPOWER ENABLES EXPANSION OF RENEWABLES, WHICH DRIVES FURTHER EMISSIONS REDUCTION

Hydropower reduces the overall emissions intensity of the generation fleet by supporting the increased rollout of wind and solar. It does this by complementing the variability of these generators, providing system stabilising services and soaking up any surplus energy produced during low-demand periods. Each of these effects is discussed later in this paper.

The Australian renewable energy sector is uniquely positioned to drive rapid and low-cost decarbonisation across the entire economy. Mature technologies like solar, wind and battery storage are already here and will only continue to decrease in cost. This means that the energy sector can do the heavy lifting to support the overall decarbonisation of the economy given that it is more expensive to decarbonise other sectors such as transport, agriculture and manufacturing. Other trends, particularly electrification and the shift to a hydrogen economy, will only enhance this effect.

Hydropower will play a central role in the decarbonisation of the energy sector. While it is itself a renewable source of energy generation, it also has a multiplier effect by enabling increased penetration of wind and solar generation. This occurs through its ability to match wind and solar variability as well as its inherent system stabilising effects.

Figure 3 demonstrates just how much value is provided by hydropower.

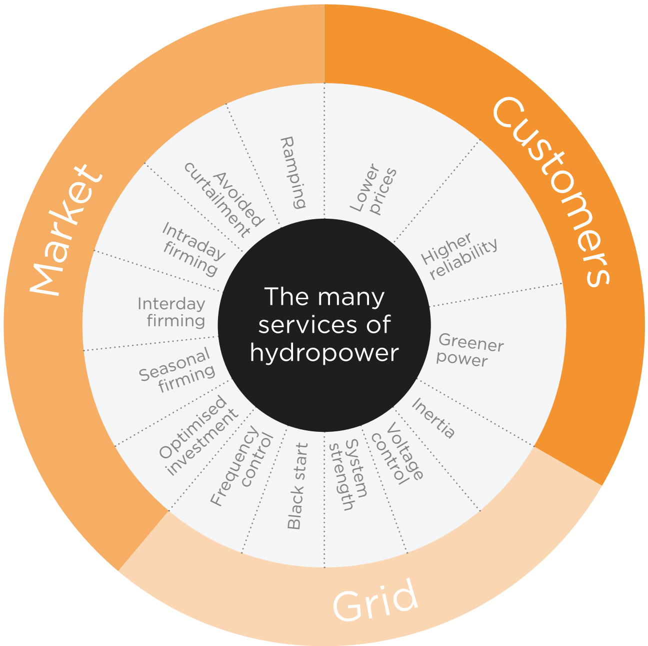


Figure 3: The many services provided by hydropower

Broadly, these value streams can be considered as follows:

HYDROPOWER IS DISPATCHABLE

As long as it has sufficient water available, hydropower can turn on when needed to provide a firm energy supply. This can help to manage any fluctuations that may occur due to changes in supply from wind and solar. This helps with firming and ramping, and also reduces price volatility for consumers.

HYDROPOWER IS SYNCHRONOUS AND STRENGTHENS THE SYSTEM

Hydropower operates as a kind of pacemaker to keep the system ticking along evenly. Hydropower can provide important services such as system strength, voltage control, inertia, black start and many types of frequency control. The provision of these synchronous services helps other types of generation, particularly wind and solar, to stay connected to the system.

HYDROPOWER CAN COMPLEMENT VARIABILITY

Pumped storage hydro can help to 'soak up' any excess energy produced by renewable generation. This is very important as during daytime when there is plenty of wind and solar available, the amount of energy produced can be more than what is demanded at that moment by commercial and residential users. This abundance of power can be effectively stored by pumped storage hydro, ready to be used later at night when demand increases. This helps in avoiding renewable curtailment and keeping prices lower for consumers.

FLEXIBILITY TO MEET INTRA-DAY DEMAND CHANGES AND PEAKING CAPABILITY

Like all power systems, it is a fundamental requirement that the power consumed is matched with the power supplied at any given moment (with some margin for error). This requires the power system to operate 'flexibly'. Hydropower can quickly transition from idle (producing no energy) to full output within a matter of minutes, making it highly capable of responding to variations in the delicate supply/demand balance.

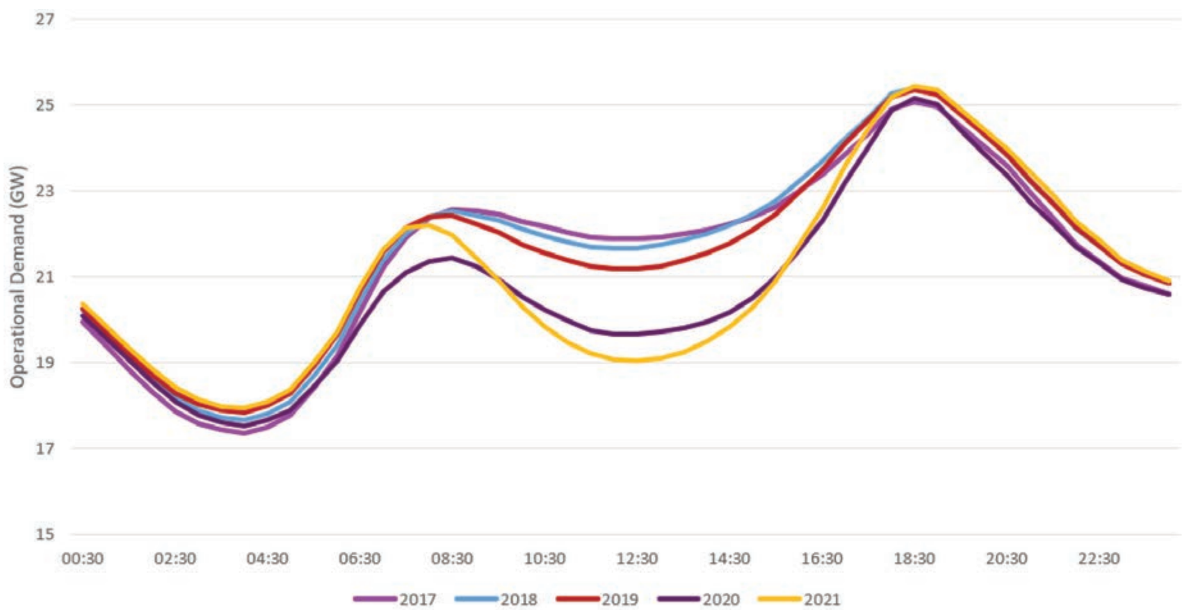
This capability is integral to managing the transition to a generation fleet that is dominated by wind and solar generation. With fast-start and fast-ramping characteristics, hydropower is able to respond rapidly to dynamic changes in our energy system and can maintain this service provision for as long as is necessary to keep the lights on.

This rapid ramping capability means that hydropower can cover for shortfalls in generation when output from renewables falls unexpectedly. In this way, hydropower can provide intra-day and inter-day firming for renewables. This kind of responsiveness will become increasingly important as intra-day demand patterns continue to change, as shown in Figure 4.

This kind of demand pattern is becoming increasingly common as increased rooftop PV output means that demand from the main grid continues to fall during the middle of the day. During these times, output from large-scale wind and solar may be quite high, but there is simply not enough demand to soak it all up.

Pumped storage hydro is able to absorb this 'spare' wind and solar output when an excess exists by running in pump mode and using this low-cost and abundant energy. It can then run in generator mode to meet demand during the significant ramp up that occurs during the evening peak, where reductions in rooftop PV result in an increase in demand on the grid. This not only mitigates the effects of the midday low load conditions, but also means that demand can be met in the evening.

In effect, pumped storage hydro turns wind and solar that would otherwise have been curtailed into a peaking power source. This has obvious benefits in that it helps meet customer demand for energy when it is needed most. It also helps to stabilise wholesale market prices by using up energy when it is cheap and providing it back into the market when it is more valuable.



Operational demand for the NEM between 2017 and 2021. This shows a reflection of the downward trend in demand over a whole season

Figure 4: The duck curve[8]

8 Australian Energy Market Operator, *Fact sheet: Minimum Operational Demand, 15 June 2021*, aemo.com.au/-/media/files/learn/fact-sheets/minimum-operational-demand-factsheet.pdf

DEEP STORAGE ENABLES A HIGH RENEWABLES FUTURE

Hydropower has a key role to play in maintaining supply during seasonal events. These include prolonged supply shortfalls that may occur in high renewables grids during winter as well as the more traditional peak demand periods that can occur in summer.

A range of storage technologies will be required as the share of wind and solar increases in the electricity system over the next decade. Short-duration storage will be required to manage rapid changes in the system, while long-duration (or deep) storage will be needed to balance daily and seasonal cycles and weather patterns.

Long-duration hydro storage can provide confidence to manage these kinds of events and scenarios.

Additional storage 'depth' will allow continued generation, even in instances where an imbalance between supply and demand persists for extended and unforeseen periods of time.

As part of the 2020 ISP, AEMO modelled how the energy balances of deep storage would change across the year to stabilise the grid against seasonal variation in renewable output. This is demonstrated in Figure 5. This analysis showcases the need for this kind of storage and the benefits it would bring to the market.

Further analysis demonstrates clearly how hydropower can help meet seasonal demand patterns in different regions. For example, Figure 6 demonstrates how hydropower plays a role in helping to meet winter demand for energy in Tasmania and Victoria.

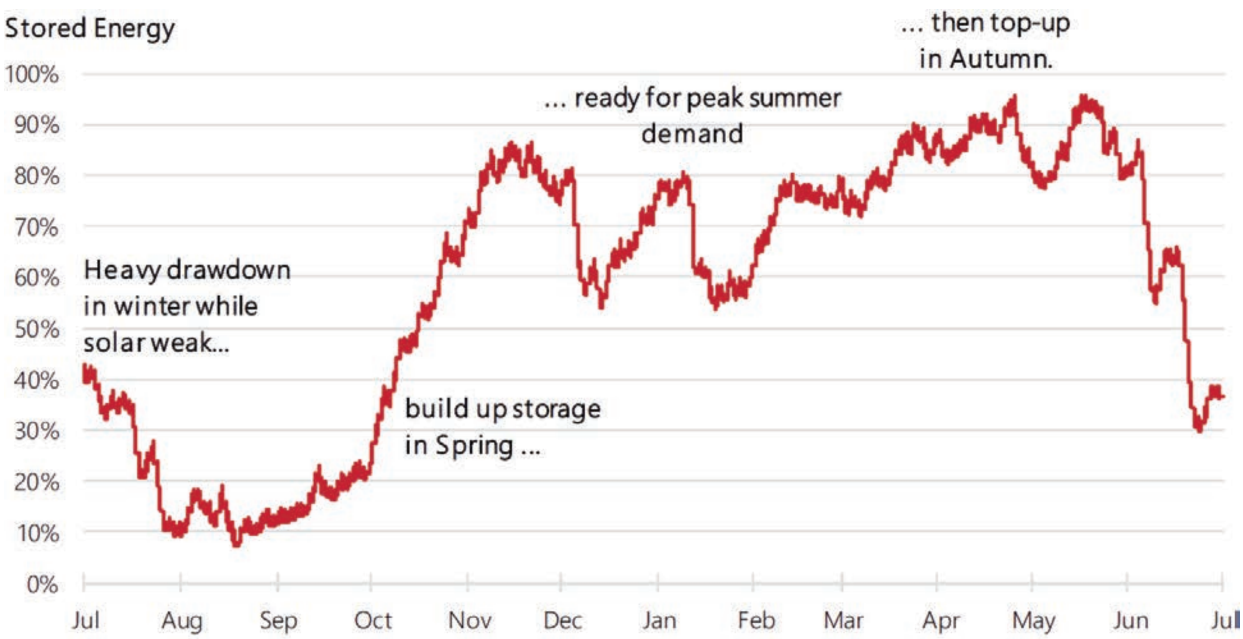


Figure 5: Projected deep storage energy balance, 2034-35[9]

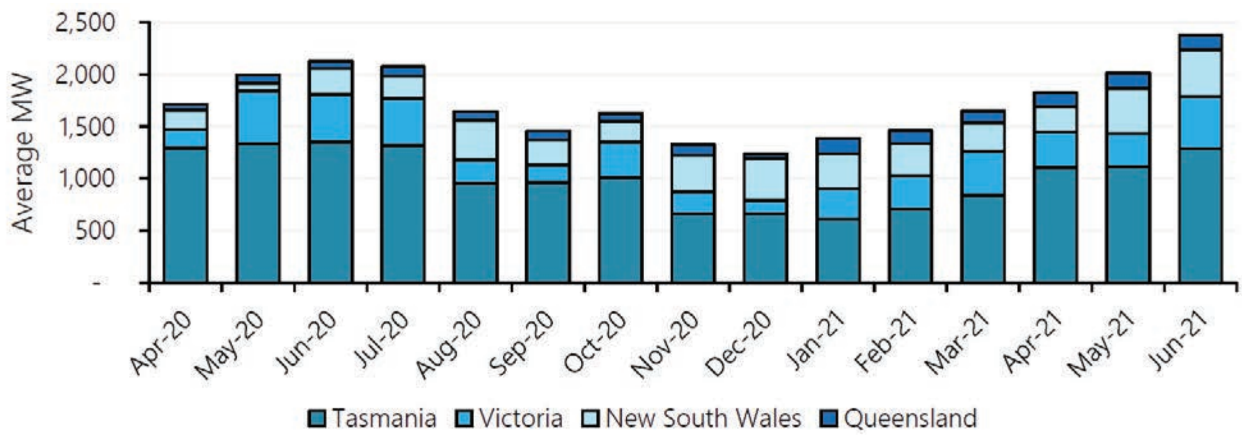


Figure 6: Average hydropower generation by state and month[10]

9 Australian Energy Market Operator, *2020 Integrated System Plan*, 30 July 2020, aemo.com.au/-/media/files/major-publications/isp/2020/final-2020-integrated-system-plan.pdf

10 Australian Energy Market Operator, *Quarterly Energy Dynamics: Q2 2021*, 23 July 2021, aemo.com.au/-/media/files/major-publications/qed/2021/q2-report.pdf

ENABLING REZ BUILDOUT AND EFFICIENTLY SIZING TRANSMISSION

Hydropower can smooth peak demand to deliver even more energy output from a renewable energy zone (REZ). Figure 7 demonstrates how pumped storage hydro is a natural complement to other forms of renewable generation and can improve overall energy generation in a REZ, which in turn means that transmission lines can be more effectively sized and utilised.

For example, in Figure 7, including 600 MW of pumped storage hydro with nine hours of storage alongside wind and solar enables a 1.9 GW line at 60 per cent utilisation to be replaced by a 1.3 GW line at 85 per cent. This would provide both capex and opex savings.

MANAGING UNCERTAINTY

As the power system transitions to being predominantly renewable, variable and non-synchronous, a key challenge will be to ensure the system is sufficiently robust to a wide range of weather-driven and technology-driven scenarios and uncertainties, alongside lower-probability but more extreme events. This could be anything from the daily solar cycle and seasonal wind patterns to transmission corridor failures or unexpected and extended plant outages (such as was seen recently at the Yallourn and Callide coal-fired power stations).

Understanding and managing these challenges in the real world differs from conventional system modelling approaches, which typically produce results based on 'perfect foresight' where both capacity and energy generation are optimised to meet system needs at lowest costs. Modelling approaches will typically identify the perfect mix of storage assets needed to meet system requirements under a specific modelled scenario, rather than a mix of storage assets that is robust to a variety of possible grid conditions for which we must be prepared.

As AEMO's 2020 ISP noted:

> *"The 2020 ISP analysis assumes optimal operation of the installed storage with perfect foresight. However, even minor inefficiencies in real-world operations would lead to the need for more storage or other forms of dispatchable generation to ensure reliable supply for consumers."*[12]

Compared with least-cost modelling and after accounting for imperfect foresight, additional storage will be required to help manage further uncertainty. Deep storage will be better placed to manage these uncertain decisions in the real-world electricity market. Realistic operations will likely result in a need for storage two to three times longer in duration to achieve similar outcomes with the same capacity.

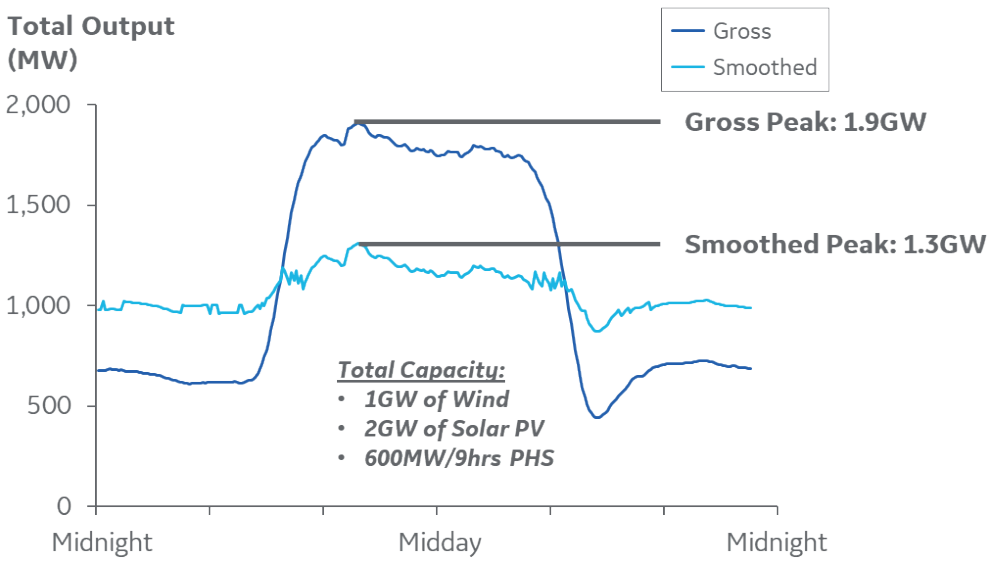


Figure 7: Average winter weekday output for a hypothetical REZ in Queensland[11]

11 GE Renewable Energy, *Pumped Hydro Storage in Australia*, ge.com/renewableenergy/sites/default/files/related_documents/GEA34801%20PHS_Development_Australia_WP_R2.pdf

12 Australian Energy Market Operator, *2020 Integrated System Plan*, 30 July 2020, aemo.com.au/-/media/files/major-publications/isp/2020/final-2020-integrated-system-plan.pdf

While any storage can strengthen the grid, investing in a sub-optimal mix of storage assets can pose risks for governments, operators and energy consumers. For example, a sub-optimal mix of storage assets may result in an inefficient over-build of shorter-duration storage, some of which would be developed only to meet rare or unforeseen variations in supply or demand. As noted in the Clean Energy Council's report *Battery Storage: The New Clean Peaker*[13], alternative conventional peaking generation such as gas could be used to balance prolonged periods of low wind and solar output, but this would be far more costly relative to available renewable storage options, subsequently imposing greater costs on customers and increasing the carbon footprint of the energy sector. In addition, unlike pumped storage hydro, gas is incapable of storing energy during periods of excess supply.

Imperial College London recently undertook analysis of system benefits of long-duration energy storage in the UK. This analysis demonstrated that developing long-duration storage would lower overall capital costs, reduce the need for additional transmission build and complement the use of demand response. Together, these strategies can produce significant cost savings for consumers.

HYDROPOWER ENHANCES SYSTEM STABILITY AND PROVIDES SYSTEM SERVICES

Like all power systems, it is a fundamental requirement that the power consumed is matched with the power supplied at any given moment (with some margin for error). This requires the power system to operate 'flexibly'.

The International Energy Agency defines 'power system flexibility' as:

> *"The ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply."*[14]

The role of hydropower will become increasingly important in the NEM over the next two decades in maintaining a stable footing for the electricity system as ageing and increasingly unreliable coal-fired power stations are replaced with zero-emissions wind and solar and the risk of extreme weather events increases due to climate change.

Hydropower can quickly transition from idle (producing no energy) to full output within a matter of minutes, making it highly capable of responding to variations in the delicate supply/demand balance. This can be helpful in managing the growing solar cycle in Australia by ramping down (reducing production) as the sun rises in the morning and solar output increases, or ramping up (increasing production) as the sun sets and solar output decreases. Hydropower can also react swiftly to variations in output from wind generation assets.

Hydropower's ability to ramp rapidly allows it to provide many of the frequency control services needed to maintain grid stability. It is also able to provide system strength, voltage support and black start services to 'reboot' the grid in case of blackouts. Fixed-speed equipment can additionally provide synchronous inertia, helping to further protect the system against sudden changes in frequency.

For these reasons, hydropower is perfectly positioned to operate in a complementary manner with low-cost renewable energy technologies. When paired with other flexible, short-duration energy storage technologies such as grid-scale batteries, it is clear that Australia can effectively integrate significantly higher shares of renewable wind and solar to replace our ageing, expensive and increasingly unreliable thermal generation fleet.

13 Clean Energy Council, *Battery Storage: The New Clean Peaker*, 10 April 2021, assets.cleanenergycouncil.org.au/documents/resources/reports/battery-storage-the-new-clean-peaker.pdf

14 International Energy Agency, *Status of Power System Transformation 2019*, May 2019, iea.blob.core.windows.net/assets/00dd2818-65f1-426c-8756-9cc0409d89a8/Status_of_Power_System_Transformation_2019.pdf

Hydropower is a source of employment and opportunity

500

jobs created by the Kidston Pumped Storage Hydro Project

$2B

value of the Kidston Pumped Storage Hydro Project to Queensland in ancillary economic benefits

REGIONAL EMPLOYMENT AND ECONOMIC IMPACTS

Hydropower and pumped storage hydro can be an economic boon and creator of employment opportunities in regional communities. During construction phases for new plant, there are significant direct and indirect economic benefits for local communities, with ongoing opportunities during operation. Today, hydropower and pumped storage hydro together employ around 2500 people or 10 per cent of the renewable energy sector workforce.

A recent example of the kinds of economic benefits provided by hydropower can be found at the Kidston Pumped Storage Hydro Project in Queensland.

This project will provide significant economic benefits in Queensland. Construction of the project will create 500 jobs, with a strong focus on local employment. The construction of the associated 275 kV transmission line from Kidston to Mt Fox will also result in the creation of an additional 400 jobs, bringing the total number of jobs created as a direct result of the project to approximately 900. Townsville is the primary port for receiving materials for the project, while Cairns has been designated as the fly-in-fly-out city. It is estimated the project will create $2 billion in ancillary economic benefits for Queensland. Moreover, a cost-benefit analysis found that the project would deliver a reduction in wholesale energy costs in the NEM, resulting in a net present value of over $500 million of savings for consumers.

Similarly significant economic benefits, both direct and indirect, will be associated with the other pumped storage hydro projects currently proposed or under development, particularly the Battery of the Nation project in Tasmania; the Central West, Oven Mountain and Dungowan pumped storage hydro projects in New South Wales; and the Cressbrook project in Queensland.

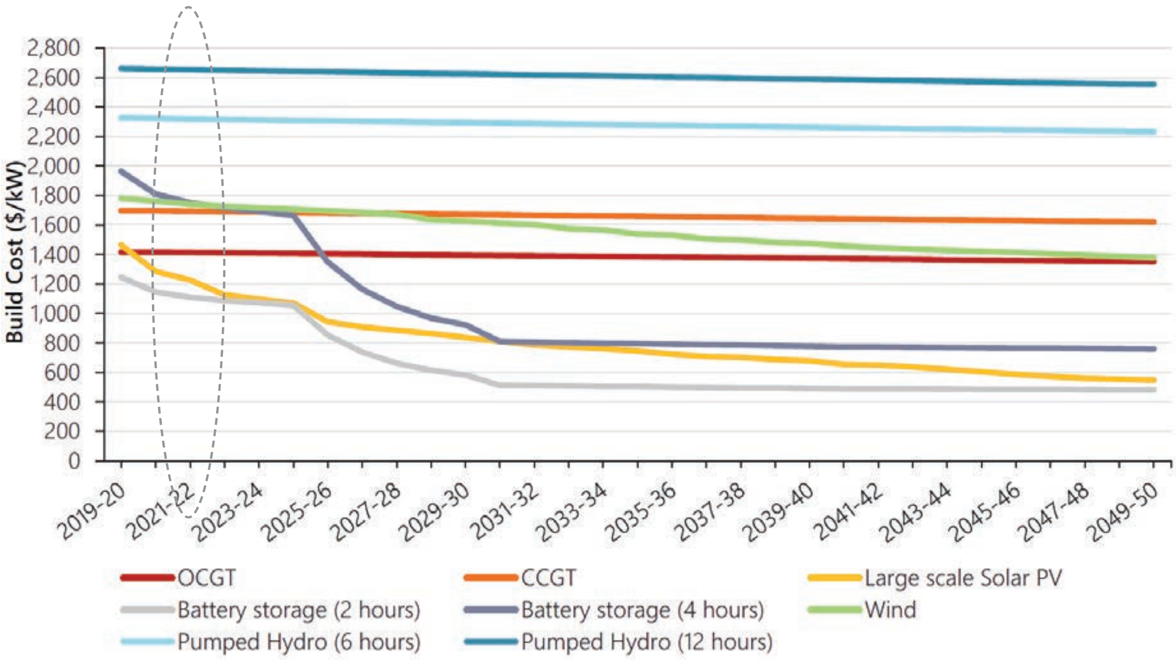
Recent analysis undertaken by the Clean Energy Council, based on the various scenarios included in AEMO's ISP, suggests that hydropower could provide up to 3000 jobs in the period up to 2030 across all ISP scenarios. Construction work is the main driver of these jobs and will fluctuate as new schemes are built.

This analysis found that a very high proportion of hydropower jobs are in regional areas, with more than 80 per cent of construction work and more than 90 per cent of operations and maintenance work expected to be local to the hydropower scheme.

Hydropower is capital intensive and needs a stable investment environment to flourish

Despite a clear need for flexible and dispatchable energy generation and deep storage assets such as hydropower and pumped storage hydro, there are a number of core investment challenges that need to be overcome. These relate to long lead times to construct plant, large capital expenditure requirements and future revenue uncertainty for investors.

While around 19 GW of new dispatchable energy such as battery storage and pumped storage hydro will be required by 2040[15], of the 15 GW of pumped storage hydro projects in the pipeline, only two projects with a capacity of 2.3 GW have progressed to financial commitment since the beginning of 2017. In that same period of time, 27 battery storage projects with a capacity of 1.5 GW have progressed to financial commitment.



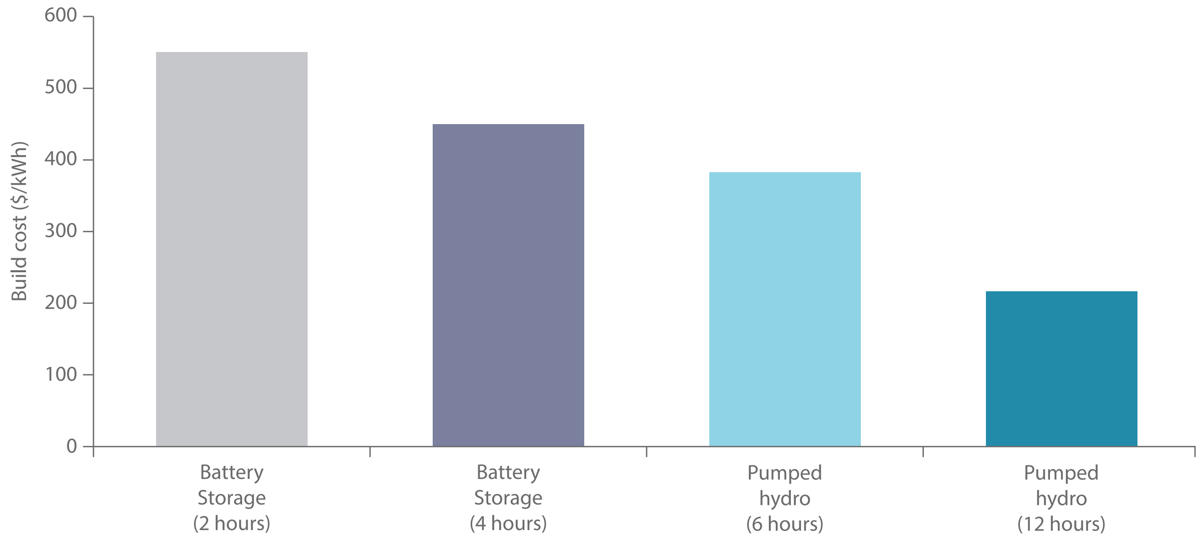


Figure 8: Build cost projection for selected technologies[16]

15 Australian Energy Market Operator, *2020 Integrated System Plan*, 30 July 2020, aemo.com.au/-/media/files/major-publications/isp/2020/final-2020-integrated-system-plan.pdf

16 Australian Energy Market Operator, *2020 Inputs, Assumptions and Scenarios Report*, 31 August 2020, aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2020/2020-forecasting-and-planning-inputs-assumptions-and-scenarios-report-iasr.pdf

50

average age of operating hydropower plants in Australia, in years

90%

of Australia's current hydropower generation comes from plants that are at least 30 years old

The difference in these deployment rates largely reflects the higher degree of complexity and costs of pumped storage hydro projects relative to battery storage projects, which can be readily designed and constructed within a two-year period. However, safe and stable decarbonisation of the electricity systems requires hydropower to act as a complement to battery storage.

Hydropower assets are long-lived generation assets. As outlined in Figure 8, pumped storage hydro is capital-intensive when compared with other technologies on a megawatt basis alone (top chart). However, once duration is accounted for, it is clearly the lowest-cost solution for storage durations of six hours or longer (bottom chart). Furthermore, as the majority of project costs are spent locally, pumped storage hydro brings significant jobs and investment to the communities in which projects are built.

In terms of new investment, supporting these kinds of capital-intensive assets requires properly designed market mechanisms to provide the stable signals needed to attract investors.

In terms of existing assets, signals are also needed to encourage operators to upgrade and maintain legacy plant. The average age of operating hydropower plants in Australia is around 50 years, with 90 per cent of Australia's current hydropower generation capacity coming from facilities that are at least 30 years old. On the basis that turbines will typically need to be replaced or upgraded every 50 years, many assets will need to make substantial financial investments within the coming few years to maintain reliable operation.

Other investments may be needed to upgrade legacy plants to enhance their capability so that they can provide the new services needed in a high renewables grid. For example, retrofitting turbines to allow them to operate in 'synchronous condenser' mode may help increase the rollout of wind and solar. Other alterations can allow existing plant to participate in markets for frequency control or system restart capability. In all these cases, effectively designed markets are critical to sending the right signals. The Clean Energy Council's preference is for the creation of markets to incentivise the provision of hydropower services. However, where market failures persist in delivering necessary investments, targeted government support that recognises the unique value of hydropower production is warranted.

To address these challenges, we encourage governments and policy makers to engage with the hydropower sector to identify, design and implement bespoke Australian approaches to facilitate hydropower investment. These mechanisms can be developed based on international experiences.

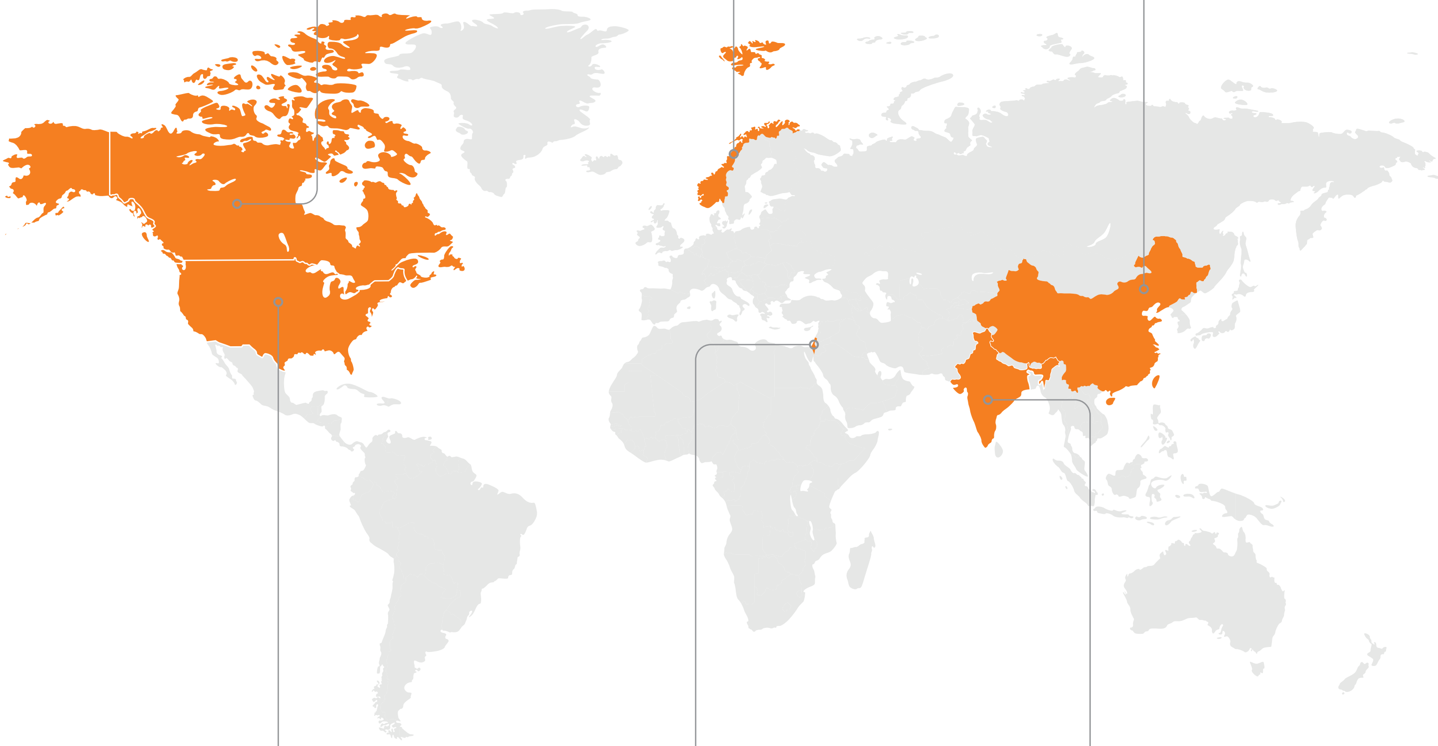
EXAMPLES OF INTERNATIONAL POLICIES AND RESEARCH MAXIMISING VALUE OF HYDROPOWER-RICH REGIONS

In recognition of the many benefits that hydropower can bring to the energy transition, various policies and mechanisms are in place around the world to support hydropower. Some aim to expand transmission capacity to allow existing hydropower assets to better serve nearby markets with high renewable penetrations (e.g. Norway), while others seek to incentivise the construction of new hydropower capacity to meet needs within the host country (e.g. Israel).

CANADA (QUEBEC)
Hydro Quebec is actively seeking opportunities to export energy and services from its hydropower fleet (e.g a 9.45 TWh p.a. 20-year deal with Massachusetts signed in 2018).

NORWAY
'European Clean Battery' concept seeks to leverage Norwegian hydropower resources to support wind and solar across Europe.

CHINA
Capacity and energy payments set on a project-by-project basis by government based on cost plus an agreed return.



USA (CAISO)
New Flexibility Resource Adequacy (FRA) mechanisms being introduced to incentivise assets with different ramping capability and operation durations.

ISRAEL
Government reverse auction process for 800 MW of long-term pumped storage hydro power purchase agreements (PPAs), with payments linked to availability and performance metrics.

INDIA
Long-term PPAs to provide peak power, combining wind/solar with firming such as hydropower.

Figure 9: International policies to support hydropower

What can we do here in Australia?

To enable a high renewables future for Australia's NEM, it is critical that we provide the right investment signals and market mechanisms to deliver the required investment in our hydropower assets and capitalise on the diversity of our natural resources.

Firstly, it is critical that regulatory arrangements send appropriate market signals for owners and operators of hydropower to **refurbish and modernise existing hydropower assets** to ensure they are fit-for-purpose in a high renewables future. This requires a degree of certainty that the assets will continue to be valued and utilised for the long extended lifetime enabled by refurbishment exercises. In developing regulatory frameworks to enable this, it is critical to reflect the particular reliability and security benefits associated with hydropower.

Secondly, new markets need to be created to reflect the true value of the particular services delivered by hydropower assets, such as medium- to long-period energy reserves and contributions to system security such as inertia and fault level.

Since its inception in 1998, the NEM has operated as an 'energy-only' market, supported by ancillary service markets. As the fleet of generation and storage resources change, **it is essential that market frameworks adapt to remain fit-for-purpose and continue to efficiently and cost-effectively deliver the services required** to underpin the safe, secure and reliable operation of the power system. There are a number of regulatory reform programs currently underway to value and remunerate these ancillary services, and the Clean Energy Council is working closely with the relevant market bodies to ensure that these market design processes are effective.

Finally, **we need to provide mechanisms and support programs to lower the risks of investment in new and existing hydropower assets**.

Hydropower projects are highly capital intensive and involve long construction timeframes. The current contract market in the NEM only provides forward price visibility approximately three years in advance. With construction periods for hydropower assets reaching to over five years, there is no way for developers to know what revenue stream their investment will achieve between the time that construction commences and commissioning.

Australia has an enormous opportunity to leverage its hydropower history and expand it further to meet the needs of an energy system increasingly dominated by variable wind and solar.

A modern and reformed energy market combined with targeted government policy and strengthened and new strategic grid interconnection are all critical to unlocking this enormous opportunity and setting Australia up to be a global renewable energy leader.

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