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NZ Battery Project
Indicative Business Case

FEBRUARY 2023

PREPARED BY ERNST & YOUNG

MINISTRY OF BUSINESS,
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Te Kāwanatanga o Aotearoa
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Glossary

Term	Description
BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
CSF	Critical Success Factor
D+C	Design and Construct procurement model
GHG	Greenhouse gas
GROS	Government Rules of Sourcing
ILM	Investment Logic Map
JV	Joint Venture
KPI	Key Performance Indicators
LSF	Living Standards Framework
MBIE	Ministry of Business, Innovation and Employment
MCA	Multi Criteria Analysis
MoU	Memorandum of Understanding
MPI	Ministry of Primary Industries
MYA	Multi Year Appropriation
NPV	Net Present Value
OECD	Organisation for Economic Cooperation and Development
RfP	Request for Proposal (phase of the procurement lifecycle)
SME	Small and Medium sized Enterprise
TBC	To be confirmed
TRM	Te Rōpū Matatau

Executive Summary

The Case for Change

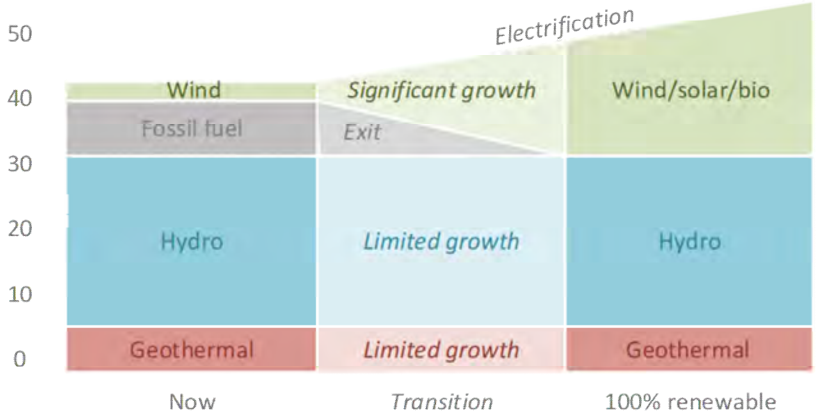
As part of our role in addressing the climate crisis, New Zealand is on a pathway to net-zero carbon emissions by 2050. Reaching this target will require urgent, coordinated, and transformational change across the economy.

The New Zealand Government has a legislated target of achieving net-zero carbon emissions by 2050, and an aspirational target for 100% renewable electricity generation by 2030. The Emissions Reduction Plan (ERP), released in 2022, also sets a target for 50% of total final energy consumption to come from renewable sources by 2035.

Decarbonisation of our electricity system is a key enabler of these targets. New Zealand's energy system contributes 44% of the country's total greenhouse gas (GHG) emissions and nearly 90% of total carbon dioxide emissions. Electrification of parts of the energy system, specifically transport and process heat, is one of the most effective ways of reducing these emissions. While electricity generation is already largely renewable, transitioning away from fossil fuel generation, which currently makes up around 15-20% of annual generation, will be key in achieving New Zealand's emissions goals.

Achieving these targets will require rapid phasing out of fossil fuels and the build out of renewable sources in their place. Together these shifts will require an unprecedented build of new renewable electricity generation, mostly wind, solar, and emerging technologies. A nearly 50% greater pace of build is needed than experienced during the country's 'think big' era.

Figure 1: Visual depiction of changes in the electricity generation mix over time



Finding solutions to manage security of supply and to maintain energy affordability are required on the path to 100% renewable electricity.

New Zealand, like all countries, faces the 'energy trilemma' – the challenge of achieving positive outcomes across the sometimes-competing pillars of energy sustainability, affordability, and security.

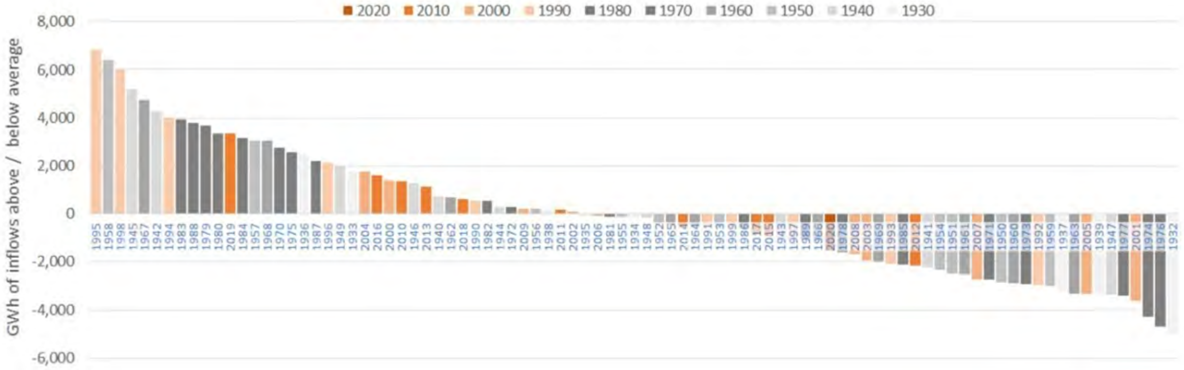
The NZ Battery Project was established to focus on maintaining security of supply, specifically during a 'dry year', while maximising renewable electricity in order to provide a pathway to achieve the goal of 100% renewable electricity. It must also remain cognisant of doing this in a way that maximises affordability for consumers and take into account wider social, cultural, and environmental factors.

Within New Zealand's existing electricity system, fossil fuels currently play a key security role in 'topping up' supply when renewable generation is low, and demand is high. This includes providing cover during extended periods of low hydrological inflows (due to prolonged periods of low precipitation) – these periods are known as 'dry years'.

The dry year problem is known to be large-scale, long-term, uncertain, and with no easy renewable solutions.

The term 'dry year' can be misleading. In reality, dry year events are extended periods of weeks or months in which reduced hydro inflows put pressure on the electricity system. Dry year events are dependent on weather patterns, and each is different. This makes them inherently uncertain and difficult to predict. Looking at historical data, we know the size of New Zealand's dry year problem is substantial – with shortfalls in electricity ranging between 3 – 5TWh over a period of several months. To put the scale of the shortfall in context, New Zealand currently consumes around 40TWh of electricity a year. A dry period may also extend beyond a year, or reoccur in quick succession. Figure 2 shows 89 years of hydrological inflows and the variation that can occur year-to-year.

Figure 2: Hydro inflows, by year since 1930 (compared to mean inflow)



Delivering this energy in the timeframe requires a powerful response. For example, making up for a 5 TWh energy deficit across a year requires a continuous response of around 600 MW, while making up for a 3 TWh energy deficit across a season would require around 1,400 MW – equivalent to New Zealand's existing flexible fossil fuel thermal capacity.[1]

The approaches for providing this cover are limited to four options: storing energy, importing energy (e.g. fuels), importing electricity through a connection to a neighbouring network, or reducing demand in line with supply (conservation campaigns aimed at encouraging voluntary electricity conservation by the public have been used in previous dry years). The scale and timeframe of a dry year means that demand-side solutions alone are unlikely to cover the deficit without significant social and economic impacts.

New Zealand is an isolated island, and our climate response targets require the phase out of fossil fuels. In order to achieve this, the aim of the NZ Battery Pis to find renewable storage solutions to the problem. ***The NZ Battery Project seeks to address the core problem statement: 'Failure to address dry year risk in an increasingly renewable electricity system will impose significant costs on New Zealand'.***

The electricity industry is doing a lot to help achieve a highly renewable electricity system – both the Climate Change Commission (CCC) and industry see a future of 95-98% renewable electricity being feasible under current settings[2]. However, it is widely accepted that making

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[1] Since 2015, NZ has had between 1,800-1,900 MW of thermal generation, of which 400 MW of this generally operates baseload (Genesis' E3P generator). Source: MBIE Electricity Data Tables.

[2] See, for example, BCG, The Future is Electric, 2022.

the final few percent of generation renewable will be difficult to achieve without government support.

Covering dry year risk and achieving security of supply without fossil fuels requires one or more large scale investments. The large upfront capital investment, coupled with infrequent and uncertain returns from operations, mean that these investments are unlikely to be commercially feasible in the current market without a significant increase in prices.

A future without targeted intervention in the form of the NZ Battery Project is likely to result in a spectrum of outcomes that falls somewhere between the following two scenarios:

- Future one: the electricity system is not decarbonised
- Future two: the electricity system is decarbonised, but security of supply and affordability are compromised.

Future one: the electricity system is not decarbonised

This would involve fossil fuels continuing to provide cover during dry years indefinitely, with no plans for a future with 100% renewable electricity. Commercial realities may mean fossil fuels would need to be used more broadly across the system – i.e. not just in a dry year. New Zealand’s electricity system would therefore continue to generate GHG emissions and contribute to climate change; and New Zealand would not reach its goal of achieving 100% renewable energy.

Future two: the electricity system is decarbonised, but security of supply and affordability are not achieved

In this future, the transition from ~95% to 100% renewable electricity would go ahead, but without specific investment in a renewable dry year solution. While there may be significant overbuild of renewable generation, dry years, as well as short- to medium-term variation in renewable supply, would result in increasing electricity shortage events and supply interruptions. The mismatch of supply and demand would cause higher trending prices on average and electricity price volatility. Individuals and households may experience unexpected loss of electricity supply, and more people may be unable to afford to pay for the electricity they need. Business and industry may experience outages and price volatility, resulting in lost production. These effects make electricity an unattractive way to power business processes, so industries may be less likely to electrify, slowing the shift of the wider energy system to renewables. Lack of electricity reliability and affordability would also likely make New Zealand a less attractive place to invest.

Success for the NZ Battery Project therefore means achieving security of supply, alongside affordable electricity, in a dry year, in an eventual future without fossil fuels. Doing so would have benefits for the electricity sector, electricity consumers, individuals and whānau, businesses and industry, and New Zealand as a whole. Successfully solving the dry year problem in a 100% renewable electricity system would facilitate the following benefits[3], when compared with a 100% renewable world without a battery solution in place:

- **It would reduce the risk of electricity supply outages or unexpected demand-side interventions caused by shortage of supply in a dry year**: this means individuals and

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[3] These benefits are a summary description of the benefits identified through Investment Logic Mapping workshops with key stakeholders.

businesses can rely on the electricity system to provide the electricity they need, when they need it, with benefits ranging from health and wellbeing to economic prosperity.

- **It would reduce the speed and magnitude of increases in wholesale electricity prices**: this means that all individuals and households across New Zealand are better able to purchase the electricity they need to support their health, livelihood, and comfort.
- **It would reduce price volatility**: the ‘smoothing’ effect of a NZ Battery investment means prices are less likely to ‘spike’ as much in response to scarcity, meaning businesses exposed to spot prices can predict and plan for likely electricity prices, providing a more favourable investment and business environment.
- **It would provide increased confidence in emissions reduction and increased renewable share of the wider energy system**: if energy-using businesses can rely on electricity being secure and reliable, they are more likely to favour electricity to power their processes, supporting decarbonisation through electrification. Depending on how a NZ Battery solution is operated, it could also put a ‘cap and collar’ on generation weighted average prices (GWAP) which can provide greater incentives to invest in renewable electricity generation. This is particularly true where the solution is a buyer of electricity in times of electricity abundance (typically when both wind and solar are generating or when wind is generating at night) as it will create a price floor providing generators with a return for electricity otherwise lost as spill. This will contribute to accelerated emissions reduction, electrification, and increased renewable share of both the electricity and wider energy systems.

The NZ Battery Project is just one element of the transition of New Zealand’s electricity system towards 100% renewables and the decarbonisation of New Zealand’s economy.

The project fits within a wider programme of work to contribute to New Zealand’s energy and climate change goals and aspirations. It aims to address an element that neither the market, nor policy or regulatory measures, are likely to solve on their own – the large-scale, long-term, and highly uncertain dry year problem.

The nature of this problem means a physical solution, in the form of infrastructure which delivers the necessary storage or flexibility, is required. This infrastructure is likely to have a long lead time to deliver, as well as to develop the required policy and regulatory settings to enable it. As such the NZ Battery Project must occur in parallel with, and cognisant of, the development of other energy strategy and policy work in order to meet our decarbonisation goals.

This Indicative Business Case is supported by a significant body of technical evidence – but uncertainties exist across all options.

The NZ Battery Project was set up with a predominant focus on the option of a pumped hydro scheme at Lake Onslow in Central Otago. This option has been raised as a potential dry year solution since as early as 2005. The project has also sought to identify alternative feasible options to address the dry year problem.

In support of this mandate, technical work to date has been significant. Robust investigations into the following items have supported the development of this Indicative Business Case:

- Significant engineering, environmental, and geotechnical investigations on the Lake Onslow option, including environmental, cultural, geotechnical, geological, and hydrogeological fieldwork

- A country-wide scan for possible other pumped hydro locations, followed by desktop feasibility studies of three alternative sites for hydro and pumped hydro schemes
- An initial feasibility assessment of 28 longlisted options, followed by further desktop investigation of five short-listed non-hydro alternatives
- Advice and analysis on Lake Onslow power systems connection, integration, transmission implications and resilience
- Studies on market integration, market economics (including expected gross benefits for all shortlist options), and the effect of climate change on hydro inflows.

Technical advice for the NZ Battery Project has been peer reviewed to provide assurance of the findings of the feasibility phase.

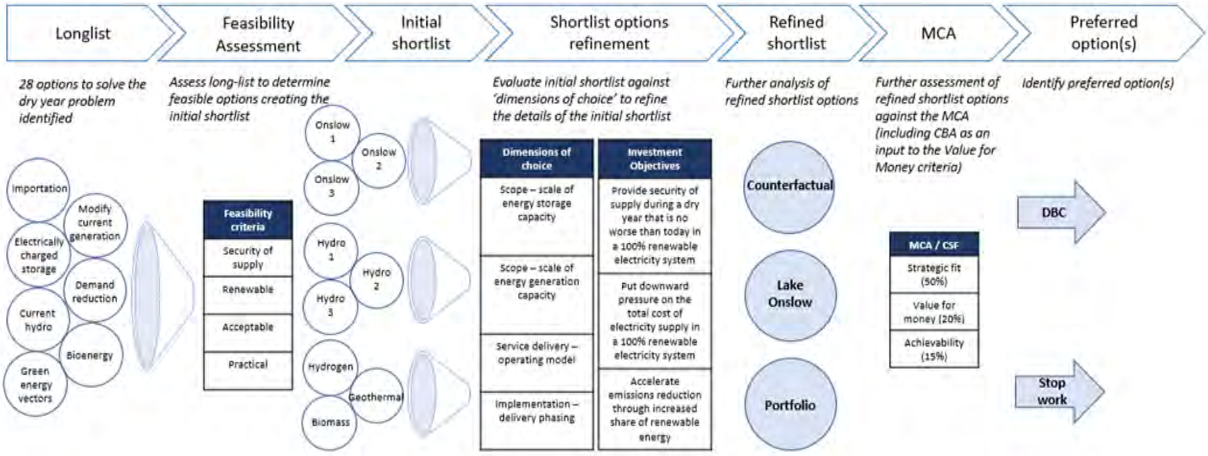
This significant body of work provides a strong evidence base to consider the Lake Onslow option. Thorough exploration of other options to expand hydro storage and technology alternatives to solve the dry year problem has also been undertaken, though investigations have not been to the same level of detail. This means there are differences in the certainty and depth of understanding of the various options which is a critical overlay to the conclusions drawn in the remainder of this IBC.

Choosing a preferred option

A robust economic assessment has been completed to select the options to take through to Detailed Business Case (DBC).

Given the magnitude of this investment, and its impact on society and the economy, it is important that, in determining a preferred option to solve the problem statement, a blend of 'tried and tested' Treasury tools are applied. A three-stage filtering process, using quantitative and qualitative economic assessment tools, has been used to derive the preferred options. The process followed is outlined in Figure 3 below:

Figure 3: Economic Assessment Framework



While a wide range of theoretical solutions exist to manage dry year risk, only five passed the feasibility test.

Around 30 longlist options have been explored through the project. These covered both physical and demand response solutions. However, when considered against three core feasibility criteria – "is the option able to provide a minimum acceptable amount of flexible electricity supply to support dry year management, is it renewable, is it practically feasible" (including technological, affordability and social license considerations) – only five solutions emerged. These were:

1. The Lake Onslow option
2. A pumped hydro scheme in the central North Island.
3. Flexible geothermal: involving developing geothermal generation and operating it in a flexible manner
4. Biomass: involving diverting logs from export, and then chipping and burning them in a combustion turbine to generate electricity
5. Hydrogen: involving the build out of electrolysers to produce green hydrogen domestically and then storing it as green ammonia

A wide range of supporting activities, including demand response, rooftop solar, and energy efficiency measures were seen as a critical part of the wider system – but did not credibly meet all feasibility criteria for an NZ Battery solution.

This shortlist of solutions was further refined and defined to identify two shortlist options.

Once the five solutions were assessed against the Investment Objectives and further refined – with consideration given to scale, operating models, ownership structure, and implementation timelines – two shortlist options emerged.

- A 5TWh, 1,000MW, pumped hydro solution at Lake Onslow.
- A ~2.4TWh, 1,200MW Portfolio option. Work to refine the shortlist demonstrated that none of the three alternative technologies could, on their own, produce the scale required to address the dry year problem. However, it was recognised that they could each form part of the solution. As a result, a Portfolio option made up of a mix of flexible geothermal, biomass peaker capacity, and an interruptible hydrogen facility was identified.

A 2.7TWh, 570MW pumped hydro solution in the North Island was also identified. However, insufficient information was available to confirm whether it is acceptable and feasible. This option was removed from further consideration at this time pending further engagement with iwi. Pending that engagement, further work would be required to better understand how it would interact with existing hydro schemes, and so its real economic potential.

The two shortlisted options were compared against a counterfactual world of a 100% renewable electricity system without a battery solution in place. The counterfactual contemplates a 100% renewable system with ~1,200MW of renewable ‘overbuild’. This includes the presence of enough ‘green peakers’ to fill the current peaking role played by fossil fuels, and the future need for peaking due to the increase in the frequency and severity of low generation periods due to the intermittency of wind and solar.[4]

A 12-criteria Multi-Criteria Analysis (MCA) was employed to select the preferred options. This analysis identified that a NZ Battery solution produced significantly better outcomes than the counterfactual. Of the two NZ battery options, the Portfolio option marginally outperformed the Lake Onslow option. However, given known

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[4] Green peakers are technology agnostic, renewable plant that could take the form of flexible generation, dispatch or demand response. E.g., biodiesel fired plant. Green peakers are an electricity market modelling tool used to balance the electricity market in a 100% renewable system. Green peakers are defined in greater detail at section 2.5.2.1.

uncertainties around delivery model, technology uncertainty and market appetite, it is recommended that both options be taken forward for further consideration.

The 12-criteria MCA is based on Treasury's critical success factors (CSF) framework. CSFs establish the elements that are essential for an option to successfully deliver the project in a way that satisfies the investment objectives and solves the problem statement. These are described in Table 1.

Within each CSF heading there are a range of sub-considerations essential to understanding the full impact of an NZ Battery solution. These considerations include:

- local environmental impacts,
- socio-economic impacts,
- the ability to retain option value, and
- resilience to shocks and stresses.

A monetised cost benefit analysis was also used to inform the 'value for money metric'.

No option performed strongly across all MCA criteria reflecting the size, magnitude and complexity of the problem to be solved. However, both the Lake Onslow and Portfolio options outperformed the counterfactual. Both are recommended to be taken forward for further work. A summary of their performance is provided below.

- Lake Onslow is the option that provides the greatest confidence in achieving security of supply objectives on the pathway to 100% renewables. The option carries significant cost implications but demonstrates slightly better value for money and affordability characteristics than the Portfolio option. In addition, more work has been undertaken to understand the cost implications of the Lake Onslow option, this provides greater confidence that the cost estimates are robust when compared with the Portfolio option which is comparatively less understood. However, Lake Onslow will have significant cultural, social, landscape, recreational and environmental effects.
- The Portfolio option was assessed as providing a credible way of achieving security of supply objectives on the pathway to 100% renewable while also retaining significant option value should newer and more effective technological pathways emerge. However, this option also has a poor benefit to cost ratio and affordability concerns. It also has significant uncertainties about the extent to which this option is realistic given that no market consultation has taken place, the lack of maturity of some of the technologies, and confidence in the development of necessary supply chains/markets. Better understanding these uncertainties should therefore be a core focus for further assessment of the Portfolio option.

A summary of the MCA results and the Cost Benefit Analysis are provided below.

Table 1: MCA Results

Treasury CSFs	Assessment Criteria	Weighting	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
Strategic fit and business needs (50%)	Confidence of security of supply	20%	-1	2	1

Treasury CSFs	Assessment Criteria	Weighting	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
	Pathway to 100% renewables	5%	0	3	2
	Retaining option value	5%	2	-1	3
	Reducing wholesale electricity prices	5%	0	3	3
	Reduced emissions	5%	0	1	0
	Socio-economic impacts	5%	0	-1	1
	Resilience to shocks and stresses	5%	3	0	2
Value for money (20%)	Potential value for money	20%	-3	-3	-3
Affordability (5%)	Affordability	5%	-1	-2	-3
Supplier capacity and capability (10%)	Supplier capacity and capability	10%	2	1	1
Potential achievability (15%)	Localised environmental impacts	7.5%	-1	-3	-2
	Legislative, regulatory and market risk	7.5%	0	-1	-2
Unweighted total		100%	**1**	**-1**	**3**
Weighted total		100%	**-0.48**	**-0.25**	**-0.20**
Rank			**3**	**2**	**1**

A range of sensitivities were assessed. In particular, value for money and benefit-cost ratio (BCR) calculations are particularly sensitive to changes in the modelling assumptions.

In two of the key sensitivities tested as part of the CBA, the BCR results for both options materially improved:

- NZAS stays: In a world where the New Zealand Aluminium Smelter (NZAS), or some similar South Island load remains, BCRs for the Lake Onslow and Portfolio options move from 0.42 to 0.66 and 0.40 to 0.54 respectively.
- Discount rate sensitivities: With the application of a sensitivity of a lower discount rate of 2%, the BCRs for the Lake Onslow and Portfolio options move from 0.42 to 0.75 and 0.40 to 0.54.
- NZAS stays and discount rate sensitivities: With the application of both sensitivities above being applied simultaneously, the BCRs for the Lake Onslow and Portfolio options move from 0.42 to 1.12 and 0.40 to 0.73.

A lower discount rate sensitivity is relevant given the multi-generational nature of the potential investment. ANZAS sensitivity has been included given the significant impact this has on near term electricity demand.

Options for ownership, operation, and procurement

There are feasible operating, ownership, and procurement models for the Lake Onslow option.

Procurement model

Due to the scale, cost, and complexity of a Lake Onslow build, Traditional, Design and Construct, Design / Construct / Maintain and Public Private Partnership procurement models are not considered feasible. These options do not allow for sufficient flexibility in design and would not give the time certainty required to give the right market certainty to electricity market stakeholders.

Pure Alliance, Competitive Alliance, Two-stage Early Contractor Involvement moving to Engineer Procure Construction (i.e., an ECI moving to an EPC), and Engineer Procure Construction Management are considered feasible options as they allow for innovation, risk to be appropriately allocated, and time certainty/shorter time to FID.

Ownership

Full Crown ownership and control, hybrid ownership, and mixed ownership are considered the most viable ownership models and have advantages in terms of their ability for risks to be efficiently allocated across the asset lifecycle, financing of the project, and the ability for future use options to be maintained.

Operating model

A range of feasible operating models exist for Lake Onslow, ranging from operation purely for security of supply to operating more actively in the market, within defined boundaries to maintain minimum storage volumes and minimise the impact of market power.

These operating models ultimately put different weights on the competing objectives of market power, confidence in security of supply, and commercial attractiveness.

It is possible that a variant of the market participation approach (a ‘virtual slicing model’) could be employed that supports wider electricity market access to energy stored in the facility. However regulatory oversight would be required to oversee operation of capacity auctions, ensure the facility is run in accordance with market rules and ensure that the operation of the facility does not allow any player to accumulate excessive market power.

There are options for the operation, ownership, and procurement for the Portfolio option, but they are less well understood and require further investigation.

Three high level approaches to the delivery of a Portfolio option have been identified – all with pros and cons. It is also possible that combinations of the below could be employed in practice.

- Crown procures reserve capacity generation assets – this would involve direct procurement of the generation assets themselves, which would be similar in approach to the Lake Onslow option
- Crown procures contracts for reserve capacity – this would involve procurement of reserve capacity on long term contracts that obligate the owner to hold generation capacity available for use in dry year or peaking events
- Development of a reserve capacity market – this would involve procurement of reserve capacity for specified periods of time through an open market.

Regulation of market participants - requiring electricity market participants to hold sufficient reserve capacity collectively for dry year and peaking cover - has also been identified as a potential intervention to deliver this option but is considered unlikely to be desirable.

Regardless of any option chosen, it is likely that there would need to be expanded regulatory oversight either in terms of a capacity market operator or regulator ensuring market participants hold sufficient dry year/peak cover.

A key step in implementing a Portfolio option would be testing the delivery options with market participants and ensuring electricity market stakeholders are well prepared for any eventual changes.

Understanding the financial impact

An investment in Lake Onslow would represent a significant commitment with multi-generational costs, revenues and benefits.

The expected financial cost of the Lake Onslow option over the modelling period of 42 years is outlined in Table 2 below. A 42-year modelling period is chosen to align with the information presented in the economic case. In practice this asset would have an operational life well beyond 42 years. Moreover, the analysis of the expected revenue impacts is highly aggregated. Detailed forecasts of the expected revenue profile would be a key focus of a DBC.

Table 2: Financial cost – Lake Onslow

Lake Onslow expenditure items Negotiations*, 1.0GW, 5TWh,* Commercial Infor*)*	**Estimated financial cost** ($'m, 42 yrs, nominal)
Construction CAPEX	15,493.3[5]
Transmission connection CAPEX	614.6[6]
Commercial Information	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

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[5] This figure excludes $190.3m of CAPEX which is scheduled to occur pre-FID (this is instead included in system administration costs below). Where pre-FID CAPEX was included, the Construction CAPEX figure would total $15,684m.

[6] This figure includes $25m for improvements to grid protection schemes in the South Island (to improve grid stability when Onslow is pumping) and $416.5m for a new substation at Onslow (connected to the three local 220kV lines), these costs have then been escalated for inflation to reach $614.56m.

Note, this figure excludes $286m (un-escalated) for a double-circuit 220kV line from the new Onslow substation to Benmore, plus duplexing of the Aviemore-Benmore line (to improve grid capacity between the Roxburgh region and Waitaki Valley) as these costs are expected to be paid through annual TPM payments. These costs have been included in transmission connection OPEX figures.

A range of potential funding, financing, and cost recovery mechanisms for Lake Onslow have been explored and most appear feasible – depending on the eventual option selected and the fiscal objectives that should be pursued.

The Commercial and Management Cases set out a preference for either partial or full Crown ownership. For the purposes of this IBC, the Financial Case assumes this is facilitated through a Schedule 4A company (under the Public Finance Act 1989). Under this structure, the Crown will need to provide a minimum 51% of the equity to fund the construction and operation of Lake Onslow. However, the value of this investment is not 51% of the total funding required. The total value of the Crown's equity position will depend on the capital structure and gearing ratio of the S4A. The remaining equity stake, and or debt, that makes up the eventual capital structure of the entity could then be provided by the Crown or by private investors.

Cost recovery would then be expected to be achieved through operating revenues, a levy imposed on electricity consumers, or through general taxation given the benefits that would accrue to all New Zealanders from the investment.

The specific funding, financing and cost recovery model would be explored through a DBC.

Portfolio option: Delivering the Portfolio option would also likely require significant investment, however further work is required to better understand the costs, revenues, and benefits of this option.

As noted previously, there is considerably more available and certain information about the Lake Onslow option than the Portfolio option at this point in time. As a result, it is not possible to explore the financial considerations for the latter to the same extent as the Lake Onslow option. As for the Lake Onslow option, there are a range of key decisions to be further investigated, particularly on refinement of the Portfolio configuration and potential delivery models. The outcomes of these decisions will also materially impact the funding requirements for the option. A summary of the potential financial costs of the Portfolio option over the modelling period of 42 years is outlined in Table 3 below. Further work would be needed in the next phase of the project to better understand the potential costs and revenues of a Portfolio option.

Table 3: Financial cost – Portfolio option

Portfolio *(Biomass, Geothermal and Hydrogen)*	**Estimated financial cost** ($'m, 42 yrs, nominal)
Construction CAPEX	13,275.8
Transmission connection CAPEX	363.7
Commercial Information	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
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Funding required to progress to Detailed Business Case and Final Investment Decision.

The IBC has developed cost estimates for progressing the NZ Battery Project to DBC and FID, based on Lake Onslow being the preferred option as there is greater certainty for what activities would be required. These estimates are preliminary and have not been informed by formal market sounding.

The IBC sets out a funding pathway to DBC estimated at $103.6M, including some property acquisition and pre-implementation activities. Commercial Information [redacted] The timing and nature of some activities is dependent on the work programme agreed by Cabinet, outcome of further analysis, and achievability given market constraints. Therefore, these costs are subject to change. At present, $69M has been appropriated for the next phase of the project. A DBC can be delivered on this funding. This would mean some Lake Onslow works that would otherwise be frontloaded before DBC being delivered in the post-DBC stage. However, there will be a need to commit additional funds to progress the NZ Battery roject from mid-2024. It is noted that:

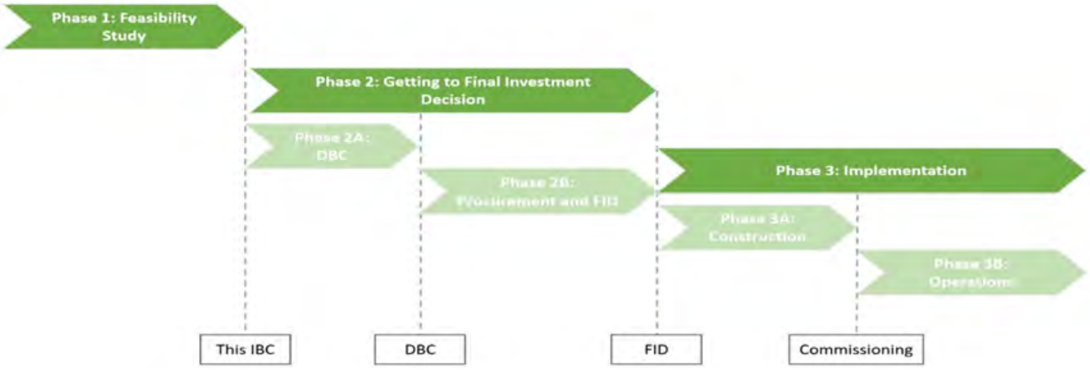
- The financial costs for FID have been developed based on Lake Onslow being the preferred option as there is greater certainty for what activities would be required.
- If another option is preferred at DBC, expenditure from FY24 onwards would need to be reconsidered.
- If at DBC a decision is made to stop work on the NZ Battery Project, expenditure from DBC to FID would not need to be incurred and expenditure up to DBC would be considered sunk.

Managing the delivery of the project

Continuing delivery of the NZ Battery project will differ depending on which options decision-makers choose to advance (i.e., whether Lake Onslow, the Portfolio solution, or both are advanced).

Cabinet set the project up in three phases – first, the Feasibility Study, to be concluded with a Cabinet decision in December 2022 on the preferred NZ Battery investment option(s) to take forward. This IBC has been developed to inform this decision. Phase 2 is focused on getting to a Final Investment Decision on the way forward into delivery, and Phase 3 is the implementation of that preferred option. The later phases are largely applicable to progressing a large infrastructure project like Lake Onslow option through procurement and construction. Implementing the Portfolio option might instead require a later focus on design and implementation of the preferred delivery mechanism.

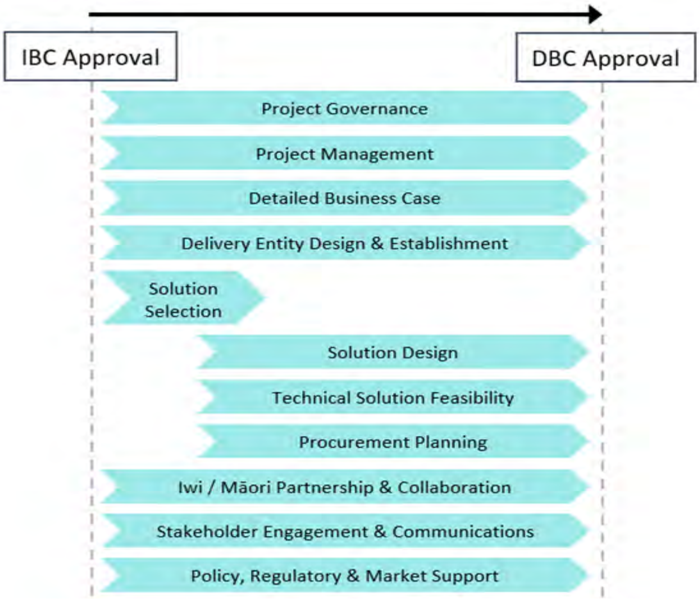
Figure 4: Phases of the NZ Battery project



Phase 2A, delivering the DBC, continues to require a high degree of ministerial oversight, as well as continuity from the current feasibility phase. This makes the current MBIE team well placed to deliver the DBC, supplemented with the additional capabilities and resources required for this phase.

Developing the DBC for Lake Onslow will leverage a broad range of activities, skills, advice, and investigations to continue to gather evidence and to confirm the preferred way forward. The next steps for the Portfolio option are to optimise the solution design and clarify the delivery mechanism. Subject to iwi engagement, the next steps for the North Island pumped hydro option are to determine whether it could have sufficient economic benefit to be worth investigating further.

Figure 5: Workstreams to get to DBC (Phase 2A)



The project will therefore need to be adequately resourced across policy, project management, engagement and partnership, investment, and technical competencies. This will involve building out the existing project team, from around 9 FTE currently to around 22-25 internal FTE, supported by consultant and contracted resources, to support the workstreams shown in Figure 5.

Following DBC, the focus of the project would shift to being more commercially and delivery oriented, with the sole objective being effective delivery.

International and New Zealand experience has demonstrated that delivery of major infrastructure projects benefits from the dedicated resourcing, autonomy, accountability, mandate, and ability to partner provided by an independent entity. The options for this will be further explored during DBC development, including broad engagement across and beyond government. If the DBC identifies the Portfolio option as the preferred option, the required resourcing and structure will need to be developed based on the recommended delivery model.

The NZ Battery project will require a focus on building strong relationships with iwi / Māori, as well as engagement with other stakeholders. The NZ Battery Project may continue for many years, so getting relationships right early will significantly benefit the project in the future.

The project is nationally significant, intergenerational, and has potential environmental and cultural impacts, so is of interest to many iwi / Māori groups. The NZ Battery Project has started to build relationships with interested iwi / Māori, particularly in relation to the Lake Onslow option. The project team will ensure iwi / Māori input into the project at all levels, to understand cultural impacts, integrate mātauranga Māori and identify opportunities for shared benefits.

Industry and other stakeholders have already identified the implications of uncertainty and speculation associated with the project, so a proactive approach is needed. The electricity industry will be regularly engaged with meaningful opportunities for input and feedback on the project as it develops.

Existing engagement channels will continue to be leveraged for locally impacted stakeholders for Lake Onslow, including landowners, local government, and communities. Media and public communications will focus on creating widespread understanding of the project and the challenges it is trying to solve.

The NZ Battery Project is large, complex, high-risk, and includes a broad range of workstreams.

The project will continue to be managed through the next phase using MBIE’s existing project management methodologies, tools, and controls. This includes risk, change, and benefit management approaches. Project management will be supported by a project management and corporate support team that will grow as the project size and complexity increases. Governance of the project has been fit for purpose to date but should be enhanced for subsequent stages of work to ensure effective steering and advisory support is in place.

1. Strategic Case | The Case for Change

Summary

The case for investment stems from a complex combination of physical, policy, and market factors, within New Zealand's unique electricity system context. New Zealand derives a significant proportion of electricity from hydro generation, which supports a highly renewable electricity system. However, this introduces a need to compensate for lower hydro generation when inflows to the reservoirs are low due to weather conditions (known as 'dry years'). The dry year problem is currently managed using fossil fuel thermal generation, which can be flexibly scaled up using stored or imported fuels to cover low hydro generation and ensure electricity supply continues to meet demand. As New Zealand transitions away from using fossil fuels and moves along the path to 100% renewable electricity, a different solution is needed to provide this dry year cover and ensure continuous security of supply.

A renewable alternative to cover dry years provides greater certainty about how a future highly renewable electricity system will function, and particularly how supply and demand will be balanced without the use of fossil fuels. This provides greater confidence for market investment in renewable generation, for decarbonisation through electrification, and for foreign and domestic investment in New Zealand industry.

Failure to act would have implications for all New Zealanders. Without an alternative dry year solution to fossil fuels, New Zealand would be unable to meet its renewable electricity aspirations without a range of negative consequences (for example, increased frequency of electricity shortage, increased reliance on demand curtailment etc.). This would bring associated economic and reputational impacts. Removing fossil fuels without an alternative solution for dry year cover would result in reduced security of supply, experienced through increased risk of shortage, more supply interruptions, unplanned demand curtailment, increasing price volatility, and unaffordable electricity costs. This has implications for the physical and financial wellbeing of New Zealanders and creates an unattractive environment for future investment.

Given the scale of the energy deficit in dry years, a solution needs to be able to deliver a significant amount of energy over a long period (around 3 – 5TWh over several months). This requires a significant upfront investment. Coupling significant upfront cost with the inherent uncertainty and infrequency of dry year events (and therefore potential revenue) means there is currently limited commercial incentive for private investment in solving the dry year problem and achieving the final shift to 100% renewable electricity. A dry year solution is also likely to have a long lead time, so waiting for the market to provide sufficient commercial incentive for investment is likely to mean the problem is not solved for an extended period of time.

The purpose of this Strategic Case is to outline the case for investment in a dry year solution in a 100% renewable electricity system. This investment is intended to help maintain a reliable electricity supply as New Zealand's electricity system moves away from fossil fuels, in line with the government's climate change and sustainability goals. This Strategic Case includes:

- A description of the origin and mandate of the NZ Battery Project, including the scope and key objectives of the project
- Identification of the key problem(s) the investment is intended to solve and the benefits to be delivered by the project
- Contextualisation of how the NZ Battery Project fits into government's energy and climate change strategic and policy agenda and wider government objectives.

1.1 Overview and background

1.1.1 Origin of the NZ Battery Project

In 2018, New Zealand's Interim Climate Change Committee (ICCC) provided advice to the Government on planning for the transition to 100% renewable electricity generation. The ICCC's April 2019 report, *Accelerated Electrification*, identified that a key challenge in reaching 100% renewable electricity is addressing 'dry years'. The report defined this as the shortfall in electricity generation that can occur in a year where inflows to hydro reservoirs are below average. This is a particular challenge for New Zealand because of the comparatively high proportion of electricity generated by hydro, and the lack of connection to other electricity systems (i.e., New Zealand does not have an electrical connection to another market to provide dry year cover).

The ICCC's modelling identified that achieving 100% renewable electricity is technically feasible by 'overbuilding' renewable generation, substantially increasing battery storage, and relying more on demand response. Overbuilding is considered a feasible way to achieve 100% renewable generation as it makes use of mature and well understood technologies (wind and solar) that can be built at scale under existing market and regulatory settings. Overbuilding refers to building sufficient intermittent capacity (like wind and solar) to balance the market in all scenarios, including when electricity output is low due to natural variation. Sufficient wind and solar generation is built to cover dry years, as well as shorter term calm and cloudy periods, which requires significantly more capacity than would otherwise be necessary to cover normal day-to-day demand. The ICCC concluded that renewable overbuild would be costly, would lead to significant energy wastage during normal times, would be reliant on high electricity prices, and would require significant levels of shortage and demand response.[7]

Given the negatives of renewable overbuild, the ICCC examined alternative ways to achieve security of supply with 100% renewable electricity. This investigation identified a range of promising alternatives to solve the dry year. These included:

1. The development of a large-scale pumped hydro scheme at Lake Onslow in the Otago region of the South Island. This requires the creation of a dam at Lake Onslow with a tunnel to the Clutha River (between which water is pumped and released). Desktop engineering assessments first identified the potential for a pumped hydro scheme at Lake Onslow in 2005[8]

2. Biomass and hydrogen schemes. These alternatives were considered suitable candidates for ongoing research and development.

Based on these findings, the ICCC recommended that the Government should investigate, as a priority, the potential for pumped hydro storage to address the dry year problem.

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[7] Interim Climate Change Committee. (2019). Accelerated Electrification – Evidence, analysis, and recommendations.

[8] Bardsley, W.E. (2005). Note on the pumped storage potential of the Onslow-Manorburn depression, New Zealand. Journal of Hydrology (NZ) 44 (2): 131-135.

In response, the NZ Battery Project was established in July 2020 and received funding from Cabinet for investigative work as part of the 'Shovel Ready' Infrastructure Reference Group infrastructure investment programme. The project team was established within the Ministry of Business, Innovation, and Employment (MBIE) in December 2020, and a Technical Reference Group was established in April 2021 to provide the project team with independent expertise, sector knowledge and advice.

1.1.2 Scope of the NZ Battery Project

The purpose of the NZ Battery Project is to investigate options to resolve New Zealand's dry year problem within the context of a transition to a 100% renewable electricity system.[9]

Currently, the shortfall during dry years is covered by coal and gas fired generation. Identifying feasible renewable alternatives is a key challenge in achieving a 100% renewable electricity system and the focus of this project. The primary objective of the project is to assess the viability of pumped hydro at Lake Onslow and to consider this solution against alternative options and technologies if identified.

The NZ Battery Project is just one part of the Government's work programme to decarbonise New Zealand's economy and transition the energy and the electricity system towards a greater share of renewables. It sits within the context of the Government's:

- Legislated target of achieving net-zero carbon emissions by 2050, contained in the Climate Change Response Act 2020, and
- Aspirational target of 100% renewable electricity by 2030.

Several challenges need to be overcome to achieve the 100% renewable electricity target. New Zealand needs to retire or repurpose over a gigawatt (GW) of existing fossil fuel-based generation. At the same time, an unprecedented build of new renewable generation will need to be achieved, in a way that maintains electricity affordability and prices that encourage fuel switching and decarbonisation of the wider economy. Work is underway across government and within the electricity sector to address these challenges.

Within this context, the NZ Battery Project is focussed specifically on supporting New Zealand's electricity system to maximise renewable electricity through providing a renewable security of supply solution to the dry year problem.

1.1.3 Security of supply

Security of electricity supply is a challenge that all countries face, with the nature of the challenge varying depending on the make-up of electricity generation and supply, and the ability to import energy. The problem spans a temporal spectrum, with security risks occurring across timescales, from seconds and minutes through to seasons and years, as shown in Figure 6. The properties of electricity security**Figure 6** include:

- **Operational security**: the ability of the electricity system to maintain or, after disturbances, regain an acceptable state of operational condition, covering dynamic and real-time system management issues
- **Flexibility**: the ability of the electricity system to cope with short- and medium-term variability of generation and demand, so that the system is kept in balance

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[9] Office of the Minister of Energy and Resources. (2020). Cabinet Paper: December 2020 Update on the NZ Battery Project.

- **Resilience**: the medium-term capability of the electricity system to absorb the effects of any disruption and recover a certain performance level
- **Adequacy**: the ability of the electricity system to supply adequate electrical demand at all times under normal operating conditions, including generation, storage, transmission and distribution network, import, market, and end user adequacy.

Figure 6: Electricity security properties and timing dimensions

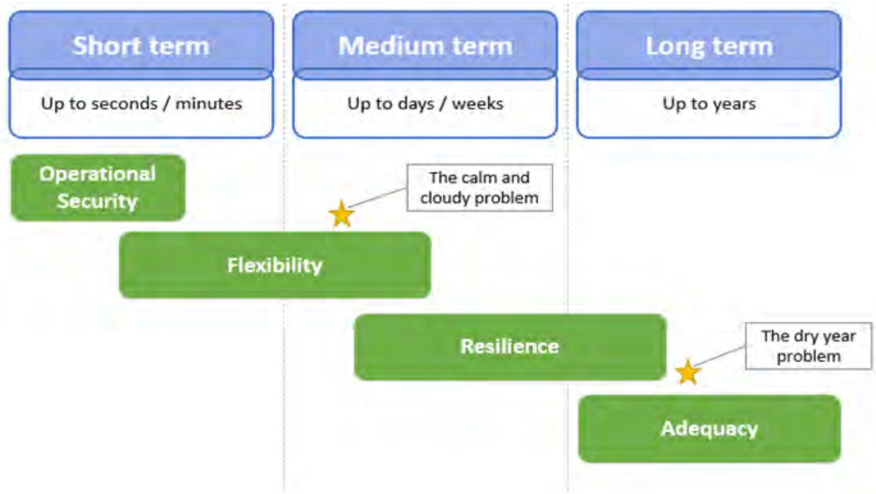


Figure 6 also shows two of the key electricity security problems associated with having a high level of renewable generation in the electricity system:

- There is emerging understanding of the **calm and cloudy problem**, which occurs because of the short to medium term variability in the availability of sunshine and wind for solar and wind generation. As these types of renewable generation make up a greater proportion of a country's electricity stack, calm and cloudy periods pose a growing problem for security of supply
- The **dry year problem**, associated with longer term variability in the availability of hydro generation due to seasonal and yearly variation in hydro inflows.

Moving further along the pathway to 100% renewable electricity and relying more heavily on intermittent renewable generation will exacerbate short- to medium-term security of supply challenges, like the calm and cloudy problem.

The NZ Battery Project was established to identify a renewable solution to the long-term security of supply challenge of dry year risk. However, in many cases, a solution that provides dry year cover will also provide increased flexibility and help balance shorter term variations in supply. While this is not the primary focus of the project, such benefits can be significant and have been considered in the assessment of different options.

1.1.4 Cabinet criteria for assessing NZ Battery Project options

In December 2020, Cabinet agreed to a set of criteria against which options for the NZ Battery investment should be assessed. These are the ability for the project to:

- Provide a sufficient level of energy storage or equivalent energy supply flexibility to cover the magnitude of the dry year problem based on future projections for electricity supply and demand
- Reduce emissions, either directly or indirectly through facilitating decarbonisation

- Maximise renewable electricity in order to provide a pathway to achieve the goal of 100% renewable electricity
- Lower wholesale electricity prices
- Provide employment opportunities
- Be practical and feasible
- Cabinet also noted that the assessment of any option should take into account wider social, cultural, and environmental factors.

The NZ Battery Project team has used these criteria as guiding considerations for identifying and assessing potential solutions that could be feasible alternatives to pumped hydro at Lake Onslow, and for comparing the options. More detail on how these principles have been used in practice is provided in the Economic Case.

1.1.5 Evidence Base

There is a considerable technical evidence base that underpins this IBC. Procurement for technical advice and investigations to support the identification and assessment of a range of NZ Battery options began in February 2021. A list of technical advice provided is included in Appendix A. Briefly, this evidence includes:

- Significant engineering, environmental, and geotechnical investigations on Lake Onslow pumped hydro, including environmental, cultural, geotechnical, geological, and hydrogeological fieldwork
- An initial feasibility assessment of 28 longlisted options, followed by further desktop investigation of five short-listed non-hydro alternatives, and a more detailed investigation of three non-hydro options deemed to be the most feasible for dry year support
- A country-wide scan for possible pumped hydro locations, followed by desktop feasibility studies of three alternative sites for hydro and pumped hydro schemes
- Advice on power systems integration, resilience, and interface with the NZ Battery Project
- Studies on market integration, market economics, and the effect of climate change on hydro inflows.

Key pieces of technical advice for the NZ Battery Project (including cost estimates for all shortlist options) have been peer reviewed to provide assurance of the findings of the feasibility phase. In addition, this IBC has also gone through the Gateway assurance process and has incorporated findings from that review to ensure it is robust.

At a high level, the investigations noted above have provided the following inputs to this Indicative Business Case:

- An improved understanding of the size and nature of New Zealand’s dry year problem and how it will develop over time
- A thorough understanding of the feasibility of Lake Onslow pumped hydro, including early design configuration options, and initial assessments of potential environmental, social, and cultural impacts
- A high-level understanding of alternative locations for pumped hydro that could be developed to the scale required

- An understanding of what other technologies could play a significant role in addressing the dry year problem and others that are unable to be developed to the scale required
- An initial understanding of how a battery may operate, including costs and revenue streams
- The impacts a battery would have on the electricity market and generation stack, depending on operating models, including prices and volatility, incentives for investment, amount of generation needed, amount of generation spill, and transmission implications.

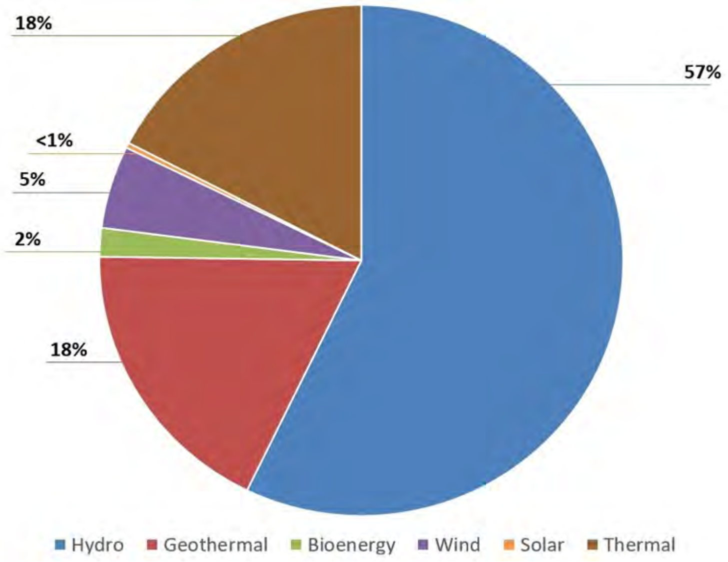
1.2 Strategic context

The NZ Battery Project fits within a framework of strategies, policies, and initiatives ultimately aimed at meeting New Zealand's target for net-zero carbon emissions across the economy by 2050. The NZ Battery Project is consistent with, and in some cases a key enabler for, New Zealand's climate change and energy objectives. This section provides an overview of New Zealand's existing electricity system, the current climate change and decarbonisation policy and strategy framework, what this means for New Zealand's future electricity system, and the role of the NZ Battery Project within this context.

1.2.1 The dry year problem is a feature of New Zealand's current electricity system

The New Zealand electricity market currently derives a significant proportion of generation from renewable sources. Over the five years to March 2022, the share of renewable generation (four-quarter moving average) has ranged from 79-86%, averaging 82%, with the remainder being provided by thermal sources (coal, gas and oil).[10] New Zealand's average electricity generation, from March 2017 to March 2022, is shown in Figure 7.

Figure 7: New Zealand net generation (March 2017 - March 2022)[4]



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[10] MBIE. (2022). Electricity Statistics. Note, these figures include cogeneration.

Hydro provides the bulk of New Zealand's generation but varies seasonally and yearly, depending on weather conditions. Wind and solar are intermittent sources of electricity whose ability to generate can fluctuate considerably depending on levels of wind and sunshine. The natural fluctuation in these forms of renewable generation can occur across a range of timescales, from minutes to years. Geothermal provides a renewable source of constant uninterrupted (baseload) generation year-round.

Thermal electricity generation predominantly comprises coal and natural gas fired generation. Most coal used for electricity generation is imported, while gas is typically produced domestically. Thermal generation use fluctuates in response to factors like cost and supply of renewable generation, fuel prices, and plant maintenance and availability. Alongside these variations in electricity generation on the supply side, electricity demand is also constantly changing, both within the day (as shown in Figure 8) and across seasons (as shown in Figure 9).

Figure 8: Electricity demand variation - daily[11]

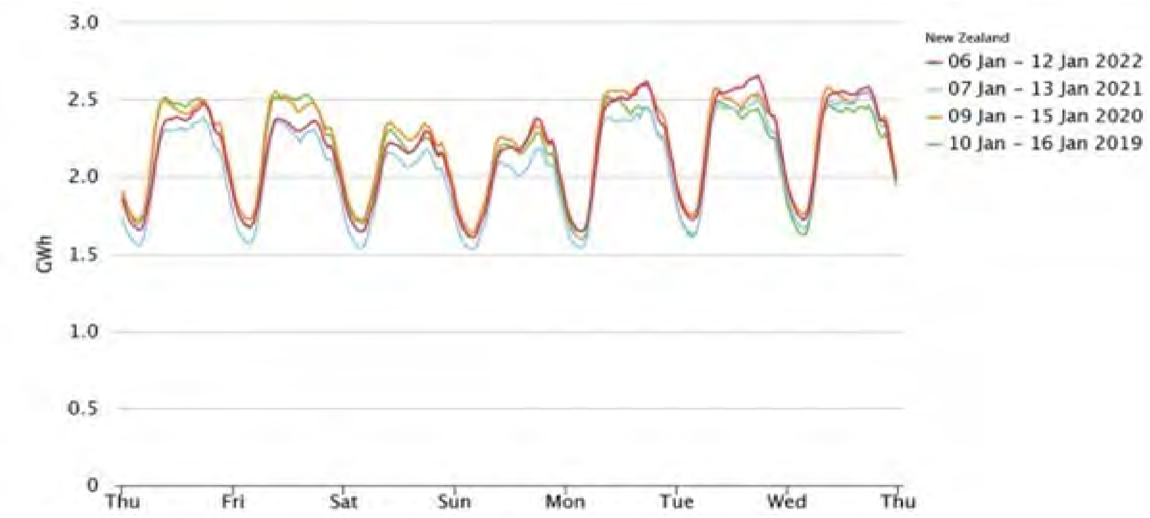
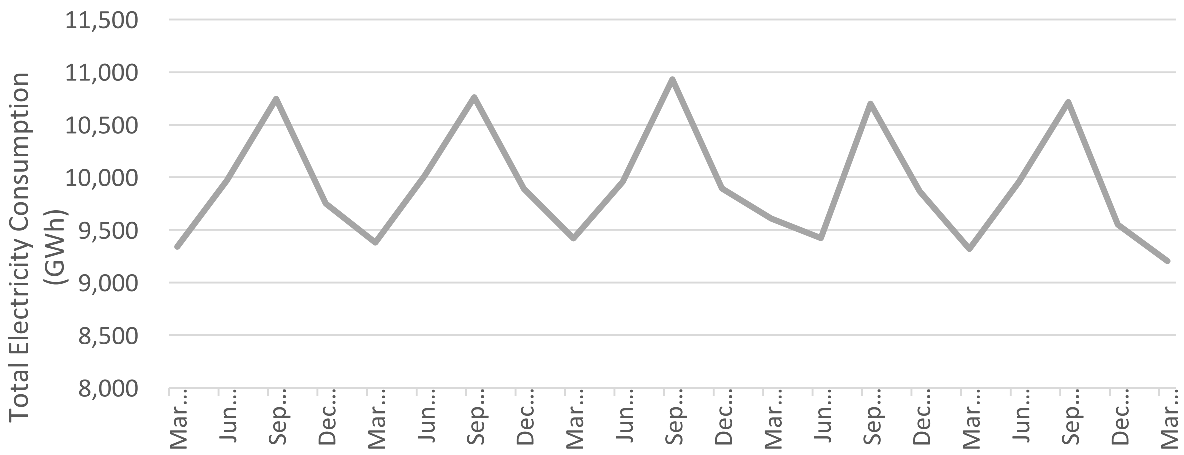


Figure 9: Electricity demand variation – seasonally[12]



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[11] Electricity Authority. (2022). Adjusting to New Zealand's Changing Electricity Future Market Insights.

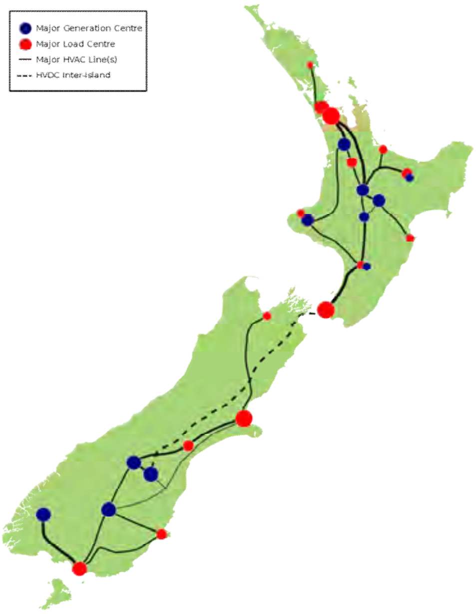
[12] MBIE. (2022). Electricity Statistics.

Given there is continual variation in both supply and demand, the electricity system requires constant management to ensure that demand is met by sufficient supply. Electricity prices continually update to reflect variations in offered supply costs, and pricing plays an important role in signalling the need for more supply to meet demand over multiple timescales.

As thermal generation is readily available, provided plant are operational and there is adequate fuel stored or able to be supplied on demand, it provides a source of on-demand generation. Fast start thermal generation (some gas turbines) along with the peaking ability of hydro generation helps balance short-term intermittent generation profiles (firming). Thermal generation also plays a key role in covering periods of low hydro inflow.

Most of New Zealand’s electricity is generated at remote locations, where natural resources are available, and requires an efficient transmission system to transport it to main demand (large population) centres. In particular, a significant proportion of large-scale generation (predominantly hydro) is located in the South Island, while most large demand centres are in the North Island. The locations of major generation and load centres, and the major transmission network connecting them, are shown in Figure 10.

Figure 10: New Zealand's electricity network, showing major demand and load centres[13]



Hydro generation plays a uniquely important role in New Zealand’s electricity system. Hydro contributes 55-60% of New Zealand’s electricity generation on average, allowing New Zealand to have a relatively high proportion of renewable electricity. Hydro generation is susceptible to variation in inflow year-to-year, dependent on levels of precipitation. This variation is entirely dependent on inherently uncertain weather conditions, so is difficult to forecast or predict. There are two main types of hydro generation schemes:

- ‘Impoundment’ schemes: these involve a reservoir as the water source, either naturally occurring (i.e. a lake) or man-made (typically created by damming of rivers). These schemes are characterised by the ability to store water and to control flows exiting the reservoir

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[13] Philpott, A., Read, E., Batstone, S., & Miller, A. (2019). The New Zealand Electricity Market: Challenges of a Renewable Energy System. IEEE Power and Energy Magazine 17(1).

- ‘Run-of-river’ schemes: these schemes take a proportion of the natural river flow by way of a weir or diversion channel and leave a residual (environmental) flow in the river. Water is discharged back to the river, returning flow volumes to normal. These schemes have little to no storage capacity.

New Zealand’s hydro plants include a combination of these two schemes, but even the impoundment scheme reservoirs tend to be relatively small and have limited storage capacity (in the range of weeks to months). The total combined theoretical maximum storage capacity of New Zealand’s hydro reservoirs is approximately 4.5 TWh,[14] with 85% of this in the South Island. This is less than 20% of the annual inflows to the hydro reservoirs or around 11% of New Zealand’s total current electricity demand.

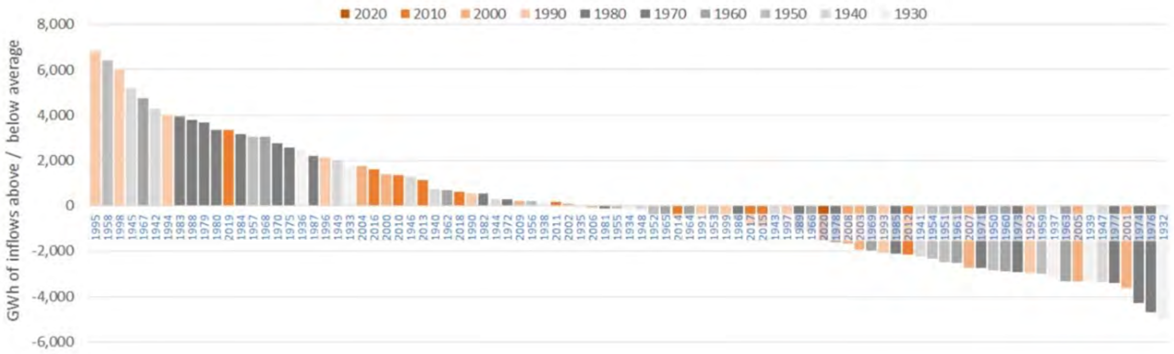
Due to New Zealand’s high proportion of renewable generation with low short-run marginal costs (SRMC), prices are set based on the interplay of hydro and thermal generation. The open competitive electricity market results in maximised use of (operationally) cheap hydro generation, and minimised use of more expensive thermal generation, subject to maintaining a healthy hydro reserve. When reservoirs are relatively full or there is an expectation of large inflows into the reservoirs, the future value of the stored water (water value) is low and therefore allowed to be converted to electricity at a significant discount to thermal generation. In this scenario, hydro will provide a baseload level of generation and put downward pressure on electricity prices. On the other hand, when reservoir levels are relatively low or there is an expectation of reduced inflows into reservoirs, water values will be high, incentivising storing of water in reservoirs and increasing use of thermal generation.

During extended dry periods, hydro generation switches from a baseload energy provider to an increasingly capacity firming role. Water is conserved in reservoirs during the night and middle of the day and offered into the market when demand peaks in the mornings and evenings. The energy deficit remaining is filled by thermal generation, including the dual-fuelled gas / coal powered Huntly Rankine units, and our gas-only turbine fleet.

1.2.1.1 New Zealand’s reliance on hydro means the ‘dry year’ problem is an important security of supply concern

Hydro generation is subject to year-to-year variability caused by changing precipitation levels, as shown in Figure 11. The lowest recorded hydro inflow (in 1932) was 5 TWh below average, while a more typical low flow year sees inflows around 3 TWh below average. As a comparison, New Zealand currently consumes around 40 TWh of electricity a year. New Zealand’s largest existing reservoir (Lake Pukaki) has a maximum storage capacity of just under 1.8 TWh of useable storage and 0.5 TWh of contingent storage and, as stated above, all existing reservoirs combined have a theoretical maximum storage of 4.5 TWh.

Figure 11: Hydro inflow per year, wettest to driest



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[14] Transpower. (2022). Security of Supply and ERCs – Hydro Information.

A simple definition for the dry year problem is a year in which reduced hydro inflows put pressure on the electricity system.

However, despite the name, a ‘dry year’ may only last for a few months. Given limited storage, the electricity system can be similarly stressed by a short period of reduced inflows, particularly if it exacerbates a divergence that normally occurs in winter between electricity demand and hydro inflows. In winter, demand increases with more heating and lighting load, while hydro inflows decline because precipitation falls as snow rather than rain that flows to catchments. To match demand and ensure they can maintain electricity supply through winter, hydro generators rely on storing inflows that come ahead of winter.

A dry period may also extend beyond a year or reoccur in quick succession. For example, 2007 was dry across the full year, with hydro storage drawn down through winter and unable to meaningfully recover through spring and summer. The dry period worsened further through 2008, when the system impacts of this dry period were experienced most severely.

Furthermore, the system can also be stressed by years that are not especially dry. A dry year event is the result of a combination of factors beyond just hydro inflows. Other factors influencing whether an event is characterised as a dry year include the impacts on individual catchments or generators, hydro storage levels leading into a dry period, levels of demand, other fuel constraints or generation outages, and overall system configuration and supply adequacy.

As evidenced above, there is no simple definition of the dry year problem. Each dry year experience is quite different, and there are few patterns. This makes dry years hard to forecast and difficult to detect even as they are happening. Given the uncertainty of future inflows, action often needs to be taken before a dry year fully materialises. This means that in some cases, dry year action is taken, but subsequent rainfall solves the problem before it becomes a dry year.

Past dry years have typically been characterised by high electricity prices and above average use of thermal generation, as scarcity of water is priced into the market influencing generation choices. As shown in Figure 12, dry years in 2008, 2012, 2017, 2020, and 2021 correlate with relative price spikes.

Figure 12: Electricity market price (demand-weighted average) over time[15]

The high prices that can occur in dry years affect the price that most consumers pay for electricity in all years. This is because hydro variability and uncertainty creates a risk that the market will be unable to manage the conditions that eventuate, and that very high prices will result. By paying a fixed price for their electricity, most consumers are paying a premium to insure against the risk of future scarcity causing sustained and extreme high prices.

In some instances, dry years have previously been managed using conservation campaigns aimed at encouraging voluntary electricity conservation by the public of up to 10% of total electricity demand. Conservation campaigns were used in 1992, 2001, 2003, and 2008. Subsequent policy interventions have prevented these being used as readily as they were in the past.

The latest dry year event was experienced in 2021, when low rainfall caused low hydro inflows and declining hydro storage. This coincided with gas supply pressures, which reduced gas availability for electricity. While a public conservation campaign was not initiated, several demand management actions, including agreements between generators and major industrial electricity users, helped to address the situation. The heavy reliance on thermal generation during this time exacerbated already high wholesale electricity prices and resulted in the highest proportion of coal fired generation since 2013.

Overall, while dry year events are complex to define and detect, historical observation suggests that periods of low hydro inflows could require cover of between 3 and 5 TWh, over a period of several months. Delivering this energy over that period of time requires a powerful response. For example, making up for a 5 TWh energy deficit across a year requires a continuous response of around 600 MW, while making up for a 3 TWh energy deficit across a season would require around 1,400 MW – equivalent to New Zealand’s existing flexible thermal capacity.[16]

A dry year in the current system results in a combination of demand management, electricity price increases, and increased use of thermal generation. Public calls for voluntary conservation start when the risk of shortage exceeds 10%, and rolling outages are implemented if voluntary conservation is insufficient. Greater use of New Zealand’s thermal plant is currently the most economical solution to cover the supply deficit caused by low hydro generation, as it makes use of fossil fuels that are easily stored and/or have a flexible supply source.

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[15] Electricity Authority. (2022). Electricity Market Insights – Wholesale price trends.

[16] According to MBIE Electricity Data Tables. Since 2015, NZ has had between 1,800-1,900 MW of thermal generation, of which 400 MW of this generally operates baseload (Genesis’ E3P generator).

1.2.1.2 Importance of price in the electricity market

As described earlier in the Strategic Case, the electricity market is constantly managed to ensure (as best as possible) that the market always clears (i.e., supply always meets demand). As with most financial and energy markets, the mechanism by which the market clears is price. Price acts as a proxy for the relative supply vs demand of electricity at any point in time. Where demand outstrips supply, the price increases both as a function of market allocative efficiency principles, but also as higher SRMC generation sources are progressively brought online to meet marginal demand.

Prices also have a secondary importance in the electricity market as an investment signal. When prices are consistently high (above the SRMC of new generation) this creates a signal for generators to invest in additional generation capacity.

Therefore, high and low electricity prices both have benefits and trade-offs. Low prices mean a lower cost of electricity for consumers but potentially reduce incentives for new generation investment. Alternatively, high prices have implications for electricity affordability but create economic incentive for additional investment. However, it is important to remember that markets are not perfect. Investment in generation is not only a function of price – it is also a function of other factors such as availability of land, resources, technology, capability, competition, barriers to entry, access to capital and labour etc. In addition, generation investment is not instantaneous. Additional generation takes time to build and principles of economies of scale also apply – often additional generation capacity is built in blocks rather than as standalone assets that meet marginal demand. This can dull the connection between price and investment and mean that prices can fluctuate significantly over the short to medium term, as the market moves between states of relative overbuild to scarcity of supply.

1.2.1.3 The emerging 'calm and cloudy' problem

The calm and cloudy problem refers to extended periods (of days to weeks) when there is minimal or no sunshine and wind to support solar and wind generation. Like the dry year problem, this is entirely the result of weather patterns, so is uncertain and unpredictable. It often occurs during winter, coinciding with times when demand for electricity is higher.

The calm and cloudy problem is experienced in locations with a relatively high penetration of solar and wind generation, including Australia, the United Kingdom, and Germany. In these markets, drops in wind and solar output are covered by increased use of coal and gas generation, and these periods are starting to correlate with spikes in electricity prices.[17] During 2021, the UK experienced a drop in both solar and wind output due to unusually low wind speeds and reduced sunshine hours. Only 26% of electricity was generated by solar and wind, compared with 30% the previous year, despite increases in generation capacity. Coal and gas generation increased to cover the deficit. This coincided with significant international gas price volatility. Wholesale electricity prices in the UK reached a record high during this period.[18]

The calm and cloudy problem will require a large amount of immediately available capacity (MW) to make up for reduced wind and solar output, but a much smaller energy requirement (GWh) compared to the dry year problem.

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[17] Australian Energy Council. (2017). Dunkelflaute: Dealing with renewable growth in the grid.

[18] Day, J., Wilson, G., & Godfrey, N. (2022). Unusually calm and cloudy weather lead to resurgence in fossil fuel use in 2021. The Conversation.

In New Zealand, hydro plays a key role in providing additional dispatchable generation when wind and/or solar generation are low. However, as the proportion of solar and wind generation grows, the calm and cloudy problem will become an increasing challenge for New Zealand. In particular, corresponding dry year and calm and cloudy periods would be difficult to address in a 100% renewable world.

1.2.1.4 There are limited approaches available to balance electricity supply and demand

Balancing variation in the supply and demand of electricity, and ensuring supply always meets demand, requires a choice between a limited number of options. In particular, the significant shortage in hydro generation that can occur in a dry year can result in a very large deficit between supply and demand that needs to be covered over a relatively long timeframe. Options to balance variable supply and demand are as follows:

Storage: This involves storing energy during periods of relatively high production and low demand, then releasing it into the power grid during periods of lower production and/or higher demand. This includes storing reserves of fossil fuels, storing electricity in batteries, and pumped hydro storage.

Fuel import: This involves increasing volumes of fuels imported from international markets to use to generate electricity. This includes fossil fuels (coal, gas, and oil), as well as biofuels or other green fuels (e.g., hydrogen).

Electricity import: This involves importing electricity through direct electricity links to other markets. Examples include the link between Tasmania and mainland Australia and links between countries in Europe.

Demand management: This involves reducing demand to match reductions in supply. This could be through flexible supply contracts, incentives to shift time of use, public conservation campaigns, or rolling blackouts that switch off parts of the network for periods of time.

New Zealand is an isolated island nation, so this significantly limits the option for direct links to import electricity from other markets. Increasing storage and/or import of fossil fuels does not support the intentions of the NZ Battery Project to provide a pathway to achieve the goal of 100% renewable electricity. This requires a focus on renewable energy storage options (such as pumped hydro) and/or demand-side solutions.

Iceland is a suitable case study for New Zealand, as it is also an island country that has a highly renewable electricity system and grapples with the challenge of balancing supply and demand variation, particularly at the scale and long timeframe of the dry year problem.

Case Study: Iceland’s demand-side solutions

Iceland’s electricity system is 100% renewable, and it is hydro-dominated – around 73% hydro generation and 27% geothermal. Also like New Zealand, Iceland is an isolated island, and the electricity system is not physically connected to any neighbouring systems.

Annual electricity demand in Iceland is around 19,000 GWh and growing (as Iceland attracts interest from energy-intensive industries looking for low-emissions energy supplies). Around 80% of electricity generated is consumed by heavy industry, including aluminium smelting, ferroalloys, and, more recently, data centres.[19]

Like New Zealand, Iceland’s hydro generation is dependent on weather and droughts can have a significant impact on energy availability. Being isolated and 100% renewable, a key tool used in Iceland to balance the system during particularly low hydro inflow events is demand management, which can have significant impacts on energy users.

Long-term supply contracts directly between Landsvirkjun, Iceland’s state-owned energy company, and large industrial users are structured in one of two ways to manage shortage:

- Interruptible contracts, which allow Landsvirkjun to interrupt supply as needed – these attract a lower electricity price and are drawn on first
- The option for Landsvirkjun to ‘buy back’ power, which applies to all other large consumers, and is a last resort that is drawn on if interruptible contracts cannot address a shortage.

The 2021-2022 winter saw Iceland experience a significant drought, with key reservoirs holding around 600 GWh less storage than normal (3% of demand). Interruptible customers were affected for four months before rain eased system stress. The need to exercise the ‘buy back’ option was narrowly avoided.[20]

Most customers on interruptible contracts have a reliable back-up supply, typically based on diesel or oil-fired generation, with technology often remaining from pre-electrification. During these times – for example, for four months in 2021-2022 – Iceland’s electricity system is not able to be 100% renewable. Continuing to maintain these back-up supplies to top up electricity during dry years is likely to become less feasible for consumers on interruptible contracts into the future. Though avoided in recent years, the ‘buy back’ option would be much more disruptive than interruptible contracts. Fossil fuel back-up supplies are not always in place for ‘buy back’ consumers, so this can result in long-term interruptions to industrial processes and production.

1.2.2 Policy directions and New Zealand’s future electricity system

1.2.2.1 Government’s climate change and energy programme seeks to reduce emissions across the economy

The New Zealand Government has established a significant work programme to reduce GHG emissions, as well as adapt to the effects of climate change. This framework of policies, strategies, market-based initiatives, and projects supports New Zealand’s Nationally Determined Contribution under the Paris Agreement, to reduce emissions by 50% below 2005 levels by 2050, and New Zealand’s legislated 2050 net-zero emissions target [21].

The Emissions Reduction Plan (ERP), released in 2022, lays out the actions that will be taken over the next 15 years to take us towards the long-term target for all greenhouse gases, other than biogenic methane, to reach both emissions targets. The ERP sets out the ‘stepping stone’ interim emissions budgets and the initiatives required across the economy to meet those budgets.

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[19] Ember. (2022). Global Electricity Review and European Electricity Review.

[20] Landsvirkjun. (2022). Media release: Drought leads to a deterioration in reservoir level.

[21] This target was set in the Climate Change Response (Zero Carbon) Amendment Act 2019.

The ERP sets out the long-term vision for New Zealand's energy system to be highly renewable, sustainable, and efficient, and to support a low-emissions and high-wage economy. The vision sees energy being affordable and supporting the wellbeing of all New Zealanders, while energy supply is secure, reliable, and resilient, including in the face of global shocks. The ERP also set a target for 50% of total final energy consumption to come from renewable sources by 2035.

The Energy and Industry focus of the ERP is to:

- Use energy efficiently and manage demand for energy
- Ensure the electricity system is ready to meet future needs
- Reduce reliance on fossil fuels and support the switch to low-emissions fuels
- Reduce emissions and energy use in industry.

The final focus area is on developing strategic approaches and targets to guide New Zealand to 2050. Government has in place or is working to develop a number of strategies and plans that will enable realisation of the vision set out in the ERP, including:

- The New Zealand Energy Strategy, which will address strategic challenges in the energy sector and signal pathways away from fossil fuels and towards 50% renewable energy by 2035 – the strategy is due to be completed by the end of 2024
- A Gas Transition Plan, which will help guide the fossil gas sector to reduce emissions in line with climate change targets and emissions budgets – this is due to be completed by the end of 2023g
- The New Zealand Energy Efficiency and Conservation Strategy, which sets out the direction for government support and intervention for promoting energy efficiency and conservation – this is set to expire in 2022, and a new one will be developed
- A roadmap for hydrogen to set a strategy guiding investment in hydrogen while maximising economic benefits and emissions reduction – this is due to be completed in 2023
- Investigating the need for electricity market measures by 2024 that support affordable and reliable electricity supply while accelerating the transition to a highly renewable electricity system
- Electricity Authority and Transpower New Zealand studies to investigate future security and electricity system resilience as we move toward 100 per cent renewable electricity.

Electricity is just one part of the energy sector, and while the electricity system already has a high penetration of renewable generation sources, at roughly 80 to 85%, it relies on fossil fuels to cover the remaining 15 to 20% of generation. Recognising the role of the electricity system in the country's decarbonisation ambitions, the government has set an aspirational target for 100% renewable electricity generation and has brought the target date for this forward to 2030.[22]

The ERP includes a specific focus on ensuring the electricity system is ready to meet future needs, including investigating storage options to mitigate dry year risk, while reducing use of coal and fossil gas for this purpose. It notes that this is the key role of the NZ Battery Project.

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[22] Labour Government. (2020). Our manifesto to keep New Zealand moving.

1.2.2.2 Electrification of transport and industry will drive up electricity demand

New Zealand’s climate change targets and the ERP are also driving decarbonisation of transport and industry. Transport and industrial process heat currently contribute 21% and 10%, respectively, of New Zealand’s total emissions[23] (52% and 24% of energy sector emissions, respectively). Therefore, decarbonising these sectors is also a key focus for meeting climate targets, and electrification is projected to play a key role in this decarbonisation.

Replacing internal combustion engine (ICE) vehicles with electric vehicles (EVs) or other low emission vehicles is a key shift required to decarbonise transport. This transition is being driven by policies like the Clean Vehicle Standard and EV Feebate scheme, which aim to improve the relative economics of low emissions vehicles. The ERP includes a target to increase zero emissions vehicles to 30% of the light vehicle fleet by 2035, and Climate Change Commission modelling demonstrates much higher uptake is needed by 2050 to meet longer term climate targets. The current proportion of light vehicles that are EVs is roughly 1.8%.[24] While other low emissions technologies, like biofuels and hydrogen, may play a role, EV technology is well advanced, so is likely to play the most significant role in the next 10 to 15 years.

Technology is also advancing quickly to decarbonise industrial processes that traditionally rely on fossil fuels. This includes energy technologies like biomass and hydrogen, as well as electrification – for example, high-temperature process heating is increasingly utilising industrial-scale heat pumps. The ERP includes a commitment to develop an action plan for decarbonising industry by 2024, and initiatives like the Government Investment in Decarbonising Industry (GIDI) fund aim to alleviate economic barriers to conversion of industrial processes to low-emissions technologies.

The electrification of transport and industry has significant implications for New Zealand’s electricity demand and therefore generation requirements. As shown in Figure 13, transport electrification is projected to add 14 TWh of electricity demand and process heat another 6 TWh by 2065.

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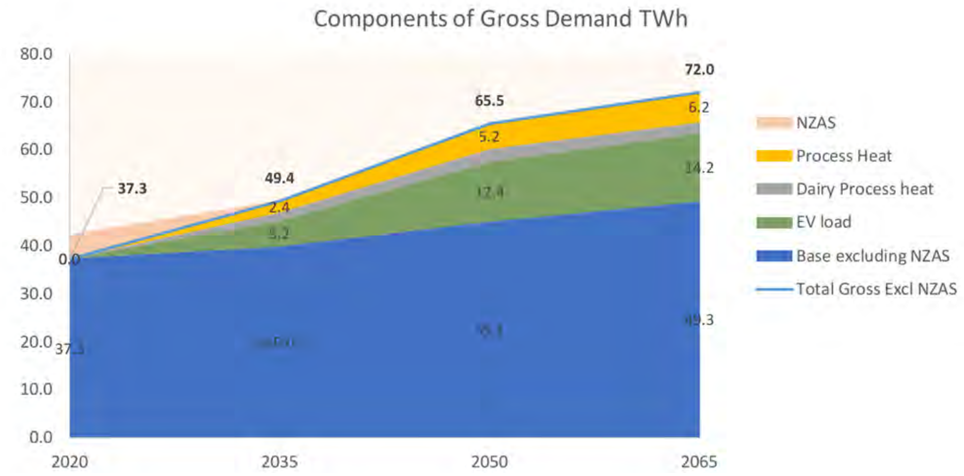
[23] Ministry for the Environment (2022). Greenhouse Gas Emissions Inventory.

[24] Ministry of Transport. (2022). Fleet Statistics.

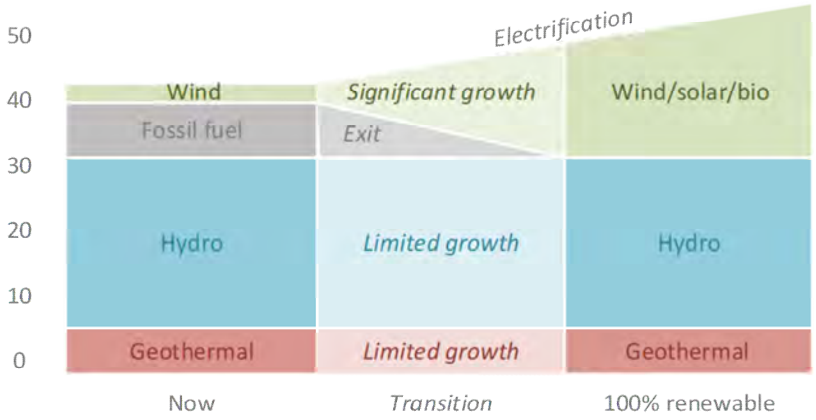
Figure 13: Electrification demand increase to 2065 (modelling completed for the NZ Battery project)



1.2.2.3 New Zealand’s future electricity system will have a more diverse generation stack than today

New Zealand’s total renewable electricity generation needs to significantly increase to both replace thermal generation and support additional demand associated with electrification, as stylistically represented in Figure 14.

Figure 14: Stylistic indication of electricity generation increase to support thermal exit and electrification

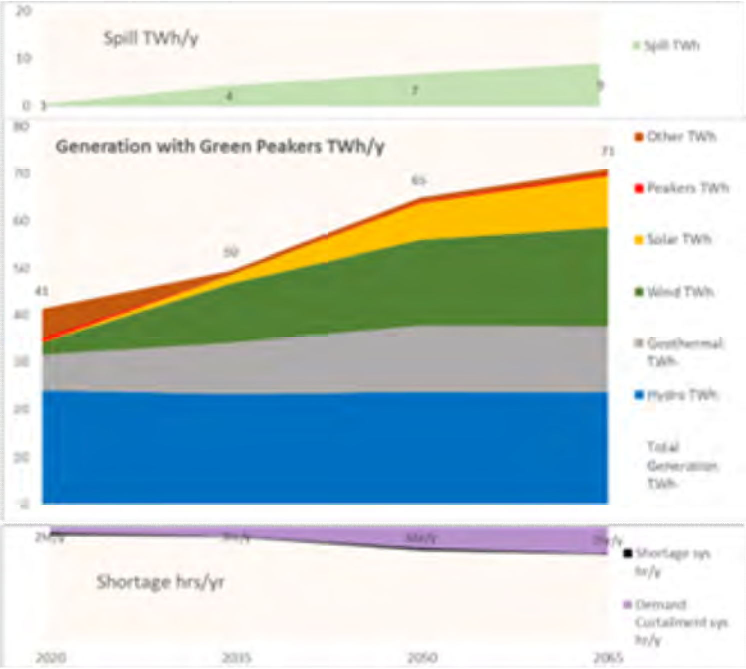


Electricity market modelling has been undertaken for the NZ Battery Project, outlining what a 100% renewable electricity future could look like, both with and without a NZ Battery investment. This has provided key findings on the future generation stack, the necessary build of new renewable generation, and the changing nature of the dry year problem.

As shown in Figure 13, total electricity demand is projected to nearly double by 2065. To support the growth in generation required to meet this demand, an average of 420 megawatts (MW) of new capacity needs to be built per year until 2050. Net supply growth has averaged only 60 MW per year from 1990 – 2020[25], and even at the historical 'peak' of energy generation build in the 1970s, annual build was only around 300 MW.[26] Given New Zealand's climate change targets, this new generation will be renewable, with high levels of wind and solar investment projected.

As shown in Figure 15, NZ Battery modelling sees various renewable generation technologies playing a much greater role in the electricity system than they currently do (see section 2.5.2.1) for further information on NZ Battery modelling and green peakers).

Figure 15: Electricity generation 2020 vs. 2065 (modelling for NZ Battery Project)



As the system transitions to this future state, reliance on hydro generation will reduce but it will still play a key role in the system. Increased reliance on wind and solar generation will exacerbate problems associated with shorter-term intermittency, with lower supply during periods of hours, days, or weeks with minimal wind and/or sunshine (the calm and cloudy problem). As wind and solar increasingly provide more energy, hydro generation can increasingly be used to provide peaking capacity (i.e. hydro energy can be stored to provide energy when wind and/or sunshine levels are low).

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[25] Electricity Authority

[26] Te Waihanga / NZ Infrastructure Commission – Technical Paper: Leveraging our energy resources to reduce global emissions and increase our living standards

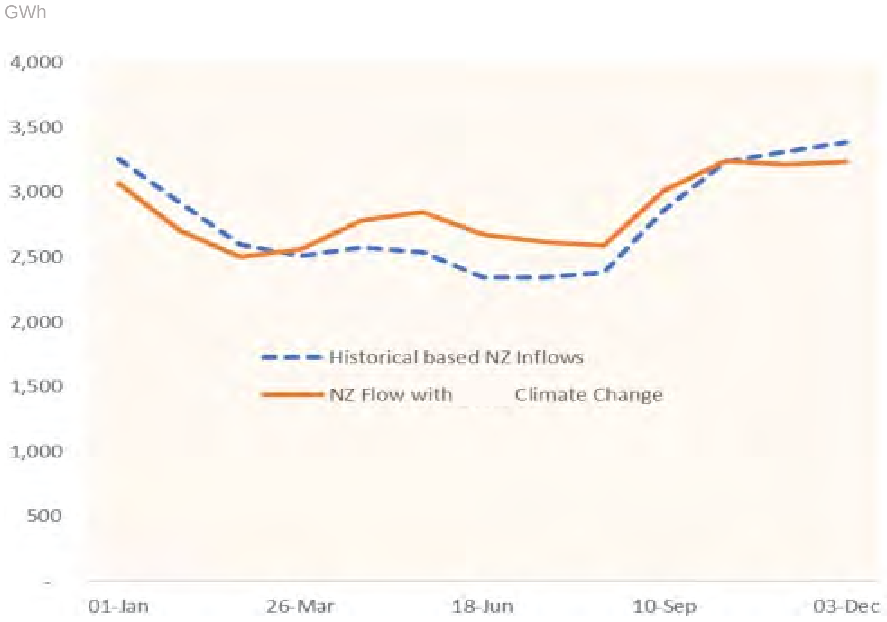
1.2.2.4 Security of supply will continue to be a challenge

As New Zealand transitions towards 100% renewable generation, managing dry year risk without the use of fossil fuels will become more complex and challenging. Hydro is likely to continue to represent a large proportion of the generation mix as the electricity system transitions to 100% renewable. It will also play an important short- to medium-term firming role.

As such, the need to cover low hydro generation in dry years will continue through a combination of flexible generation, energy storage, and demand response. To reduce reliance on fossil fuels, and particularly the role they play in managing dry year risk, will require finding a way to meet electricity demand in low hydro flow years using renewables. Without addressing this problem, the ability to reduce reliance on fossil fuels and meet New Zealand's emissions and renewable energy targets will be limited.

Modelling completed for the NZ Battery Project indicates that climate change effects in New Zealand are anticipated to increase rainfall in autumn and winter (warmer average temperatures are expected to reduce the amount of precipitation falling as snowfall – leading to higher inflows into hydro lakes), while rainfall in spring and summer is expected to reduce, as shown in Figure 16. This is expected to happen by around 2050, but we have more confidence in the direction of change than its timing. Over time, this will slightly reduce the likelihood that low autumn and winter rainfall leads to a dry year (by around 10%). However, increased electrification and greater reliance on hydro to balance a worsening calm and cloudy problem means addressing the dry year problem in future is not expected to be any less important.

Figure 16: Impact of climate change on average hydro inflows by four week period (modelling completed for NZ Battery project)



1.2.3 Other strategic developments and initiatives

Alongside the government's strategic and policy work on decarbonisation, electrification, increasing renewable generation, and developing a solution to the dry year problem, other energy system stakeholders are grappling with the same considerations.

1.2.3.1 Electricity Authority's programme of work

The Electricity Authority is the independent Crown entity charged with promoting competition in, reliable supply by, and the efficient operation of the electricity industry for the long-term benefit of consumers. The Electricity Authority has several work programmes underway focused on supporting the electricity sector to navigate a pathway to 100% renewable electricity. This programme includes workstreams on generation investment and reliability, as well as system security and resilience.

The Electricity Authority has established the Market Development Advisory Group (MDAG), who are focused on the future of electricity markets. The MDAG is undertaking a project to investigate how the wholesale electricity market might operate with a 100% renewable electricity system. It has excluded the NZ Battery Project from its scope.

The Security and Reliability Council was established by the Electricity Authority, as required by the *Electricity Industry Act 2010*, to provide independent advice on reliability of supply issues. Recently, this has included a review of the 2021 dry year event[27]. The Electricity Authority's work programme includes an investigation, with the system operator, of the stability, security, and resilience of the electricity system over the long-term, including when risks and opportunities may emerge and how they should be addressed.

1.2.3.2 Private sector initiatives and investments

The electricity (and wider energy) sector is also considering what the pathway towards a 100% renewable electricity system might look like and have undertaken independent work to identify how a future system might operate.

The Low Carbon Energy Roadmap was developed in 2021 with contributions by a group of more than 50 stakeholders from across the New Zealand energy sector. One of the roadmap's key recommendations is to prioritise low carbon investments that improve system reliability and security, with a number of actions suggested to establish market settings, products, and regulations to support management of increased intermittency of renewables. Additionally, a group of electricity generators, retailers, and network operators has commissioned an independent study to be completed in 2022 to provide an electricity sector view on the best route to a low carbon electricity system. The views of the private sector are an important consideration as the NZ Battery project develops further.

The energy sector's plans and commitments to invest in new renewable electricity generation will also play a critical role on the path to 100% renewable electricity, particularly in a future system that is more electrified. An unprecedented build of new renewable generation is projected to be required to be built per year to 2050. New Zealand's five major electricity generators have committed to several new and expanded wind and geothermal projects that are either in development, consented, or being investigated. This includes Contact's Tauhara geothermal scheme and the Harapaki, Turitea, Puketoi, and Waipipi wind farms to be developed by Meridian, Mercury, and Genesis. New market entrants and smaller developers

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[27]

2021 Dry Year Event, EA, October 2021.

URL: https://www.ea.govt.nz/assets/dms-assets/30/Final-Electricity-Authority-Dry-Year-Review-2021.pdf are also investigating or have committed to new renewable generation, including offshore wind and commercial solar. New projects continue to be announced.

Investments in new renewable generation by the electricity market are essential for replacing a large proportion of the fossil fuels currently used in the electricity system. Analysis by Genesis indicates that with the level of announced investment in renewable generation, New Zealand will be able to reach 96-98% renewable generation by 2030, but that during times of low rain, wind, or sun, fossil fuels will continue to be needed to provide security of supply.[28]

In addition to signalled investments in renewable generation mentioned above, current market participants are also looking at developing biomass generation and hydrogen production facilities.[29,30] These solutions could assist with inter-seasonal dry year cover and may form part of the overall solution. However, it is anticipated that these projects alone will not be able to solve New Zealand's dry year problem without additional government support.

1.2.4 Te Tiriti o Waitangi and Māori rights and interests

Any solution proposed through the NZ Battery Project will need to be developed with the principles of Te Tiriti o Waitangi at its core. Te Tiriti o Waitangi forms the basis for the Crown-Māori relationship, and for all obligations and responsibilities of Treaty partners. Māori have significant rights to and interests in freshwater and geothermal resources, which have been considered by the Courts and Waitangi Tribunal.[31] At a high level, this includes proprietary rights, commercial rights, and the right to develop, along with the authority of Māori to make decisions relating to freshwater and to exercise kaitiakitanga. Understanding these rights and interests is critical for the NZ Battery Project, as renewable energy solutions often involve natural resources of significance to Māori. It should be noted that the idea and issues relating to 'ownership' of natural resources are contested by Māori.

Freshwater bodies are of spiritual, cultural, social, and economic importance to hapū and iwi. Early hydro power scheme developments have caused historic grievances for associated iwi, and the magnitude of this impact continues to be felt today.[32] This has been the result of several factors, including the compulsory acquisition of lands, the alienation of iwi from their traditional resources and taonga, and the lack of engagement, consultation, or compensation. Many of these schemes have had detrimental impacts on the health of the relevant rivers and lakes, which has impacted the relationships of iwi with their traditional waterbodies. Many of these schemes were developed in a way that is inconsistent with tikanga, such as the mixing of waters from different rivers for the Tongariro Power Scheme.[33] This context impacts upon the Crown's relationship with Māori and is material to the consideration of certain dry year solutions proposed through the NZ Battery Project.

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[28] Genesis Energy Limited. (2022). Empowering New Zealand's sustainable future – Annual Report 2022. Note, this modelling assumes continued operation of the New Zealand Aluminium Smelter at Tiwai Point.

[29] URL: https://www.newsroom.co.nz/genesis-imports-us-wood-pellets-to-fuel-huntly-renewable-energy-trial

[30] URL: https://www.meridianenergy.co.nz/news-and-events/meridian-selects-southerngreenhydrogen-partner

[31] Wai 2358 (inquiry into national freshwater and geothermal resources), WAI 1999 The Whanganui River Report.

[32] Ngāti Tūwharetoa Claims Settlement Act 2018

[33] This is noted in for example the Te Kāhui Maunga – National Park District Enquiry Report (WAI1130) 2013 and the Taihape: Raingitīkei Ki Rangipō District Inquiry (WAI2180) 2180

Specific treaty settlement legislation recognises the role and relationship of iwi with specific freshwater and geothermal resources, and some create specific legislative frameworks for the management of such resources.[34]

1.2.4.1 Mātauranga Māori and Te Mana o te Wai

Mātauranga Māori is about a Māori way of being and engaging in the world, including using kawa (cultural practices) and tikanga (cultural principles) to critique, examine, analyse, and understand the world. Leveraging mātauranga Māori alongside other forms of knowledge provides New Zealand with a unique point of difference to innovate solutions. Working alongside Māori to ensure authentic and appropriate use of mātauranga Māori will be an important consideration throughout the NZ Battery Project.

Mātauranga Māori concepts, such as Te Mana o te Wai, have been incorporated into New Zealand's environmental policy and resource management framework. Te Mana o te Wai refers to the vital importance of water and requires the health and wellbeing of water itself to be protected, as well as human health needs, before providing for other uses of water. It recognises the reciprocal nature of the health of the environment with the health of people.

1.2.5 What this strategic context means for the NZ Battery Project

The NZ Battery Project sits within the context of the Government's legislated and aspirational targets for emissions reduction, decarbonisation and increasing share of renewable generation.

These targets will create shifts in New Zealand's electricity system, including electrification and increasing electrical demand, substantial renewable generation build, and a change in the generation stack. The NZ Battery has been initiated with the specific purpose to identify a renewable solution to the long-term security of supply challenge of dry year risk, to support the transition to 100% renewable electricity.

Understanding the context of New Zealand's current and future electricity system, the strategic drivers for the renewable transition, and the role of the NZ Battery investment within this has been critical to shaping the case for change and identifying and assessing the options for investment.

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[34] Examples are the Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010, Te Awa Tupua (Whanganui River Claims Settlement) Act 2017, and Ngāti Rangi Claims Settlement Act 2019

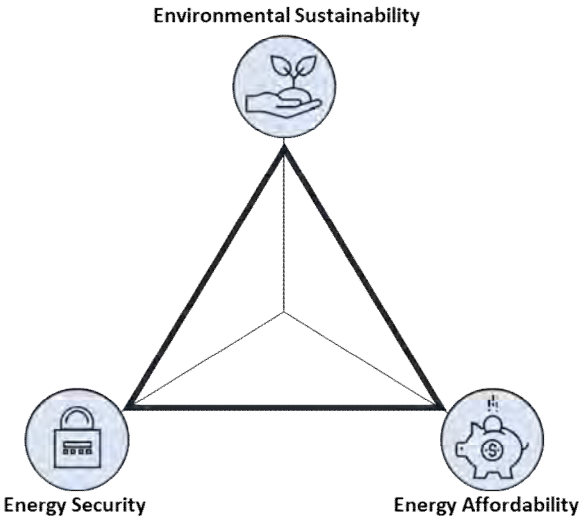
1.3 Problem definition

The previous section provided the context for the problem the NZ Battery Project is aiming to solve. The project aims to ensure security of New Zealand's electricity supply without the use of fossil fuels, to support New Zealand on the pathway to 100% renewable electricity. In particular, the NZ Battery Project focuses on security of supply on the longer timescale of the dry year problem (months to years). With this strategic context providing background, facilitated Investment Logic Mapping (ILM) workshops were held with key project stakeholders in July and August 2022 to gain a common understanding of the problems the NZ Battery project is seeking to solve. The ILM has also been tested with the NZ Battery project's Technical Reference Group.

1.3.1.1 The energy trilemma

A useful framework for considering the NZ Battery problem, is the 'energy trilemma', as shown in Figure 17. This is a framework for describing the balance between three often conflicting aims: maintaining secure and reliable energy, ensuring energy is affordable for all, and achieving environmental sustainability.

Figure 17: The energy trilemma



The elements of the energy trilemma are further defined in Table 4, along with how each element of the trilemma relates to the problem the NZ Battery Project is trying to solve.

Table 4: The energy trilemma – definitions and how this applies to the NZ Battery problem

Element	Description	How this applies to the NZ Battery problem
Environmental Sustainability	The ability to mitigate adverse environmental impacts of the energy system, with a predominant focus on mitigating climate change impacts associated with greenhouse gas emissions. There are additional environmental considerations, including using renewable resources responsibly and mitigating local impacts on air, land, water, and biodiversity.	The ERP recognises the problem being addressed by the NZ Battery Project as an element of ensuring the electricity system is ready to meet future needs, in order to achieve New Zealand's climate change and decarbonisation targets. For the electricity system, this means providing sufficient capacity to enable electrification of parts of the economy currently reliant on fossil fuels and increasing the renewable proportion of electricity generation, eventually to 100%. This also requires recognition of the local environmental consequences of the project.
Energy Security	The energy system's capability to ensure uninterrupted availability of energy by withstanding and recovering from disturbances. This includes operational capability to return to normal operating state as quickly as possible, adequacy of energy supply to cover demand, reliability of supply under varying conditions, and resilience to short-term shocks and longer-term changes.	Where New Zealand's security of supply is currently typically achieved using fossil fuels (particularly during dry years), sustainability drivers require the exploration of alternative renewable, sustainable, and low-emissions ways to achieve reliable and secure supply. Increasing reliance on variable renewable generation also introduces greater challenges of continuously matching supply with demand, from shorter periods of calm and cloudy weather through to months and years when hydro inflows are low.
Energy Affordability	The ability to provide energy that is affordable and accessible to all parts of society – enabling energy to support economic development and prosperity.	Decarbonising the energy system and achieving sustainable mechanisms to ensure reliable supply may come at a high cost and may change how the electricity market operates in terms of matching supply and demand. The NZ Battery Project is looking for solutions that best meet the energy affordability limb of the energy trilemma.

1.3.2 The Problem Statement

Through the Investment Logic Mapping (ILM) workshops (see ILM overview in Appendix B), the following problem statement was identified to encapsulate the problem the NZ Battery Project is trying to solve:

Problem Statement: "Failure to address dry year risk in an increasingly renewable electricity system will impose significant costs on New Zealand"

This problem statement attempts to condense a very complex topic into a single sentence. Each part of this sentence requires interpretation, and this is further explained in Table 5.

Table 5: Description of the components of the NZ Battery Problem Definition

Component	Description
Failure to address	There is a problem that needs action to be taken to address it, and this is a problem for all of New Zealand – not only the electricity sector, the government, or any other individual party.
Dry year risk	Addressing dry year risk involves maintaining security of supply in years of low hydrological inflows, which requires a significant capacity of electricity (around 3 – 5 TWh) to be able to be dispatched over a long period of time (at least three months). The potential approaches to addressing this include storage, imported energy or electricity, and/or demand-side responses.
In an increasingly renewable electricity system	Government policy is that the proportion of renewable electricity should increase through the commitment to net-zero carbon emissions by 2050, there is a 50% renewable energy target for 2035, and an aspiration for 100% renewable electricity by 2030. Market trends are also signalling increasing renewable electricity through announcements of thermal plant exit and increasing investment in renewables. As the system becomes more renewable, the risks associated with variable renewable generation become more pronounced, such as the short-term intermittency 'calm and cloudy' problem. Hydro will continue to play a vital role in New Zealand's future electricity system, including short-term firming of solar and wind energy. Fossil fuels in the current electricity system play an important role in covering reduced hydro capacity during dry years. Without a renewable solution to the dry year problem, it is likely the electricity system could achieve around 95-98% renewable on average, but the final few percentage points to 100% renewable cannot be achieved without a renewable replacement for fossil fuels to cover the reduced capacity of hydro generation during dry years. While continuing to use fossil fuels (namely natural gas) helps to achieve security of supply and reduce generation emissions (when compared to coal), such a situation cannot continue forever, and the feasibility of relying on them becomes less certain as their role dwindles and becomes more variable. Ultimately Aotearoa will need to move to a more renewable electricity system as we head towards our 2050 target. While the timing of the 100% renewable electricity target may change, a renewable solution to the dry year problem will be needed at some point.

Component	Description
Will impose significant costs on New Zealand	A failure to proactively address the dry year problem in an increasingly renewable electricity system is likely to lead to one of two outcomes, each of which would impose costs on New Zealand and New Zealanders. First, an increasingly renewable electricity system could continue to rely on fossil fuels for security of supply, particularly to cover the gap between around 95% and 100% renewable electricity. However, this would mean New Zealand's electricity system continues to generate emissions and contribute to climate change, resulting in the following potential costs: • Cultural costs associated with continued failure to address the intergenerational and kaitiakitanga issue of climate change • Environmental costs associated with continued reliance on fossil fuels contributing to climate change • Impact on New Zealand's international reputation through failure or slowness to meet international decarbonisation commitments and on New Zealand's 'clean, green' image • Economic costs of maintaining thermal generation assets (e.g., pipelines, wells, import terminals etc.) with a declining fossil fuel user base • Costs associated with offsetting any resulting operating emissions from thermal generation (either economic through the purchase of offsets, or social and environmental through the planting of monoculture plantations to offset emissions). In the scenario that the transition towards 100% renewable electricity occurs but without investment in a renewable alternative to fossil fuels to cover the energy deficit during dry years, the likely outcomes are increasing electricity shortage and supply interruptions, as electricity supply is unable to meet demand at all times. Electricity price volatility and increases will also likely result as shortages are priced into the market. The costs of this future include: • Social costs of shortage and supply interruptions, including health, safety, and wellbeing of individuals, households, and whanau (for examples, see case studies below) • Economic costs of shortage and supply interruptions impacting business and industry productivity (for examples, see case studies below) • Social and economic costs of high and volatile electricity prices • Reduction in the confidence of energy-using industries in the reliability of electricity supply, leading to slower decarbonisation of the wider economy (as businesses continue to rely on alternatives perceived as more reliable), a reduction in international competitive advantage, and an increase in industry emigration. These costs will fall on electricity consumers, electricity-using businesses and industry, and the economy through a reduction in competitive advantage and GDP. These costs will also fall on individuals, whanau, and society, as reliable, affordable electricity is needed to support many aspects of health and wellbeing.

Electricity users both in New Zealand and internationally have experienced the impacts of generation shortage and electricity supply interruptions in the past. The below case studies demonstrate the potential economic and social costs of medium- to long-term electricity outages that can be experienced if security of supply is not achieved.

Case Study: The economic cost of shortage – New Zealand's Maui gas pipeline outage

The Maui pipeline is a high-pressure gas transmission pipeline running from the Oaonui Production Station (south of New Plymouth) to the Huntly Power Station, with injection and offtake points at various junctions. It transports natural gas produced in the Taranaki region to large gas users, including electricity generators, as well as being the primary source of supply for other gas transmission and distribution pipelines. On 24 October 2011, the pipeline was damaged by a landslide, requiring a section of the pipe to be shut down. The pipeline was not recommissioned back to normal operation until five days later.

A 'critical contingency' was declared, with consumers (excluding residential) directed to curtail use of gas, with approximately 12,000 consumers impacted. Gas users affected by the outage included electricity generators, hospitals, milk processing plants, food production facilities, and various industries reliant on process heat or steam from gas fired boilers. The effects were mainly economic, resulting from loss of production.

The loss of gas supply saw six milk processing plants impacted, with more than 48 million litres of raw milk required to be disposed of on-farm. Some health facilities cancelled elective surgeries, and many hospital linen services were disrupted.

The impact of dry year shortage would be very different to this scenario. However, as an illustration of the cost of shortage, the gross cost of the outage to New Zealand's economy was estimated to be $200 million, through industry and business disruption across the upper North Island. This is an average of around $40 million per day.[35]

1.3.2.1 What is government's role in addressing this problem?

The Government has set an aspirational target for 100% renewable electricity by 2030. The Climate Change Commission has modelled that the market could reach levels of 95-98% renewable electricity by 2035 under the current market conditions and with readily available technologies.[36] Existing electricity market players, such as Genesis, have indicated a similar level of renewable electricity could be achieved by market investment in renewable generation.[37] These scenarios assume the remaining 2-5% of generation would continue to rely indefinitely on fossil fuels to cover periods of low renewable generation due to weather (low hydro inflows, low wind, and/or limited sunshine).

The ICCC explored a range of options to solve the dry year problem in a 100% renewable electricity system, but it identified that any large investment targeted at solving the dry year problem, like pumped hydro, was unlikely to be made by the market, due to factors including cost and consenting risk.[38]

The preferred solution and commercial operating model of the NZ Battery solution is explored in the Economic and Commercial Cases of this Indicative Business Case. However, any new dry year solution is likely to make for a challenging investment.

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[35] MBIE. (2011). Review of the Maui pipeline outage of October 2011.

[36] He Pou a Rangi Climate Change Commission *Ināia tonu nei: A low emissions future for Aotearoa,* 2021

[37] Genesis Energy Limited. (2022). Empowering New Zealand's sustainable future – Annual Report 2022.

[38] Interim Climate Change Committee. (2019). Accelerated Electrification – Evidence, analysis, and recommendations.

The scale of the dry year problem is significant. A solution needs to be able to provide a lot of energy (around 3 – 5 TWh), and deliver it to the system over several months, justifying capacity of 1,000 MW or more. This is in the context of annual generation of around 40 TWh today, peak demand of around 7,000 MW, and a market with just a handful of major generators, the largest of which generated 13.5 TWh of electricity in the year to June 2022.[39] Additionally, a dry year solution is likely to only be required (particularly to its full capability) infrequently and on an ad hoc basis with limited warning. This operating environment:

- Reduces the potential value a solution can capture as it has limited and unpredictable operating opportunities and may sit idle for prolonged periods, and
- Increases the commercial risk of the investment as revenue streams are hard to predict and there is significant uncertainty around the ability of a solution to recover costs.

Overall, the scale and risk of an investment in a renewable solution to the dry year problem makes it unappealing to most market participants and the commercial incentives for the market to address the final few percentage points to get to 100% renewable electricity are lacking. Further, a solution to the dry year problem may have a long lead time. Waiting for the market to address this based on commercial incentives alone may mean the costs of the dry year problem are felt before it is addressed.

Without targeted government intervention to provide a renewable solution to this problem, the likely outcome is a combination of the following:

- Renewable electricity aspirations and climate change targets are not met within targeted timeframes. The market reaches a high level of renewable penetration on average, but fossil fuels continue to be used to achieve security of supply and manage the dry year risk
- Increasing pressure to avoid use of fossil fuels, without a feasible renewable and controllable (rather than intermittent) alternative, results in increasing security of supply issues. Electricity consumers are required to reduce demand, or may experience supply interruptions, when there is insufficient renewable generation to meet demand (with associated social and economic costs – see case studies on the implications of shortage above)
- A combination of overbuild of renewable generation, more frequent periods of shortage, and/or monopoly ownership of dry year support results in increasing electricity costs to consumers, particularly during periods of low renewable generation.

As a result, the NZ Battery Project has concluded that the market is unlikely, acting on commercial incentive alone, to address the large, uncertain and low likelihood dry year problem and achieve the final few percentage points to 100% renewable electricity within the timeframe required. Government intervention is therefore needed.

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[39] Meridian Energy, Monthly operating report for June 2022

1.3.2.2 Challenges to security of supply can be short, medium or longer term, and the market is well set up to resolve some of these

The NZ Battery Project is focussing predominantly on the longer term, dry year risk problem because the market is least likely to solve this problem in a system with 100% renewable electricity. The ability of the market to address the temporal spectrum of security of supply challenges associated with renewable intermittency are shown in Table 6.

Table 6: Anticipated market response to electricity security problems across the temporal spectrum in a 100% renewable world

Short term **(hours to days e.g. evening peak)**	**Medium term** **(days to weeks e.g. calm/cloudy periods)**	**Long term** **(years or more e.g. prolonged periods of low hydro inflow)**
Market will address	***Market likely to address***	***Market unlikely to fully address***
• Maturing technologies available ◦ Existing battery technologies already being deployed at scale to address this problem ◦ Smart EV charging evolving • Greater certainty of revenue through probability of arbitrage revenue • Regular charging and discharging cycles • Grid ancillary services opportunities • Suits small and incremental investments • Industry currently collaborating to realise value from flexibility markets • Unlikely to require government intervention other than to remove barriers to entry as technologies evolve	• Strong role for existing hydro but little potential to extend capability • Technology opportunities developing in response to global need for medium-term flexibility (e.g. flow batteries, compressed air, biofuels) • Economics do not currently support investment in these technologies, but as need and opportunity increases, prices and operating models will become more certain • Revenue likely to be sufficiently certain to support investment given regular use • May require some form of government support initially	• A challenging investment case given irregular and uncertain revenue • Becoming even more challenging due to need for renewable alternatives (few technology options, high capex, consenting risks) • Scale of need large relatively to size of market participants

1.3.2.3 A physical problem that requires a physical solution

As discussed, the dry year problem involves a significant amount of energy (of around 3 – 5 TWh, or larger than New Zealand's existing largest hydro facility), requiring significant capacity to deliver it in the timeframe required. While policy and regulation currently play an important role in managing dry years, the problem is fundamentally a physical problem, that requires a physical solution.

It is not necessarily the case that the government must be the party to develop a renewable solution, and this IBC does not determine it to be. It may be that existing or amended regulation and policy settings can facilitate or incentivise a market-based response.

However, there is not enough renewable flexible generation or storage capacity in the current electricity system or planned for development to cover dry years. Traditional hydro is the only renewable energy storage technology that is mature at scale that New Zealand has meaningful experience with. However, there are few opportunities to develop this further. Developing new renewable energy storage therefore also requires consideration of new, unfamiliar or undefined technology options. Some of these technologies are only just emerging internationally, and some may be beyond the capability of existing market participants to deliver. This is evident in the ICCC advice to government.

While regulatory and policy measures may help to enable the delivery of a renewable solution to the dry year problem, it remains unclear what the physical solutions could be, and which would be best for New Zealand. The lack of this understanding hinders the ability of any such regulatory and policy measures to be specific to the physical buildout.

The government will need to proactively investigate the physical solutions to cover the large-scale and long-term problem of dry year risk without fossil fuels and support implementation with appropriate intervention, including regulations and policies as required.

1.4 Investment objectives, existing arrangements, and business needs

The investment objectives developed based on the ILM process for the NZ Battery Project are shown in Table 7. These specify the desired outcomes for any NZ Battery investment, in specific, measurable terms, and can be used to inform later assessment of the investment's success. The three agreed investment objectives for the NZ Battery Project map to the three dimensions of the energy trilemma.

The success of the project will be determined by its ability to achieve improved outcomes for energy security, energy affordability, and the sustainability of the energy system (in terms of renewable generation and reduced emissions). The NZ Battery Project cannot be considered successful if it enables or creates poor outcomes across any one of the trilemma dimensions.

Table 7: NZ Battery project investment objectives

Investment Objective		Weighting	Description
1	Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system	55%	New Zealand's electricity system is currently relatively secure, and the NZ Battery project should ensure that the transition to 100% renewable electricity and the phase out of fossil fuels does not result in increased security of supply issues, shortage events, and associated social and economic costs. **Measures:** • Provision of storage, dispatch, and demand management sufficient to manage reasonable expectations for the dry year risk • Reduced electricity shortage compared to a 100% renewable future without NZ Battery • Reduced demand curtailment compared to a future without NZ Battery • Reduced use of green peakers compared to a future without NZ Battery
2	Provide for more affordable electricity, compared to a future without NZ Battery, in a 100% renewable electricity system	25%	There is the potential that achieving the other two objectives, or any investment that distorts the market, will drive up costs. Electricity costs in the future are likely to be higher than today, but the NZ Battery project should put downward pressure on the cost of electricity supply compared to a future without NZ Battery. **Measure:** • Lower total cost of electricity supply compared to a future without NZ Battery – as measured through wholesale electricity prices
3	Accelerate emissions reduction through increased renewable share of energy	20%	The solution should provide greater confidence in investment in renewable electricity developments, which supports acceleration of the transition of the electricity system to renewables. It should also provide greater confidence in the electricity system, which enables acceleration of the electrification of other sectors, such as industrial processes. **Measures:** • Higher relative share of renewables in the energy system, compared with today and to a future without NZ Battery • Lower total operating emissions of electricity generation, compared with today and to a future without NZ Battery • Higher support for renewable energy, compared to a future without NZ Battery (measured using generation weighted average spot prices (GWAPs)

Table 8 shows the existing arrangements and business needs for each of the three agreed investment objectives. This demonstrates the difference between the desired state (the investment objective) and the current state (the existing arrangements), and therefore the gap that the investment in the NZ Battery Project is intended to fill (the business needs).

Table 8: NZ Battery investment objectives – existing arrangements and business needs

Investment objective 1	*Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system*
Existing arrangements	The current electricity system manages security of supply, including the dry year problem, using fossil fuels, which are easily stored and/or have a flexible supply source. Use of thermal generation is scaled up in response to market conditions resulting from scarcity of hydro inflows, which manages hydro generation variability and maintains security of supply. The nature of New Zealand's electricity system, being isolated and with a high proportion of hydro, means variability of inflows and scarcity of water results in security of supply challenges. The electricity system is currently, with fossil fuels, providing a good level of security. Dry year shortage issues have not been passed on to electricity consumers by way of conservation campaigns since 2008.
Business needs	The NZ Battery solution is intended to provide a renewable way to make up for scarce hydro generation in dry years. Without fossil fuels, which are currently used to maintain security of supply in dry years, electricity security becomes much more difficult to achieve. Additionally, climate change and decarbonisation targets are driving increased electricity demand, which must be met with adequate supply at the times it is needed. The NZ Battery Project seeks to ensure that security of supply during dry years will not be less than today, and to ensure that consumers do not experience greater supply interruptions following the exit of thermal generation from the system.

Investment objective 2	*Provide for more affordable electricity, compared to a future without NZ Battery, in a 100% renewable electricity system*
Existing arrangements	Consumer electricity prices reflect the cost of supply, including generation, transmission, distribution, and retail costs. Prices also reflect risk - driven in part by uncertainty caused by variable and unpredictable hydro inflows and intermittent generation. Wholesale electricity prices have been high in recent years compared with historical prices due to scarcity of generation in the market, and possibly inadequate competition[40]. Investment decisions and generation availability are impacted by a range of factors, but recent influences have included supply shocks in the gas market and the uncertainty about future electricity demand, particularly with the potential closure of the NZAS at Tiwai Point. Electricity prices affect affordability for consumers. Many New Zealanders are currently unable to afford the electricity they need, with the percentage of households in energy hardship being reported between 6%[41] and 25%.[42] Affordability is however a complex issue, influenced by the characteristics of dwellings, people's income, and their particular electricity needs. Electricity prices also affect the productivity and profitability of New Zealand businesses.

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[40] Competition in the Wholesale Electricity Market, Electricity Authority, 2022.

[41] Electricity Price Review 2019

[42] Concept Consulting *Options for assisting customers in energy hardship* – prepared for the Electricity Networks Association, 2017

Investment objective 2	*Provide for more affordable electricity, compared to a future without NZ Battery, in a 100% renewable electricity system*
Business needs	A NZ Battery solution is intended to minimise the electricity price impacts on consumers associated with the cost of supply, and price volatility. A large amount of new renewable generation will be required to meet electrification demand, transition to higher proportions of renewable electricity, and to support thermal exit. The associated investment cost will be significant, and these will be recovered from consumers through electricity prices. A NZ Battery solution should reduce the amount of new generation required, and improve the utilisation of the generation available, reducing total supply costs and hence consumer price impacts. A NZ Battery solution should also improve the certainty and confidence of the system's ability to meet demand through a range of hydro conditions, reducing price risk, and the volatility of wholesale prices. Reducing price risk and volatility associated with future wind and solar variability is also desirable. Overall, the NZ Battery Project seeks to identify the option or options that will ensure total costs of electricity supply and wholesale electricity prices are lower than in a future without an NZ Battery investment.

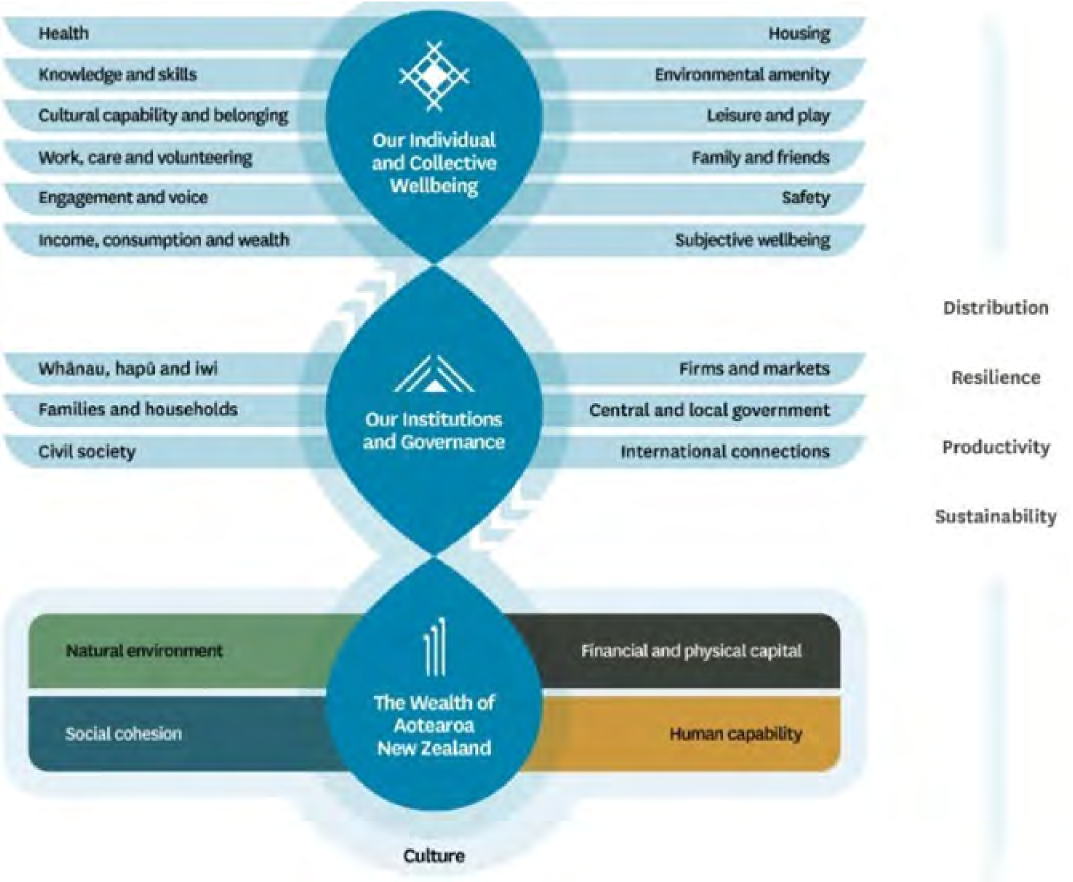
Investment objective 3	*Accelerate emissions reduction through increased renewable share of energy*
Existing arrangements	New Zealand's energy system contributes around 44% of New Zealand's emissions. This includes both transport and industrial processes, which rely significantly on fossil fuels. The electricity system itself contributes roughly 4%, predominantly through use of thermal generation.
Business needs	The NZ Battery Project should increase the renewable share of energy by being renewable, supporting achievement of 100% renewable electricity generation, and facilitating system conditions that encourage electrification. The NZ Battery solution itself must be renewable, and should aim to minimise its own emissions. The NZ Battery solution should support achievement of 100% renewable electricity generation by allowing the retirement of thermal generation and providing greater confidence in investment in other renewable generation. This might be achieved by providing the dry year security of supply that has to date been met by fossil fuels, reducing the amount of intermittent renewable output that is 'spilled', and improving the confidence of renewable generation investors in being able to recover their costs and earn a return on investment. Further, a NZ Battery solution should contribute to increased confidence in electrification as a solution for other sectors, including transport and industry, by supporting a reliable supply and putting downward pressure on wholesale electricity prices.

1.5 Benefits of a NZ Battery investment

1.5.1 The Living Standards Framework

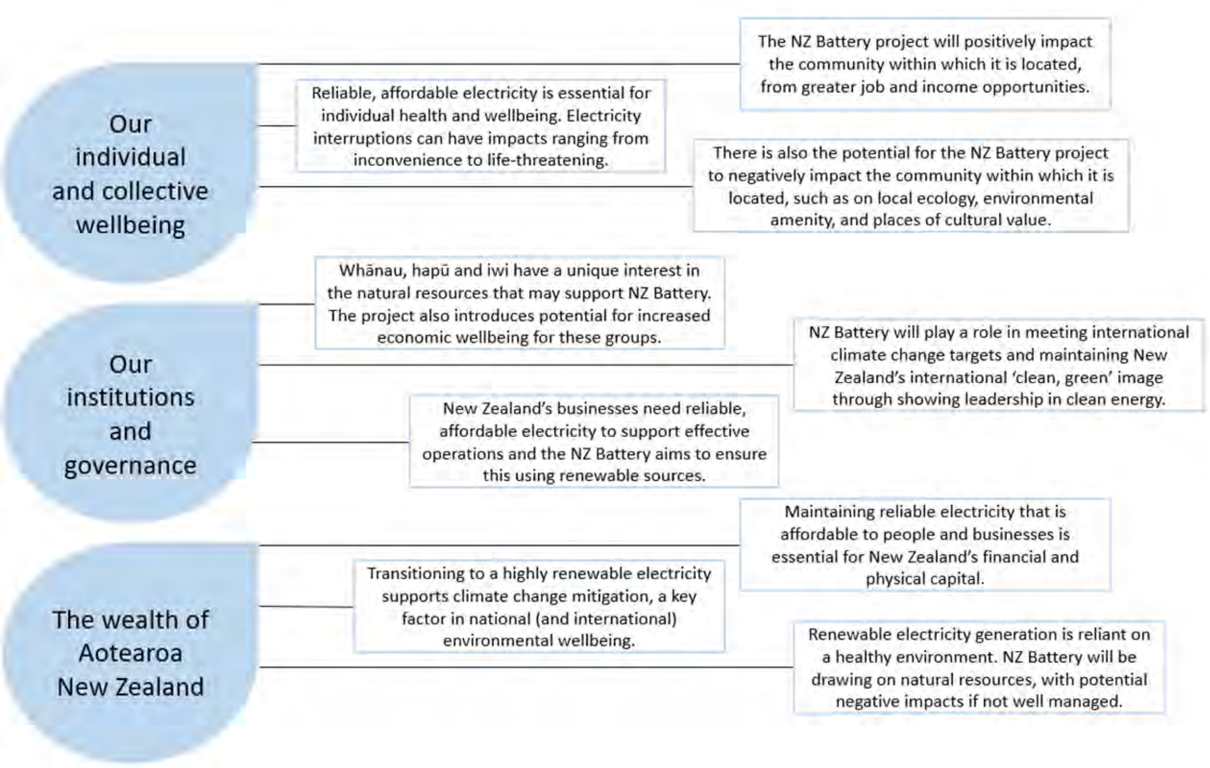
Treasury’s Living Standards Framework (LSF) sets out the factors that are important for New Zealanders’ wellbeing, now and into the future, across different dimensions of wellbeing. The current version of the LSF is summarised in Figure 18, and is used to evaluate major proposed investments, like the NZ Battery project.

Figure 18: Living Standards Framework (2021) summary diagram



The NZ Battery investment has the potential to positively impact New Zealand across all elements of the framework, from national to individual. The LSF also introduces important considerations that need to be factored into the assessment of potential solutions to the dry year problem. Potential positive and negative impacts of the NZ Battery Project across the scales and domains of the LSF are shown in Figure 19. The costs and benefits of the project are further explored in detail in the Economic Case.

Figure 19: Potential impacts of the NZ Battery investment across the LSF

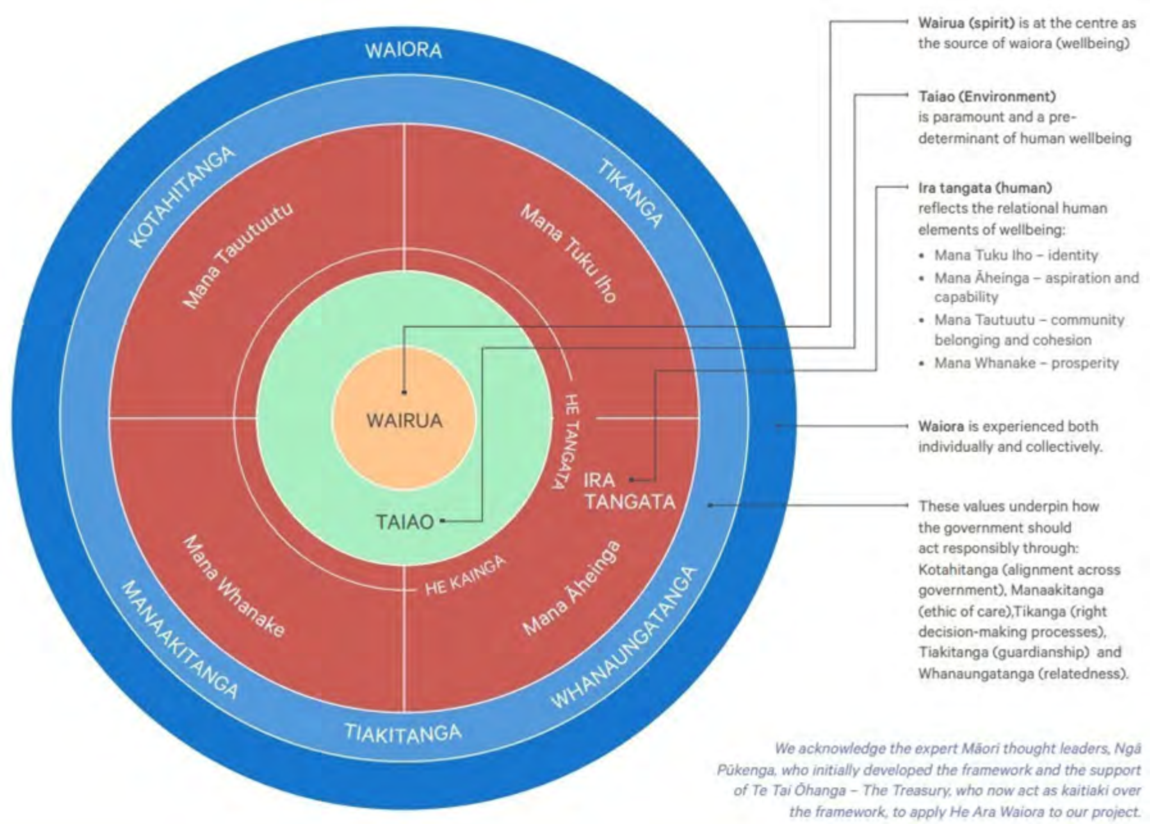


Overall, the NZ Battery Project should contribute to enhanced wellbeing for New Zealanders at both an individual and a national level. However, decisions made on the NZ Battery Project, through this and subsequent business cases, need to recognise trade-offs and consider how to optimise positive outcomes across the different LSF scales and domains. For example, while the project may result in improved national wellbeing but there is the potential for it to result in negative wellbeing outcomes locally. Likewise, the project may inherently result in positive climate change outcomes, but this may be at the expense of other elements of environmental and cultural wellbeing.

1.5.2 He Ara Waiora

He Ara Waiora is a wellbeing framework grounded in Mātauranga Māori and enables the application of tikanga Māori to inform the LSF and government policy. He Ara Waiora reflects a holistic, intergenerational, and interconnected approach to wellbeing from a te ao Māori perspective, both individually and collectively. It applies to all New Zealanders. Critical elements of this framework include 'ends' or important elements in Māori concepts of wellbeing: Wairua is at the centre, Te Taiao (environment) is paramount and inextricably linked with human wellbeing. People have responsibilities and obligations to sustain and maintain the wellbeing of the environment. The framework, as shown in Figure 20, also encapsulates 'means' or the values or principles required to achieve the 'ends' described in the framework.

Figure 20: He Ara Waiora framework



Wairua (spirit) is at the centre as the source of waiora (wellbeing)

Taiao (Environment) is paramount and a pre-determinant of human wellbeing

Ira tangata (human) reflects the relational human elements of wellbeing:

- Mana Tuku Iho – identity
- Mana Āheinga – aspiration and capability
- Mana Tautuutu – community belonging and cohesion
- Mana Whanake – prosperity

Waiora is experienced both individually and collectively.

These values underpin how the government should act responsibly through: Kotahitanga (alignment across government), Manaakitanga (ethic of care),Tikanga (right decision-making processes), Tiakitanga (guardianship) and Whanaungatanga (relatedness).

We acknowledge the expert Māori thought leaders, Ngā Pūkenga, who initially developed the framework and the support of Te Tai Ōhanga – The Treasury, who now act as kaitiaki over the framework, to apply He Ara Waiora to our project.

This framework can be applied to the NZ Battery Project alongside the LSF in order to ensure that te ao Māori informs business case analysis – particularly to understand the relationality between different wellbeing domains, and the interconnectedness between environmental and human wellbeing. An example is leveraging the intergenerational concept of mātauranga Māori, which is particularly relevant when measuring an investment that would be enduring for many generations of New Zealanders, like the NZ Battery Project. He Ara Waiora emphasises the importance of adopting a partnership approach with Māori to understand key impacts and benefits from policy and decision-making.

1.5.3 Benefits of the NZ Battery investment

Through the ILM, two high-level benefits of a battery solution to the dry year problem were identified. Delivery of these benefits assumes the problem statement is addressed and the three investment objectives are delivered on through the NZ Battery Project. These are described, including the key performance indicators (KPIs) that will be used to measure them, below.

Table 9: Main benefit 1 – Reduced risk of social harm

Benefit 1	**Reduced risk of social harm**
Description	Failure to solve the dry year problem in a 100% renewable grid will result in either electricity shortages or very high costs. Reliable and affordable electricity supply is essential for maintaining individual, household, and whānau wellbeing across multiple dimensions. Electricity supply interruptions can have impacts ranging from inconvenience to life-threatening, from interrupted work and learning to failure of life-supporting equipment. Inability to afford the electricity a household or whānau needs results in harm, including adverse health outcomes from being unable to heat or cool the house adequately. Electricity interruptions also impact learning, work, amenity, leisure, and, in an electrified future, transport. The NZ Battery Project seeks to ensure electricity supply remains reliable and secure, avoiding unplanned demand curtailment and supply interruptions, and affordable for all New Zealanders, in a future without fossil fuelled thermal generation.
LSF domains	• Our Individual and Collective Wellbeing: health; knowledge and skills; work, care, and volunteering; income, consumption, and wealth; leisure and play; safety; subjective wellbeing • Our Institutions and Governance: whānau, hapū, and iwi; families and households
He Ara Waiora elements	• Whanaungatanga: Fostering strong relationships through kinship and/or shared experience that provide a shared sense of wellbeing • Mana Āheinga: Aspiration and capability • Mana Whanake: Prosperity
Indicators	• KPI 1: Reduced risk of electricity supply outage or demand-side interventions in response to security of supply issues in a 100% renewable electricity system • KPI 2: Reduced risk of increase in electricity prices to unaffordable levels
Who benefits?	• Electricity consumers (individuals, whānau, households, businesses) • All New Zealanders
Direct or indirect	• Indirect
Monetisable or non-monetisable	• Reduced shortage and unplanned demand curtailment is quantified and monetised through the electricity market modelling (EMM). • EMM provides an indication of expected wholesale electricity price changes. • Wider impacts and implications related to the above KPIs are described qualitatively and non-monetised.

Table 10: Main benefit 2 – Improved business confidence in renewable electricity sources

Benefit 2	**Improved business confidence in renewable electricity sources**
Description	A flexible storage and dispatch solution could provide greater confidence for investment in renewable electricity generation by reducing the amount of electricity that would otherwise be spilled and raise the price floor for wind and solar generation. This will support decarbonisation of the electricity system. The NZ Battery Project also seeks to ensure energy using businesses can continue to rely on the electricity system to support continued business and industrial operations. Failure to solve the dry year problem in a 100% renewable electricity system will result in shortages and price volatility with economic costs for electricity-using businesses. Ensuring electricity supply is reliable and affordable is also essential for electrification to continue to be a desirable solution for business energy needs, which will support continued decarbonisation of the wider energy system. Electricity that is unreliable and prone to supply interruptions and demand restrictions, or that is very expensive or subject to significant volatility in price, is not an attractive option for businesses to rely on for their energy needs – in these cases, businesses are more likely to rely on alternatives, including fossil fuels like coal and gas, to support their energy needs. This is counter to the Government's strategic intentions to decarbonise the economy through increased electrification and will result in continued greenhouse gas emissions. The NZ Battery Project seeks to encourage investment in renewable generation and electrification of business energy needs to support achievement of renewable generation targets. This includes providing international confidence in New Zealand's electricity system, which is important to attract international investment. Finally, the NZ Battery Project will increase New Zealand's ability to meet electricity demands domestically, reducing reliance on international imports. This also reduces vulnerability to international fuel trade and production disruptions and price volatility.
LSF domains	• Our Institutions and Governance: firms and markets, central and local government, international connections • Aotearoa New Zealand: natural environment; financial and physical capital
He Ara Waiora elements	• Tiakitanga: Guardianship, stewardship (of the environment, particular taonga, other important processes and systems) • Manaakitanga: Enhancing the mana of others through a process of showing proper care and respect • Mana Whanake: Prosperity
Indicators	• KPI 3: Reduced price volatility • KPI 4: Increased confidence in the pace of emission reduction through increased share of energy supplied from renewable electricity generation
Who benefits?	• Electricity (and other energy) consumers (businesses, industry) • Current and prospective renewable generation entities and investors • New Zealand's economy • All New Zealanders by facilitating decarbonisation of the economy and achieving our emission reduction goals
Direct or indirect	• Direct
Monetisable or non-monetisable	• Reduced price volatility and accelerated emissions reduction monetisable • Business confidence non-monetisable

While these are the two main benefits of the project that directly link to the problem definition and investment objectives, investment in the NZ Battery project would deliver additional benefits which are set out in the Economic Case.

Enabling the increase of the renewable share of the electricity system, while maintaining a high level of reliability, is also likely to generate the benefit of maintaining or improving New Zealand's reputation as a good place to do business and attracting energy-intensive industries. Reducing reliance on imported fossil fuels could also provide energy independence benefits (see case study below).

1.6 Strategic risks

Risk is an uncertain event or circumstance that, if it occurs, has a negative effect on at least one project investment objective. The most significant risks that might prevent, degrade, or delay the achievement of the investment objectives are identified and analysed in Table 11. All risks will be monitored, managed, and updated as the project progresses.

Table 11: Main strategic risks of the NZ Battery investment

Main Risks		Comments and Risk Management Strategies (Mitigations)
1	**Incorrect assumptions result in asset redundancy** If there are material changes to the context within which the NZ Battery asset is being delivered, then it may mean a chosen solution is no longer considered to be an optimal way to address the agreed problem as intended. For example: • New technologies may become available sooner than anticipated which will address the problem • The private sector could invest in solutions to an extent that changes or addresses the problem • Climate change (e.g. more or less rainfall than projected) may mean the nature of the problem or solution changes • Assumptions for scale of storage / dispatch required may be larger or smaller than needed, resulting in either a proportion of the asset being redundant or further investment being required	The NZ Battery Project has been, and will continue to be, informed by comprehensive research, analysis, and market surveillance (e.g. on emerging technologies, climate change, market developments). Options will be assessed against their flexibility to different future state scenarios. Stage gate decision points will be built into the project schedule, at which point assumptions will be re-evaluated. Appropriate off-ramps will be provided to reduce the risks of redundant investment.
2	**Failing to be a good Treaty partner** The historic development of hydro schemes has led to Te Tiriti grievances. NZ Battery solutions have the potential to lead to further grievances where iwi / Māori are not involved meaningfully in the project.	Robust and meaningful engagement with iwi / Māori needs to be carried out throughout the project.
3	**Loss of social license** If the project is poorly communicated to project stakeholders, including the electricity industry and the public, then it is likely to experience resistance, bad publicity, loss of social license, and associated cost impacts and delays.	Develop a communications and engagement plan to ensure appropriate engagement and consultation during the subsequent stages of the project.

Main Risks		Comments and Risk Management Strategies (Mitigations)
4	**Unintended market consequences** If the market responds in unintended ways to the project, this may undermine strategic intentions of the project. For example: • Intended renewable generation build may be undermined by the project • Signalling of preferred options results in resource / land prices increasing significantly, increasing the cost of the project • Thermal asset owners may allow their assets to degrade, risking security of supply in the short-term prior to project delivery.	Current market uncertainty about the NZ Battery Project is largely a result of limited information available about what it is and how it will operate. Subsequent phases of the NZ Battery Project will involve significant engagement with the market on these points, which is likely to allay some concern. The NZ Battery Project is anticipated to improve incentives for private sector investment as it provides improved balancing of supply and demand and reduced volatility of wholesale prices. Understanding of this will be progressed through Phase 2. The NZ Battery Project will be supported by and integrated with complementary work programmes focused more broadly on delivering electricity security of supply, affordability, and sustainabili]ty policies and aspirations (see section 1.2.2).
5	**Change in government direction** If government policies, targets, and aspirations for decarbonisation, including for 100% renewable electricity, change, then the benefits of the project may be reduced.	The investment has been developed to support a range of outcomes across the energy trilemma, including providing various benefits in a less than 100% renewable electricity world, or one where this state is reached later than is currently targeted. Stage gates will be built into the project schedule. Appropriate off-ramps will be provided.
6	**Legal and environmental resource access challenges** If the project cannot address legal and environmental concerns or requirements for resource access, the project may not be able to function and deliver benefits as intended.	Early-stage consideration of consenting and environmental requirements has been and will continue to be built into the assessment of options. Stage gate decision points will be built into the project schedule, at which point the deliverability of the preferred option will be re-evaluated. Appropriate off-ramps will be provided.
7	**Project costs and funding** If the funding requirements for the NZ Battery investment are much greater than anticipated, there may be increased cost burdens for the Crown or electricity consumers.	The Indicative Business Case is informed by the current best available cost information, but this will continue to be updated as improved design information becomes available. The business case process will identify funding and financing mechanisms to support affordability assessment before progressing the design of the preferred option(s) further.

A Risk Management Strategy, and Risks and Issues Registers, have been developed and will be regularly and progressively updated as more detailed analysis is undertaken.

1.7 Key constraints, dependencies, and assumptions

The NZ Battery Project is subject to the constraints, dependencies, and assumptions outlined in Table 12. This is an initial evaluation and will continue to be updated as the project progresses.

Table 12: Dependencies, constraints, and assumptions for the NZ Battery Project

Dependencies		**Comments and Management Strategies**
D1	Energy strategy work	There is significant work occurring across the government's energy strategy workstreams. Future decisions made within the New Zealand Energy Strategy, Gas Transition Plan, Hydrogen Roadmap, action plan for decarbonising industry, transport decarbonisation, and Electricity Authority market development workstreams may impact the NZ Battery business case and investment, and vice-versa. While the NZ Battery Project is more advanced than the energy strategy work, the timelines are well set to align during Phase 2 in a way that will allow full policy integration while the design of the preferred solution is progressing. The MBIE NZ Battery team is working closely with other teams within MBIE progressing these workstreams and the project will be supported by engagement with broader stakeholders.
D2	Government decarbonisation commitments	
Constraints		**Comments and Management Strategies**
C1	Available technologies	The project requires a high assurance of delivery from any option selected, so the technological readiness of new and emerging renewable storage and flexible dispatch technologies, at scale, is critical. Delaying this project may (or may not) yield greater technology availability, but at the cost of significantly delaying the benefits of the project. The project team will continue to monitor technology developments. Given the time constraint to deliver the project , it may be that technologies that are currently mature will be most important for the NZ Battery Project.
C2	Available locations	The proposed solutions (especially pumped hydro) are limited to a distinct number of potential locations in New Zealand due to geography. Further, in the case of pumped hydro, significant land area would require flooding, and existing land uses further constrains possible locations. Broad desktop analysis of suitable sites has informed the longlist of options for pumped hydro, and these continue to be narrowed down based on various feasibility criteria.
C3	Available funding	The NZ Battery investment is anticipated to be high cost, including for both design and construction. There are competing priorities for infrastructure funding, and availability of funding may be a constraint. Each phase of the project will provide an updated cost estimate for the options, based on the best available design / technical information. Dedicated off-ramp points will provide risk mitigation if the cost becomes too high to be funded. Alternative funding and financing solutions will be explored through the business case process.
C4	Consenting	The potential solutions may be constrained by the ability to be consented (based on ability to avoid or mitigate local environmental, social, and cultural impacts) under planning legislation (the Resource Management Act 1991 / future framework). Each phase of the project will continue to progress consenting assessment, and options assessment will be informed by deliverability (including consentability).
C5	Labour / workforce	The investigations, consenting, design, and construction phases of the NZ Battery Project will require significant resourcing, including highly specialised skills, at a time when international and national workforces are constrained. This business case will begin to identify the kinds of

		capabilities required for the project and where these might come from. Future business cases will explore this in more detail.
C6	Existing infrastructure	
Assumptions		**Comments and Management Strategies**
A1	Policy direction	The business case assumes that existing policies and targets for decarbonisation and renewables will remain in place for the life of the project. The project team will continue to monitor any changes in government strategy and policy.
A2	Capable resources with capacity	The business case assumes that sufficient skilled resource, for both design and construction, can be sourced / trained. The business case process will focus on identifying specialist capabilities needed to deliver the project and exploring where these will come from.
A3	Future electricity demand / supply assumptions	The business case uses market modelling completed for the NZ Battery Project as the baseline for future electricity demand / supply assumptions. Incorrect assumptions may result any solution delivered not meeting the needs of the future. The project has placed a strong emphasis on building on and updating, rather than replacing, the ‘mainstream’ assumptions of particularly the Climate Change Commission and the ICCC. Importantly for analysis of dry years and high levels of renewable generation, the best available database of future hydro, wind, and solar ‘inflows’ and their correlations, and the likely effects of climate change, has been assembled. Flexibility is built into the options assessment, and scenario analysis further tests option performance under a range of future demand and supply scenarios.
A4	Operating and ownership model	This business case relies on assumptions about the operating and ownership model of a NZ Battery solution, though these may change significantly as the project is further refined at later stages. Different NZ Battery options may require different operating models, and these have been explored in the Commercial Case.

1.8 Summary of the Strategic Case

The Strategic Case has established the case for investment in an alternative solution to the dry year problem that does not rely on fossil fuels, to support New Zealand on the pathway to 100% renewable electricity, while maintaining reliability and affordability. A NZ Battery investment will need to solve the identified problem, *“Failure to address dry year risk in an increasingly renewable electricity system will impose significant costs on New Zealand”*. It will also need to deliver on the three Investment Objectives, which are to:

- Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system
- Put downward pressure on the total cost of electricity supply, compared to a future without NZ Battery, in a 100% renewable electricity system
- Accelerate emissions reduction through increased renewable share of energy.

The Strategic Case has identified the potential costs for New Zealand if the problem statement is not addressed, ranging from the environmental, cultural, and reputational costs of the inability to meet emissions reduction targets to the social and economic costs of unreliable and unaffordable electricity. It also outlines the benefits a NZ Battery investment could provide for New Zealanders, stemming from the electricity reliability, affordability, price stability, and market certainty that the project can provide.

The dry year problem is large-scale, long-term, and uncertain, and the potential solutions are anticipated to require significant up-front investment with some level of uncertainty in cost recovery. The Strategic Case has demonstrated that market settings and regulatory measures are unlikely to deliver a solution to the identified problem within the timeframe required for New Zealand to deliver on its emissions reduction targets and renewable electricity aspirations.

The Economic Case considers the potential solutions available to address the problem, deliver on the Investment Objectives, and provide the benefits identified in this Strategic Case.

1.9 Next steps

Any changes to government priorities, policy, and the market landscape would need to be reflected in the DBC.

The strategic case of this IBC is set against a complex policy backdrop where work is continuing to investigate the best ways for New Zealand to transition the electricity system to 100% renewables and the wider energy system to 50% renewables . Moreover, several industry participants are actively considering the future of current assets, or future investments. The DBC will need to remain cognisant and up to date with these developments to ensure the strategic case remains relevant.

2. Economic Case | Choosing a Preferred Option

Summary

The Economic Case sets out, assesses, and narrows a range of possible interventions / solutions to address the problem statement and meet Investment Objectives.

Options longlist: A long list of 28 energy storage and dispatch options were initially assessed against a set of three feasibility criteria.

Initial shortlist: Ten options remained after the initial assessment and were subsequently assessed as either being full, partial or supporting solutions for addressing dry year risk.

Refined shortlist: Geotechnical and additional feasibility studies, and, where the location was known, engagement with iwi, were then undertaken on the following five full or partial solutions to identify cost, feasibility and practical achievability in greater detail:

1. Flexible geothermal: this would involve developing geothermal generation and operating it in a flexible manner
2. Biomass: this would involve diverting logs from export, and then chipping and burning them in a combustion turbine to generate electricity.
3. Hydrogen: this would involve the build out of electrolysers to produce green hydrogen domestically and then storing it as green ammonia
4. A pumped hydro scheme at Lake Onslow in Central Otago
5. A pumped hydro scheme in the central North Island.

Electricity Market Modelling (EMM) was also undertaken on the first four of these options.

This additional work helped determine the ‘base case’ configuration of the different options. It also:

1. Confirmed that the flexible geothermal, biomass, and hydrogen options are unlikely to solve the dry year problem on their own. Instead, it was determined that a Portfolio option made up of these technologies should be taken forward to the economic assessment phase. This option is intended to provide a proxy for a distributed non-pumped hydro solution to address the dry year problem in a 100% renewable world.
2. Removed the North Island pumped hydro option from economic consideration in this IBC. This option was removed pending further engagement with iwi. Pending that engagement, further work would be required to better understand how it would interact with existing hydro schemes, and so its real economic potential. Early EMM undertaken on a North Island pumped hydro proxy scheme indicates the potential for such a scheme to provide a significant contribution to addressing dry year risk.

As a result, the options taken through to economic assessment phase were:

- **A pumped hydro scheme at Lake Onslow:** This option has 1,000 MW of pumping and generation capacity and energy storage capacity of 5 TWh.
- **A Portfolio option:** This is an additive portfolio of biomass, flexible geothermal, and hydrogen (including as demand response). The base case modelled would provide 1,200 MW of generation/load reduction capacity that could provide 2.4 TWh over three months. However, its precise configuration has not been optimised.

These two options have been compared against a counterfactual scenario of a 100% renewable world but with no new large-scale storage in place for dry year cover.

Multi-criteria analysis (MCA): A detailed MCA has been completed on these three scenarios. This includes cost-benefit analysis (CBA) embedded within the value for money criterion. This analysis has been informed by engineering and feasibility reports commissioned on each technology and by EMM that has helped determine:

1. The likely generation stack built under each option,
2. The expected revenue of each option, and

3. How effective each option is at solving the dry year problem (using curtailment, demand response and green peaker use as proxies).

The outcomes of the MCA are outlined in the table below:

	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
Unweighted total	**1**	**-1**	**3**
Weighted total	**-0.48**	**-0.25**	**-0.20**
Rank	**3**	**2**	**1**

Value for money / BCR calculations are particularly sensitive to modelling assumptions and due to the criterion's relative importance in the MCA a change in assumptions has significant influence on the outcome. In two of the key sensitivities tested as part of the CBA, the BCR results for both options materially improved:

- **NZAS stays:** In a world where the New Zealand Aluminium Smelter (NZAS), or some similar South Island load remains, BCRs for the Lake Onslow and Portfolio options move from 0.42 to 0.66 and 0.40 to 0.54 respectively
- **Discount rate sensitivities:** With the application of a sensitivity of a lower discount rate of 2%, the BCRs for the Lake Onslow and Portfolio options move from 0.42 to 0.75 and 0.40 to 0.54.
- **NZAS stays and discount rate sensitivities:** With the application of both sensitivities above being applied simultaneously, the BCRs for the Lake Onslow and Portfolio options move from 0.42 to 1.12 and 0.40 to 0.73.

A large-scale energy storage option is preferred to address dry year risk in a 100% renewable world: The outcome of the MCA indicates that, while all three scenarios could deliver a 100% renewable world, the Lake Onslow and Portfolio options out-perform the counterfactual scenario. The Portfolio option narrowly out-performs the Lake Onslow option.

Both options:

- Appear effective at solving the dry year problem
- Reduce curtailment, demand response and green peaker use when compared to the counterfactual
- Are expected to reduce the amount of renewable generation required to be built.

However, both options are very costly and score poorly on the value for money and affordability metrics.

A considerably greater amount of work has been completed to date on the Lake Onslow option. As a result, there is a greater degree of confidence in how it has performed through the MCA. There is less confidence in the performance of the Portfolio solution and further work could significantly improve or worsen its performance. Uncertainties about the option therefore need to be narrowed to confirm the outcome of the MCA.

It is recommended therefore that both options be taken forward for further consideration.

2.1 Purpose of the Economic Case

The purpose of the Economic Case is to:

- Outline, assess, and rank the potential options available to address dry year risk and meet the NZ Battery Investment Objectives
- Identify a preferred investment option that delivers the best public value to New Zealand, including wider social and environmental effects, to be taken forward to the Commercial, Financial, and Management Cases.

2.2 Introduction

As noted in the Strategic Case, the overall outcome sought from a NZ Battery investment is to solve the problem statement:

Problem Statement: "Failure to address dry year risk in an increasingly renewable electricity system will impose significant costs on New Zealand"

In doing this, the investment should address dry year risk in a way that avoids imposing significant economic and social costs on New Zealand and meets the following Investment Objectives:

- Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system
- Put downward pressure on the total cost of electricity supply, compared to a future without NZ Battery, in a 100% renewable electricity system
- Accelerate emissions reduction through increased renewable share of energy.

It is expected that an investment in a NZ Battery solution that achieves the above might also provide wider benefits and costs. That is, it may provide beneficial services other than dry year cover, for example, peaking and intermittent firming benefits or the production of alternative fuels that have value. These wider impacts are important and should be considered as part of the decision-making process but are not the primary drivers for the investment. This IBC is concerned primarily with addressing dry year risk.

2.2.1 The investment context is challenging

Before outlining the economic assessment process, options, and outputs, it is critical to acknowledge the investment context. Specifically:

- **There is a large solution set**: There are several potential technical solutions that could be used either alone or in combination to address dry year risk. Further, there are a significant number of different configurations for many of these solutions reflecting different combinations of size, location, technologies, and feedstock etc. This makes the breadth of potential solutions a challenge to consider
- **The end state for some technologies is uncertain**: Each potential solution has a different degree of technological maturity. Some solutions involve mature technologies currently in use in New Zealand and / or globally. Others are under development with significant uncertainties as to final capability and cost, and with unknown technology pathways and delivery timeframes. Additionally, it is also likely that over the long-time horizon of such an investment there may be a range of technical solutions that are developed that do not exist yet. This makes comparing different solutions difficult

- **The preferred option must operate in a complex market**: It is a challenge to predict with confidence how the market will respond to emerging renewable energy policy signals over, and beyond, a 40-year time horizon; how emissions pricing will change; and how the current electricity market might interact with a physical NZ Battery solution (if preferred). It is also unclear how such an investment (and the associated price impacts) would assist or hinder future investment activity, acknowledging that any preferred NZ Battery investment must coexist with, and complement, a significant uplift in generation investment to meet future demand
- **The impacts of an investment of this scale**: The impacts of a NZ Battery solution will affect a wide range of stakeholders and generate a breadth of costs, benefits, and impacts that need to be considered. These impacts will be both local (in the form of environmental, socio-economic, and cultural impacts to local communities) but also on a macro scale (impacting New Zealand's carbon emissions profile). Comparing and understanding the trade-off between these potentially competing interests is difficult and contentious.

2.2.2 Methodology for the Economic Case and key components

To recognise and manage the complexity, scale, and uncertainty outlined above, the assessment methodology in this Economic Case has been developed based on a principle of materiality. Applied, this means that the economic assessment framework used in this case is designed to streamline analytical effort and apply an intense lens to only those items where costs, benefits, and impacts are expected to be significant (or to significantly differentiate solution options).

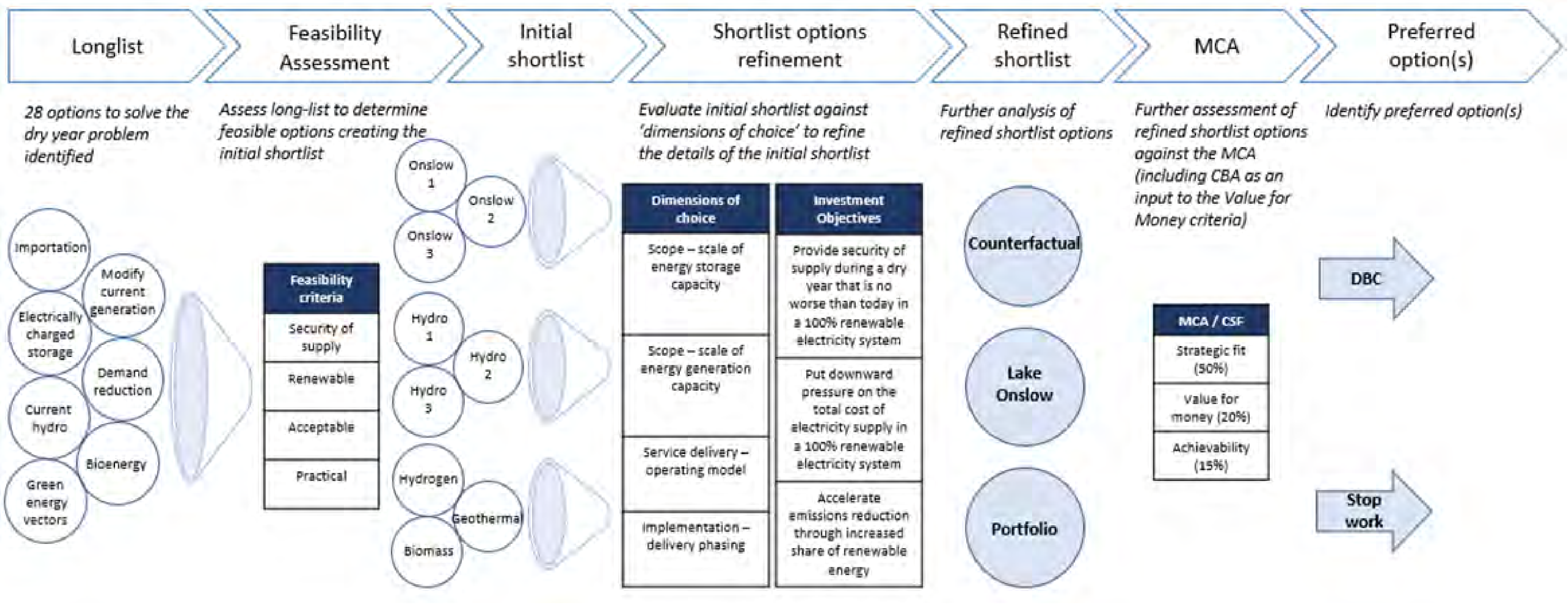
However, in recognition of the potential impact of this IBC and to ensure that the assessment undertaken has sufficient rigour, this case makes use of conventional economic tools and methodologies and relies on professional engineering and feasibility reports to draw conclusions.

The key components in this case to narrow the range of potential solution options to a robust preferred investment option are:

- Identification of a longlist of potential solutions
- Development of an initial shortlist using a feasibility filter (making use of reports and feasibility studies commissioned specifically for the NZ Battery Project)
- Refinement of the shortlist by identifying those that could meet the Investment Objectives, making use of electricity market modelling (EMM) and findings from engineering and feasibility reports
- Assessing the shortlist of options using multi-criteria analysis (MCA), which aligns explicitly to Treasury Critical Success Factor (CSF) guidance. This MCA includes a detailed cost-benefit analysis (CBA) based on the benefits and costs provided from engineering and feasibility reports, EMM and an assessment of any wider economic costs or benefits able to be monetised
- The selection of a preferred option or option(s).

A summary of the full economic assessment methodology is provided in Figure 21.

Figure 21: Economic assessment framework overview



2.3 A longlist of 28 technologies

At the outset of the project a longlist of 28 technology options that could theoretically address dry year risk was identified. This section outlines, assesses, and narrows this longlist.

2.3.1 The long list contains seven different solution types

As countries work to meet decarbonisation and emissions targets, significant investment has been directed into the research and development of renewable energy generation and storage.[43] This investment has led to the development of numerous technologies able to store and dispatch energy in a way that could help address dry year risk.

A longlist of 28 different technology options was identified early in the NZ Battery Project by the NZ Battery Project team and MBIE Energy Markets policy team. The list was peer reviewed by the NZ Battery Technical Reference Group and Arup Ltd, and further considered by WSP Ltd. The options include both commercially available solutions and those currently under development.

These 28 options are broadly categorised into seven different solution types:

1. **Reduction in electricity demand** – this category explores four options that consider different approaches to reducing electricity demand without making changes to electricity generation supply (e.g., increased energy efficiency)
2. **Increase existing hydro storage** – this category explores three options that consider different ways of increasing or improving the storage available / accessible in New Zealand’s current hydro system
3. **Develop electrically charged storage** – this category explores eight solution options that use electricity and convert it to another form of energy (e.g., gravitational potential energy, rotating mass, chemical potential energy etc.) that can be stored for months or years and then re-converted into electricity. Pumped hydro is one such technology
4. **Build or modify current generation** – this category explores five solution options that increase or modify existing electricity generation technologies (e.g., build additional baseload generation)
5. **Green energy vector (hydrogen)** - this category covers three solution options that make use of hydrogen and hydrogen carriers (e.g., ammonia) to store energy to be used to power future electricity generation
6. **Bio-energy** – this category explores four solution options for biofuel systems that can support flexible bio-fuelled generation (e.g., biomass, biogas etc.)
7. **Importation of energy** – this category explores the importation of electricity from Australia via an HVDC link across the Tasman Sea.

In addition, regulatory intervention has been considered as a potential option for addressing dry year risk. However, regulatory intervention has not been considered as a solution in and of itself through the IBC. Rather, it can create conditions necessary for the market to solve the problem, drawing on or supporting the options identified under the categories above.

Each of the longlist options are described and assessed in Appendix C.

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[43] See for example https://www.iea.org/reports/world-energy-investment-2019/rd-and-d-and-new-technologies.

2.3.2 Feasibility criteria were applied to identify an initial shortlist

To narrow the longlist to a manageable initial shortlist, a set of feasibility criteria was identified and used as an initial pass / fail hurdle. The intent of this phase was to apply a consistent analysis framework to ensure that all shortlisted options could:

- Provide a minimum acceptable amount of flexible electricity demand / supply to support dry year management
- Supply electricity from renewable sources. i.e., is compatible with a pathway to 100% renewable generation
- Be practical from a technological, deliverability, and acceptability perspective.

The feasibility criteria, their rationale, and the assessment considerations are set out in Table 13.

Table 13: Feasibility criteria

Feasibility criterion	Description
Mitigating dry year risk	Is the option able to be operated reliably and at the scale needed to provide security of supply through infrequent and prolonged dry conditions? Specifically, can the solution reasonably be expected to: 1. Have sufficient fuel and/or flexibility to vary its operations by ~ 3 TWh as a single solution, or ~1 TWh as a partial solution. 3 TWh of storage has been identified as a threshold for a full solution as it is a midpoint of typical inflow variation in dry years when compared to normal hydrological inflow years. 2. Have the ability to dispatch ~1TWh of generation within three months in dry years. 1 TWh was chosen as the threshold as similar to the energy storage threshold above it similarly provides a midpoint of generation required to meet demand in years of low hydrological inflows.
Renewable[44]	Does the option help to meet New Zealand's renewable electricity generation targets? Specifically, does it support ambitions for 100% renewable electricity generation by 2030?
Practical	Is this option broadly and reasonably considered practical to deliver? This criterion has four parts: 1. Is the technology that underpins the option viable or likely to be viable at scale by 2035. 2. Is there sufficient feedstock to operate at scale. 3. Is the option constructable by 2035. 4. Is the option likely to be acceptable from an environmental, regulatory, social, and cultural perspective. * While the Government has an aspirational target of 100% renewable generation by 2030, the Economic Case uses 2035 as the base year for consideration. This is done to allow enough time to ensure that any options progressed could be credibly built and be operational. The MCA in the later assessment stage below considers the value of a more accelerated development, including delivery by 2030 where this is possible.

The assessment of each option against the feasibility criteria has been completed using the following information sources:

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[44] Note: Renewable electricity generation means a source of electricity generation that is not depleted when used, including rain, wind, sunlight and geothermal. Renewable electricity generation does not necessarily mean zero emissions.

- Desktop research of each option and comparable case studies, as well as knowledge from within the NZ Battery Project Team, the wider MBIE Energy Markets teams, and the Technical Reference Group
- An external peer review of an initial feasibility assessment and identification of options for further consideration
- Reports commissioned for the NZ Battery Project, and subject to peer review, into options that were identified for further consideration, including:
    - Engineering, geotechnical, environmental, social and cultural feasibility reports into pumped hydro at Lake Onslow
    - A GIS scan of the country to identify other geographically feasible pumped hydro sites, and a feasibility assessment of two options it identified, as well as a traditional hydro option
    - Preliminary feasibility and applicability assessments into bio-energy, green energy vector, and geothermal options; as well as a subset of electrically charged storage technologies.

A full list of the reports commissioned is provided in Appendix A.

2.4 The initial shortlist of 10 potential solutions

The initial feasibility assessment resulted in a shortlist of 10 potential solutions, which can be split into three categories:

1. **Standalone solutions:** These are options that are large enough to provide a standalone solution to address dry year risk. Three solutions – two of which are pumped hydro options – were identified as standalone solutions
2. **Partial solutions:** These are options that provide meaningful levels of storage and generation but not to a level that is able to provide a standalone solution. These solutions would need to form part of an additive portfolio to address dry year risk. Five options fit this category
3. **Supporting solutions:** These are options that do not meet the feasibility criteria on their own but could form key elements of any solution. Four options fit this category.

A summary of the shortlisted options within these three categories is described in Table 14 below. These options formed the initial shortlist of options, with all other options discarded.

It was determined that five standalone and partial solutions warranted deeper investigation and analysis.

Table 14: Initial shortlist

Standalone solutions		
Option	**Description**	**Rationale for shortlisting**
Intermittent renewable generation	This describes the build out of renewables (predominately solar and wind) – including to an extent where significantly more energy is produced in an average year than is necessary to meet demand (overbuild), but which is just sufficient to meet demand in a dry year. This could include both large-scale projects by commercial providers and small individual and community scale projects (distributed energy resources).	Work completed indicates this option: • Could be built out incrementally to the point that there is enough energy 'spill' in an average year, such that electricity demand in dry years is substantially met. • Provides a renewable solution. • Practicality of this option may be limited by how many wind / solar developments can be built given available resources, and a limited timeframe. Significant renewable generation build out is considered a necessary pre-condition of New Zealand's future electricity system to meet demand, and hence occurs in any future scenario we consider. At the extreme, it can be considered a standalone solution. However, it may also be considered a partial solution, or supporting solution as some options could capture energy that would otherwise be 'spilled' in an average year and store it for dry year use.
Lake Onslow Pumped Hydro	This is a potential large-scale pumped hydro scheme at Lake Onslow in the South Island. This option was known prior to the instigation of this Project but has also been confirmed as a viable pumped hydro option through NIWA's nationwide GIS mapping exercise. This scheme could take several different configurations depending on the size and capacity of storage and generation required. The option would involve a large-scale dam with an upper and lower reservoir used to store energy as elevated water. Pumped hydro schemes work by drawing electricity from the grid when electricity is abundant (often when renewable generators are providing electricity to the grid in volumes that exceed demand – e.g., when it is windy during off-peak hours) and pumping water from a lower reservoir to be stored in an upper reservoir. By doing this, a pumped hydro scheme converts electricity into gravitational potential energy. When electricity becomes scarce (often during periods where renewable generators are not producing	Work completed indicates this option: • Provides energy storage and dispatch at a range of sizes (all above the targeted storage and generation thresholds). Potentially feasible size options include: a. 3 – 7.5 TWhs of potential storage capacity, b. 250 – 1,250MWs of generation capacity. • Provides a renewable solution to store and dispatch energy flexibly. • Uses mature technology (pumped hydro schemes are in use around the world) and delivery of the option is considered feasible to deliver by 2035. Work done to date also shows that this option would also have significant environmental, local, and cultural impacts. These are assessed in the MCA.

Standalone solutions		
Option	**Description**	**Rationale for shortlisting**
	enough electricity to meet demand – e.g., during calm and cloudy periods or in dry years) water is released back down to the lower reservoir converting gravitational potential energy back into electricity and providing it to the grid.	
Other Pumped Hydro options – subsequently narrowed to a central North Island option	NIWA's GIS mapping exercise identified a number of sites that had the geographical features necessary to support a pumped hydro scheme. Two of these – both in the central North Island - justified closer consideration. Desktop analysis was carried out by Stantec on these two options, plus a traditional hydro option of expanding Lake Pukaki. The conclusion of that work was that just one of the options - a pumped hydro site at the southern end of the Kaimanawa ranges, at Upper Moawhango in the North Island – could practically address the dry year problem. This scheme would pump water from, and generate into the Tongariro Power Development (TPD).	Work completed to date indicates this option: • Provides energy storage and dispatch at levels close to the feasibility thresholds. Desktop analysis shows that it could provide 2.75 TWh of energy storage and 570 MW of additional generation. • Provides a renewable solution to store and dispatch energy flexibly. • Uses mature technology (pumped hydro schemes are in use around the world) and the option is considered feasible to deliver by 2035. Similar to the Lake Onslow option, work done to date shows that this option would also have significant environmental, local, and cultural impacts. Estimated energy storage volumes for this option are slightly below the feasibility criteria thresholds for a full solution. However, it has been included as a full solution because indicative EMM on a proxy North-Island pumped hydro solution suggests that such a scheme could provide considerable benefits because of its proximity to high demand centres and location north of the HVDC link. In contrast, Lake Onslow's location in the South Island means that its potential benefits would be constrained by the link. Specifically, EMM has shown that a hypothetical North Island Battery with dimensions of 1TWh storage and 800MW generating capacity could offer levels of gross benefit equivalent to a 3TWh / 800MW South Island solution.

Partial solutions		
Option	**Description**	**Rationale for shortlisting**
Flexible Geothermal	This option would involve developing new geothermal generation and operating it in a flexible manner. Such a plant would be similar to a standard geothermal plant but would be run differently: • In a reduced capacity mode for electricity generation in normal years (maintaining some geothermal field operation would be necessary for technical reasons), and • At an increased output mode in dry years to make up for the reduced hydro output.	Work completed at the time of writing indicate this option: • Could potentially provide 300 MW of flexible capacity, capable of providing around 2.4 TWh of energy across a year, or 0.6 TWh in three months in dry years. A further 100 MW of capacity would operate in a baseload role to maintain operability of the plant. This option would not provide a full solution, because the geothermal resource in New Zealand is limited, and developing multiple sites would require an intensive development programme. • Would utilise renewable resources - though noting it does have operating carbon emission implications. • Uses mature technology, well-established in New Zealand. Our domestic expertise is considered capable of supporting an intensive development programme and uncommon deployment of the technology (i.e., flexible use).
Hydrogen	This option would involve the build out of electrolysers to produce green hydrogen domestically, and then storing it as green ammonia. Hydrogen production would provide a source of flexible capacity in two ways: 1. The electrolysers could act as a source of flexible demand that could be interrupted during dry periods. 2. The green ammonia produced could be used as a fuel within a generator to produce electricity in dry years (it is expected the balance of ammonia produced would be sold or exported).	Work completed indicates this option: • Could provide a source of flexible demand and stored fuel which, in combination, could likely contribute around 0.8 TWh within three months. Hydrogen is not considered feasibly able to solve the dry year problem on its own given the size of electrolysers and / or ammonia storage required, and the challenges to large-scale long-term demand response. • Carries uncertainty because there would be a need to rely on green ammonia import / export markets, which are in their infancy. • Provides a renewable solution, assuming it can rely on 100% renewable electricity as an input fuel. • Is potentially technically feasible and constructible at sufficient scale to provide a partial solution by 2035 - though similar large-scale projects do not currently exist internationally, and long lead times are expected on key equipment. Further, there is the risk of ammonia sales not being possible at the volume or price necessary for flexible production to be feasible.

Partial solutions		
Option	**Description**	**Rationale for shortlisting**
Biomass	This option describes the diverting of logs from export, and then chipping and burning them in a combustion turbine to generate electricity.	Work completed indicates this option: • Could provide energy storage and dispatch of 1 TWh over three months – and potentially more over a longer period if additional fuel can be accessed and delivered when required. • Provides a renewable solution, provided it draws on a sustainably managed biomass resource – though noting there would be emissions from log transport. • Uses technology that is mature, and delivery of the option is considered feasible by 2035. However, there is uncertainty around the supply chain and storage-life of logs, and the opportunity cost of other uses of the forestry resource.

Supporting solutions		
Option	**Description**	**Rationale for shortlisting**
Improved energy efficiency	Energy efficiency means achieving the same output – for example heat, light – with less energy. Increased energy efficiency results in an enduring, long-term, reduction in load.	Energy efficiency has not been further shortlisted for a NZ Battery solution as, while it reduces demand, it does so across all years and does not provide a sufficient response such that it can ensure energy sufficiency through prolonged dry periods. However, improved energy efficiency is important and highly beneficial for the electricity system (and consumers) for many reasons, and we have assumed significant improvement in efficiency will occur throughout the modelling period of this project.
Demand response – load shifting	This option describes a reduction in load (energy use) by industry, and commercial and residential consumers in response to price signals (e.g., high market prices, where the responder is exposed to the price). Most demand response results in short-term shifting of load from one point in time to another (e.g., from evening to overnight), rather than decreasing it. In general, though some price-based demand response will result in a permanent decrease in demand, and behavioural changes can have longer-term load reduction effects.	This option has not been further shortlisted, as it does not generally result in a large-scale reduction in demand that could be sustained for weeks or months during a dry year. To the extent it did achieve this, it would be expected to result in significant economic cost. However, demand response for short durations is important and highly beneficial to the electricity system (and consumers) for other reasons. We have assumed, within the EMM, that some level of price-based demand response / load shifting will occur.

Supporting solutions		
Option	**Description**	**Rationale for shortlisting**
Lithium ion and other battery storage	This option would use lithium-ion or comparable technology for short-term storage, load shifting and arbitrage, over time scales measured in hours. It could comprise large utility scale batteries or aggregated distributed batteries.	This option has not been further short listed as it not a viable or cost-effective technology for storing large amounts of energy for long periods of time, and using it infrequently – particularly at the scale needed for dry year security. However, this technology is expected to be feasible for capacity firming and peak load shifting (e.g., from evening to overnight), and will form an important part of New Zealand's future energy system in that role. The EMM includes significant uptake of batteries for this purpose.
Large scale load reduction (planned)	This option would involve pre-contracting large-scale industrial or commercial plant to reduce consumption when specified for security of supply purposes. The customer would be compensated for their response.	This option has been short listed. However, work completed at the time of writing has indicated that: • Demand response from any individual customer would not be able to provide close to a 1 TWh response over three months. The exception to this is hydrogen, which we capture above. There is also some potential for an earlier, longer, and somewhat deeper response from the Tiwai smelter, though it is assumed to have retired by 2035 as the base case within our EMM. The response available from pulp and paper is effectively captured within our modelling assumptions. Given the size of other New Zealand consumers (existing and prospective), multiple would need to be interrupted for any meaningful contribution to the dry year problem. • Provides a renewable solution, but may have emissions implications if lost production is made up for by an increase in more emissions-intensive production overseas. • Impractical for most consumers to withstand a substantial and sustained disruption to their electricity supply that was not forecast. Our consideration of demand response is limited to that from hydrogen production (above), and from the Tiwai smelter under our sensitivity analysis within the EMM work completed.

2.5 Deeper investigation and analysis of a refined shortlist of 5 options

Consultants were engaged to undertake deeper investigation of the refined short list of 5 options. This work included:

- Detailed feasibility assessments of the Lake Onslow option, carried out by Te Rōpū Matatau (TRM), a consortium of firms led by engineering consultancy Mott MacDonald New Zealand, with engineering consultancy GHD and environmental planning and design consultancy Boffa Miskell. TRM has carried out geotechnical field-work, environmental field studies, and social / cultural assessments, to develop a deeper understanding of the costs, key design elements and construction timeline for the Lake Onslow option
- Desktop feasibility assessments on the flexible geothermal, biomass, and hydrogen options, carried out by WSP Ltd. These feasibility studies outlined key considerations for each of the specific technologies, indicative costs and timelines to construct them, and environmental, social and cultural assessments
- As noted in the table above, Stantec undertook desktop engineering assessments of three alternative hydro options
- EMM to understand the potential gross electricity market benefits of each option
- A market integration report to understand how to reduce market integration risk for a large single solution
- Engagement with iwi in relation to both Lake Onslow and a North Island pumped hydro option.

2.5.1 Identification of the portfolio solution

As outlined in Table 14 and Appendix C, feasibility studies identified flexible geothermal, biomass, and hydrogen as the most feasible non-hydro options for solving the dry year problem, given their likely ability to provide storage or flexibility of material scale and duration, provide a renewable solution, and be practical to deliver by 2035.

WSP's more detailed analysis has identified feasible concept designs for these technologies as dry year solutions in the New Zealand context. The concept designs have not been optimised in an engineering or commercial sense, but are sufficient to allow an understanding of the capability, costs, risks and opportunities arising from these technologies if deployed to help solve the dry year problem.

The study indicated that each option could only feasibly store or access enough energy to produce ~1 TWh of flexible electricity generation over a few months in an infrequent dry year. As a result, none of them are considered capable of solving the dry year problem on their own.

Instead, it was determined that a Portfolio option made up of these three non-hydro technologies would be taken through to EMM and the MCA assessment. The configuration of this Portfolio option is set out in section 2.7. It includes all three technologies, using the concept designs identified through the WSP report. This combination would allow around 2.4 TWh of energy to be delivered over the course of three months, with a smaller ongoing response able to be provided where electricity deficits last longer. For example, given flexible geothermal does not rely on a finite feedstock, it could continue to be operated in a 'ramped up' mode for an indefinite period. In addition, a hydrogen electrolyser could remain switched off, and the biomass component could try to identify, purchase and use additional feedstock to generate electricity.

The build-up of the technologies within the Portfolio option has not been optimised. There are a range of ways the three technology concept designs could be configured, scaled, or replicated. It may be that a different combination presents the most net-beneficial approach to solving the dry year problem. However, the Portfolio option put forward represents a base case that allows a meaningful assessment. Further work would need to be undertaken to identify an optimal approach. It is also possible that, in practice, a Portfolio option would be progressed in a technology agnostic way. Further work would also need to be undertaken to confirm feasible delivery models.

2.5.2 Electricity Market Modelling and comparator options

A significant contributor to the evidence base for the Economic Case has been the completion of EMM results.[45] The EMM measures the benefits for each option as being their ability to optimise the electricity system by reducing the total OPEX and CAPEX required to meet demand over time.

The gross benefits of the different NZ Battery options are modelled with variable or fixed OPEX but not their CAPEX. This is done in recognition that there are multiple design sub-options for each option with different associated costs. For example, a 5 TWh, 1 GW Lake Onslow has several different possible configurations (for example lower reservoir location and size). This approach of modelling gross benefits allows each option to be compared, agnostic to these design sub-options.

2.5.2.1 A counterfactual of a 100% renewable world with no battery solution

The purpose of the NZ Battery Project has been to identify the best way of solving dry year risk in a 100% renewable world.

Accordingly, the identified counterfactual reflects a scenario where all electricity generation is renewable but no large-scale NZ Battery storage option is in place. This is intended to be a credible representation of a likely market outcome where thermal generation is phased out of the generation stack by 2035 and renewable sources are built to balance the market.

To ensure there is reliable dry year cover, this option would require, and so assumes, significant renewable overbuild.**[46]**

The counterfactual also allows for the presence of a carbon-neutral, dispatchable electricity generator, with a high short-run marginal cost (SRMC) – hereafter referred to as "green peakers". These peakers are used in the model to dispatch electricity to cover shortfalls

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[45] EMM simulates how the electricity market responds to different interventions overtime by building out a theoretical generation stack based on a range of constraints and inputs to meet future demand.

[46] Renewable overbuild describes the uneconomic build out of renewable generation – this is derived by taking the difference in the amount of renewable generation build out in the counterfactual relative to the Lake Onslow option. Renewable generators built under this scenario would spill significant amounts of electricity in years of normal hydrological inflow but be utilized more effectively in dry year when energy from hydro generators is scarce.

greater than a day (as within day shortage would be addressed by grid scale batteries). Green peakers are included in the counterfactual scenario to ensure that the scenario modelled remains credible, noting that in their absence, electricity shortages would occur at frequencies and for periods that would be socially untenable.

Green peakers are intended to represent plant that produces electricity in short bursts to balance the market, for example during demand spikes or when the wind drops off. Through the EMM they have been priced at $480/MWh, reflecting high fuel costs, which generally discounts them from playing a regular role in the market. However, during dry years, with longer term energy scarcity, the peaker plant would likely also play a role in meeting the energy gap left by hydro.

A credible generation source for a green peaker could be imported ethanol or biodiesel. An assessment by WSP of potential green fuel options suggests a $480/MWh offer price may be at the low end of what is likely for these fuels. As such, the cost of green peakers – and hence the value that NZ Battery interventions provide by displacing them – is likely understated.

Green peakers differ from the more substantial assets in the Portfolio option because they are assumed to exist on a purely commercial basis (i.e. without direct government intervention) given their frequent short-stint operation, and the relative simplicity of sourcing and storing fuel or other forms of flexibility for that mode of operation.

2.5.2.2 What happens if we "do nothing"?

Doing nothing describes a market in which no NZ Battery or further electricity market interventions are progressed. Under this scenario, it is expected that the market would retain thermal generation to meet peaking demand and address dry year risk, and the lowest cost generation would be built regardless of whether it is renewable.

The NZ Battery options have not been compared to a do nothing scenario through this IBC, reflecting the purpose of the project noted above. However, it is recommended that this comparison is undertaken to inform any Final Investment Decision. Issues of transition from the current generation fleet to 100% renewables are critical to the do nothing scenario, but have not been investigated through the NZ Battery Project. This work is underway through the broader energy transition work programme .

2.5.2.3 Each option has been modelled using the same electricity market modelling assumptions

To ensure all options are comparable, consistent base assumptions are used in the EMM. The only difference between the options is the addition of the technology they use to cover dry year risk.

All options are assessed relative to the counterfactual. This means that a key benefit of each option is the degree to which they reduce the amount of renewable generation build (and related CAPEX and OPEX) required to balance the market over time. Except where we have specifically commissioned work to inform them, the key assumptions used in the modelling align with 'mainstream' or published equivalents wherever possible and are outlined in Table 15.[47]

Table 15: Key EMM assumptions

Key assumptions	Description
Demand	In alignment with Climate Change Commission modelling, future electricity demand is anticipated to increase significantly between 2022 and 2065 - the end of our modelling period. This is due in large part to the electrification of the transport and industry sectors. For the purposes of our modelling, NZAS is assumed to leave, and demand is expected to be: • 2035 – 49 TWh • 2050 – 65 TWh • 2065 – 72 TWh Given the uncertainty of NZAS's future, we have also modelled an "NZAS stays" scenario as a sensitivity.
Demand curtailment / response	All options anticipate the use of demand response in reaction to prices. The amount of load available for curtailment is expected to be: • 2035 – 0.6TWh (1.2%) • 2050 – 0.8 TWh (1.2%) • 2065 – 1.0 TWh (1.4%) Of demand response available, curtailment is expected to occur to differing levels. These are: • 40% at $700/MWh • 30% at $1,000/MWh • 30% at $1,500/MWh All options also provide for shortage costs.
Intermittent firming	**Grid-scale batteries:** For immediate / short-run intermittent firming, all options assume the build out and use of grid-scale lithium-ion batteries, with operational storage of 5 to 12 hours. **Green peakers:** As outlined above, green peakers are a technology agnostic peaker used to firm renewable generation and cover shortfalls greater than a day at a SRMC of $480/MWh. Green peakers must also recover CAPEX of $1,000/kW and fixed operations and maintenance costs of $24/kW/year across their operating hours. We assume no limits to their use.

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[47] NZ Battery Economic Modelling Assumptions, NZ Battery Project Team, 2022.

Key assumptions	Description
Climate change	The model accounts for likely impacts of climate change by adjusting historical inflow patterns to reflect seasonal changes in wind and hydro[48]. • For hydro, it is assumed that there will be more rain in winter and less snowmelt in spring. • For wind, it is assumed there will be lower wind speeds in the North Island and higher wind speeds in the South Island.
Energy efficiency	Energy efficiency is anticipated to reduce total electricity demand by 1% per annum per person (we have adopted the Climate Change Commission's assumptions).
Thermal generation retirement	In all options, coal and gas are anticipated to be phased out of the generation stack before 2035. For all options except the do-nothing option, fossil fuelled thermal generation is anticipated to be fully retired before 2035.

2.6 Applying dimensions of choice

The options described above all pass the feasibility criteria, but are conceptual i.e., they do not yet define the design elements, size or potential configurations the option could take. In practice, their definition will have a significant impact on the functionality and eventual assessment of the options e.g., a pumped hydro option with a larger storage design size will cost more and produce different results than a smaller one.

Given this, it is important that the options are explicitly defined to ensure that it is clear what is being assessed and to ensure that the options as defined are aligned to the Investment Objectives and work to maximise potential benefits.

To determine the best configuration of each shortlist option, dimensions of choice, as proposed by Treasury, are a structured and robust way of undertaking this refinement. Six dimensions of choice have been identified across each option. These are:

1. **Energy storage capacity:** Each option has a range of potential energy storage capacity (in TWh) it can possibly hold or can feasibly be used as feedstock.
2. **Electricity generation capacity:** Each option has a range of potential generation capacity it can produce (in MW).
3. **Operating parameters:** Each option has a range of ways it can operate. This includes:
    - **Electricity market:** Should the option be restricted to operating (or reducing load) in times of electricity scarcity, or should it operate whenever economically profitable to maximise generation revenue (subject to a minimum storage thresholds)?
    - **Export and domestic markets:** For example, a hydrogen option produces feedstocks that can be sold for other, non-electricity generation, purposes. Should it make use of these channels to maximise revenue and cycle unused storage capacity?
4. **Delivery phasing:** Options may have flexibility in the way they are delivered e.g., they could be built as modules over time or all at once. Delivery phasing will influence when the option is operational and therefore when it can begin delivering benefits to the

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[48] Dr Jen Purdie, Climateworks, 2022.

electricity market. In addition, delivery phasing will also impact the market's ability to supply materials and labour for the projects.

5. **Ownership:** Ownership is discussed in greater detail in section 3.2.2 in the Commercial Case. This IBC does not determine the optimal ownership for each option. However, for the purposes of further economic analysis, the following ownership models have been assumed for each option:
   - **Pumped hydro option:** Given their size and market power it is assumed that a pumped hydro option would be Crown owned. This does not impact upon assumptions on operational decision making around energy dispatch and storage.
   - **Portfolio option:** It is assumed that the Portfolio options would be privately owned but, because of their dimensions, have their generation and storage dispatch rules determined through contract and / or regulation.
6. **Procurement method:** Procurement is discussed in greater detail in section 3.2.3 of the Commercial Case. This IBC does not determine the optimal procurement model for each option. However, for the purposes of further economic analysis, the following procurement models have been assumed for each option:
   - **Pumped hydro option:** Given its size and complexity it is assumed that pumped hydro options would be procured and designed under an alliance procurement methodology.
   - **Portfolio option:** It is acknowledged that a wide variety of procurement / delivery options exist for the Portfolio option, but for the purposes of the Economic Case it is assumed that the services provided by the Portfolio option are procured through long-term, technology agnostic, service contracts.

The four dimensions of choice used to refine each battery option have been tailored specifically for this IBC but are designed from Treasury standard dimensions of choice.[49] Appendix D outlines how the four dimensions of choice compare to Treasury dimensions and the way in which options are scored against them.[50]

2.7 The options taken through multi-criteria analysis

The infographics below set out a detailed description of each of the options taken through the MCA. This description includes for each option the:

- Dimensions of choice
- Costs (including both net present costs for the counterfactual and the nominal total CAPEX costs for the portfolio and Lake Onslow options, taken from engineering reports and the CBA)
- Key benefits and weaknesses
- A high-level indication of expected delivery timeframes.

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[49] Dimensions of choice are typically used as part of Programme Business Cases. However, they are considered an appropriate tool in this IBC given the significant optionality of each of the shortlist options.

[50] Funding and service delivery dimensions have not been included in the NZ Battery dimensions as these are dealt with in the Financial and Commercial Cases in the IBC.

Considerably more detail is provided about these descriptions in both the appendices (appendices C, D and F) and the MCA analysis at section 2.8.10. However, these headline considerations are provided to give a high-level sense of each option.

Option 1: Counterfactual

Description: This represents sufficient renewable overbuild required to address dry year risk without a NZ Battery large-scale storage investment. All electricity generation is renewable but no large-scale NZ Battery exists.

Operations: From ~2035 the counterfactual option assumes all fossil fueled generation is retired. As a result, all electricity demand is met from renewable sources. This includes for peaking to meet renewable firming requirements and dry year risk. A core element of the EMM is that the stack built to meet demand is always operated when most economically profitable to do so.

Infrastructure required

- Significant uplift in renewable generation. 14.62 GWs of renewable generation is required by 2065.[51] Of this, ~1.2 GW would not be required if there was an NZ Battery.[52]
- Significant build out of green peakers. It is estimated that 1.1GW of peaking capacity is required (with at least 250MW of that avoided if there was an NZ Battery).

Timeframe

40+ years

The build out of renewables is incremental and expected to continue throughout the modelling period.

Benefits

- ✓ This option does not require a significant Crown investment in a NZ Battery solution. However, some level of Crown investment is assumed to be required to incentivise the build out of marginally economic renewable generation.
- ✓ Investment decisions for most generation is made based on traditional economic incentives and corporate finance principles.
- ✓ Most technologies used to build the generation stack under this option are mature and proven in New Zealand. The exception is green peakers but these are assumed to some degree under all options.

Weaknesses

- × This option requires a more significant level of renewable build to meet demand and cover dry year risk.
- × For the wholesale electricity market to clear under this option, additional demand curtailment (~6.57GWh) and shortage (~0.21GWh) per annum is estimated when compared to the Lake Onslow option.[53]
- × Under this option, the electricity market is significantly oversized to meet peak demand and cover dry year risk. In times of high sun or wind this option creates significant spill (4.3TWh in 2035 – 8.9TWh in 2065).
- × This option requires build out of marginally economic renewable generation and is unlikely to be realised without government intervention / underwriting.
- × The option requires more green peaker investment and use.

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[51] This is made up of 7.33 GW of wind and 6.49 GW of solar. Culy EMM 2022.

[52] These values depend on the type of NZ Battery intervention chosen. For example, in the Lake Onslow NZ Battery option, avoided generation consists of 179MW of wind and 910MW of solar. Culy EMM 2022.

[53] These figures differ depending on the NZ Battery option compared against. The Portfolio option compares less favourably against the counterfactual than the Lake Onslow option over the long term.

Option 2: A pumped hydro scheme at Lake Onslow

Description: Development of pumped hydro scheme in Central Otago in the South Island. Lake Onslow is anticipated to have an upper reservoir capable of storing up to **5TWh of energy with turbines able to generate 1,000MW.**

Operations: The base case assessed through this IBC is for Lake Onslow to operate and interact with the market to **buy / sell into the electricity markets whenever economically viable to do so**. To avoid negative second order effects, such as the negative effects of market power, the Lake Onslow option would need to implement a **market slicing, model based, or hybrid operating model.**

Infrastructure required

1. A main dam and upper reservoir
2. Lower reservoir intake to isolate pumping operations from normal upstream generation
3. Tunnelling for pumping and release of water across reservoirs
4. An underground powerhouse and transformer complex
5. Ancillary and enabling works required to establish the site
6. Transmission connection and some upgrades to facilitate the required draw and release of electricity.
7. Build out of 850MW of green peakers.

Timeframe / phasing

To be delivered in one phase over 12 years[54] with an additional 1-3 years to fill to an operational level[55].

12 - 14 years

Benefits

- ✓ The size of storage and generation capacity, as well as the use of mature technology, provides high confidence in the ability for the Lake Onslow option to address dry year risk
- ✓ Reduces price volatility
- ✓ Improved economic conditions for renewable generators (e.g., by buying electricity in the wholesale market Lake Onslow provides a consistent buyer, increasing the value of electricity solar and wind generators receive in times of excess generation)
- ✓ Reduces renewable generation spill significantly
- ✓ Significant regional economic stimulus during construction

Weaknesses

- ✕ Significant upfront cost with no ability to phase delivery – this magnifies the cost of the project and reduces option value
- ✕ Potential benefits are constrained by transmission across the HVDC link
- ✕ Centralised, single point of failure
- ✕ Complex operating model options when compared to the counterfactual
- ✕ Significant environmental, landscape, recreational, social, and cultural affects
- ✕ Significant up front capital cost of $16,107.87 (nominal figure[56])
- ✕ Risk of distorting market generation investment and operation depending on the operating and delivery model chosen

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[54] This includes 5 years of pre-FID works (including DBC) and an estimated 7- 9 years of construction.

[55] Note that filling assumptions are complicated but have been simplified here.

[56] This includes $15,493.3m of Construction CAPEX (this figure excludes $190.3m of CAPEX which is scheduled to occur pre-FID, where pre-FID CAPEX was included, the Construction CAPEX figure would total $15,684m) and $614.56m of transmission CAPEX (this figure includes $25m (un-escalated) for improvements to grid protection and $416.5m (un-escalated) for a new substation at Onslow, but excludes $286m (un-escalated) for additional grid capacity upgrades as this would be paid for from annual TPM payments). See section 4.4.2 for a further break down of this figure.

Option 3: The Portfolio option

Description: This option is made up of three technologies; **flexible geothermal, biomass and hydrogen**. Each technology option contributes a different balance of capacity and energy storage. Together the portfolio is expected to provide around **1,200MW of generation / load reduction** that could be sustained for up to three months (**2.4TWh**), with a smaller ongoing response possible**.**

Operations: Each technology option is expected to operate independently. Biomass and hydrogen operate to maximise their ability to generate revenue within their operational constraints. Flexible geothermal is assumed to operate based on security of supply risk levels, which would need to be formally established. For comparison purposes, it is assumed that these services are procured under long term contracts.

Infrastructure required

- Biomass supply chain – this includes wood harvesting, processing, transport, storage, and generation plant
- Hydrogen electrolysers, ammonia production plant and storage, import / export facilities, ammonia-to-hydrogen cracking plant and hydrogen-capable combined cycle gas turbine
- Flexible geothermal plants
- Transmission connection for each plant and some upgrades to facilitate draw and release of electricity from and to the grid.

Timeframe / phasing

8 - 10 years

Benefits

- ✓ Can be geographically distributed adding resilience to the electricity system.
- ✓ Can be staged and built over time according to need and technology maturity – maximising deliverability and option value
- ✓ May be able to repurpose existing thermal assets
- ✓ Geothermal plant could be redeployed in a baseload role if alternative dry year solutions became available
- ✓ Excess hydrogen / ammonia can support wider decarbonisation (NZ or abroad)
- ✓ Insufficient hydrogen / ammonia production could potentially be supplemented by imports
- ✓ Supports domestic industries with associated job creation and ongoing economic benefits

Weaknesses

- ✕ Biomass feedstock has an opportunity cost.
- ✕ Biomass will require a large supply chain
- ✕ Geothermal generation is finite (there are limited sites available to house large-scale geothermal generation assets) and using geothermal sites for a battery option has an opportunity cost of baseload operation
- ✕ Geothermal has emissions associated with generation – abatement of these emissions is not proven
- ✕ Geothermal and biomass options have a longer lead time from when they are called on to when they can generate electricity. As a result, they are less able to provide short-term firming benefits
- ✕ Flexible geothermal and hydrogen technology are less mature and unproven at the scale required to address dry year risk
- ✕ The market for green hydrogen / ammonia is undeveloped so sales of production and demand response cannot be assured
- ✕ Risk of distorting market generation investment and operation depending on the operating and delivery model chosen
- ✕ Significant up front capital costs of $13,639m (nominal figure)[57].

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[57] This includes $13,275.8m of Construction CAPEX and $363.7m of transmission CAPEX. See section 4.5.2 for a further break down of this figure.

2.8 Detailed options analysis

2.8.1 Acknowledging asymmetries in the evidence base

As noted in the Strategic Case, a significant body of work has been completed to support the conclusions drawn in this Economic Case. Most notably, technical work has been completed on:

- Engineering, environmental, and geotechnical investigations on Lake Onslow pumped hydro, including environmental, cultural, geotechnical, geological, and hydrogeological fieldwork
- Engineering feasibility assessments of the three technologies supporting the Portfolio option. These also included desktop assessments of environmental, cultural and social impacts
- Advice on power systems integration and resilience and the interface with the NZ Battery Project
- Studies on market integration, market economics (including expected gross benefits for all shortlist options), and the effect of climate change on hydro inflows.

Technical advice for the NZ Battery Project has been peer reviewed to provide assurance of the findings of the feasibility phase.

These inputs provide a technical foundation for the IBC to be built off. However, the presence of this information raises issues of information asymmetry. The costs, benefits and impacts of the Lake Onslow option are inherently understood to a level of detail that the portfolio and counterfactual options are not. This means that there are naturally information gaps in the analysis and some optimism (and conservatism) bias in the way that options are assessed. The Project team has looked to acknowledge these where they exist.

2.8.2 Multi Criteria Analysis

Multi criteria analysis is a tool that enables a wide range of perspectives to be captured and considered. It enables the preferred options to be weighted and therefore trade-offs to be measured through a systematic and robust process.

The MCA assessment process includes a mixture of different quantitative and qualitative analytical techniques to provide greater rigour in determining the preferred option. Specifically, the shortlist has been assessed and compared based on the combined performance of each option against the following elements:

- *Cost-benefit analysis:* This is a monetised economic assessment of the national economic benefits and costs of an option. The performance of an option under the CBA has been given as a Benefit-Cost Ratio (BCR). This is a ratio of the benefits when compared with the costs of an option. A value greater than one indicates that the option provides net economic benefit to New Zealand.
- Non-monetised costs and benefits analysis: This represents items that:
    - Have been monetised, but the risk of double counting has meant that it has not been included in the CBA
    - Can theoretically be monetised, but have not been for materiality reasons
    - Are not readily able to be monetised but are based on detailed engineering reports, case studies, stakeholder feedback, or desktop research.

Many of the non-monetised impacts described in the qualitative analysis contribute substantially towards achieving the Investment Objectives, particularly given the diffuse nature of benefits and the difficulty in predicting areas of future importance (i.e., known unknowns). This is why they are often given importance in the MCA.

2.8.3 Critical Success Factors

Critical success factors have been used as the starting point for this MCA. CSFs establish the elements that are essential for an option to be able to successfully delivery the project in a way that satisfies the Investment Objectives and solves the Problem Statement.

The development of CSFs has been informed by Treasury Better Business Case guidance, analysis of information supporting the case for change, Investment Objectives and the original Cabinet mandate for the project. Within each CSF heading there are a range of sub-considerations that have been drawn out and given specific weightings.

2.8.4 Twelve MCA criteria

Table 16 shows the 12 MCA criteria used. The development of these criteria, including their description and respective weightings, have been informed from a range of stakeholder perspectives but ultimately represent a balanced view of decision-making criteria as determined by the NZ Battery team.

2.8.5 Approach to scoring

Each shortlist option is assessed against their ability to meet each criterion using a score between -3 to +3 as follows:

- **-3 = Extremely poor** capability to/will not achieve and/or contribute to the CSFs.
- -2 = Very poor capability to/will not achieve and/or contribute to the CSFs.
- -1 = Poor capability to achieve and/or contribute to the CSFs.
- **0 = Average** capability to achieve and/or contribute to the CSFs.
- +1 = Good capability to achieve and/or contribute to the CSFs.
- +2 = Exceeds capability to achieve and/or contribute to the CSFs.
- **+3 = Largely exceeds** capability to achieve and/or contribute to the CSFs.

The lens of this analysis is:

- For qualitative criteria, an ‘absolute’ consideration of each option in achieving the CSF is made. Once scored, a comparative lens is then applied to ensure that scoring is consistent between options
- For quantitative criteria each option is scored against the counterfactual option or an objective benchmark (where they exist e.g., value for money, affordability etc.). This means that each option has not been scored in relation to each other but rather compared against the counterfactual as a baseline.[58]

As noted above, technical inputs have been relied upon in gathering the evidence underpinning the scoring for this MCA. Table 16 highlights how, and when, this evidence base has been leveraged.

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[58] The one exception to this lens is ‘value for money’ where the electricity market benefits are measured against the counterfactual.

It is also acknowledged that in scoring each option against this MCA, that there are different levels of confidence in the underlying evidence base and that this can lead to 'over or under' representation of scores. Detailed scoring and rationale for these criteria is provided in in Appendix G.

Table 16: Assessment Criteria

Treasury CSFs	Assessment Criteria	Description	Weighting
Strategic fit and business needs (50%)	Confidence in security of supply	*The extent to which there is confidence that an option will provide enough energy storage and electricity generation / dispatch to meet security of supply requirements.* This criterion is informed by both EMM and a qualitative assessment and scores each option based on: • Consideration of how confidently the option could be delivered as described (e.g., within a reasonable timeframe) • A quantitative metric demonstrating the amount of demand curtailment, shortage, and green peaker fuel that the option uses (these metrics help stratify the options). It is noted that these metrics represent system averages. Therefore, they should be considered indicative only of the ability of an option to respond in a dry year • Qualitative description of the ability of the option to dispatch electricity quickly. This provides an indication of the ability of an option to support shorter term intermittent firming objectives as well as longer term dry year risk objectives.	20%
	Pathway to 100% renewable generation	*The extent to which an option supports the system-wide build out of renewables required.* This criterion is informed by both EMM and a qualitative assessment and scores each option based on: • A quantitative assessment of each option's ability to provide system-wide economic incentives that support renewable build out. This is measured based on modelled spill in normal hydrological years. All else being equal, a reduction in spill implies greater use of electricity generated from renewable sources. This will provide renewable generators with additional revenue (improving the economic conditions for renewable generators) • A qualitative assessment of the impact the option might have on electricity derivative product markets.	5%
	Maintains option value	*The extent to which an option enables the system to respond to current and future technology uncertainty.* This criterion is informed by technical assessments, and project team judgement, and assesses whether the option:	5%

Treasury CSFs	Assessment Criteria	Description	Weighting
		• Is modular in construction, or has clear off ramps prior to significant decisions or investments being made • Is able to maintain optionality to switch to new technologies or feedstocks as they emerge and mature (either by design, scale or timing of delivery) • Can be repurposed (i.e. does it have a future use or plant that can be used with multiple feedstock types).	
	Reduced wholesale electricity prices	*The extent to which each option reduces wholesale electricity prices.* This criterion is informed by EMM and scores each option based on expected time-weighted average wholesale prices (TWAP) over the modeling period.[59] Note, the model forecasts prices in a perfect market (e.g., generation is provided when theoretical spot prices go above SRMC – this creates an artificial connection between SRMC and TWAP). However, in a true market, generation decisions are not made solely on the balance between SRMC and spot prices (e.g., generation decisions are also based on the characteristics of a generator's stack etc.). As a result, TWAP results from EMM should be taken as indicative only.	5%
	Reduces carbon emissions	*The extent to which the option reduces emissions from the electricity system and the wider economy.* A reduction in carbon emissions is informed by technical assessments of: • The embedded carbon emissions in the construction required for each option • The operational carbon emissions for each option • Green peaker use (emissions being from the fuel supply chain) • A qualitative assessment of how each option might facilitate decarbonisation of the wider economy. It is assumed that there would be major positive emissions benefits for all options when compared to a true do nothing scenario given a move away from the use of thermal fuels to manage dry year risk[60].	5%
	Has socio-economic impacts	*The extent to which an option has impacts, both positive and negative, on local communities.* This criterion is informed by technical assessments, social and cultural impact assessments, and project team judgements, and scores each option based on:	5%

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[59] It is noted that this assessment does not take into account any expected levy that would be imposed to recover the cost of any option. This analysis is captured in the financial case.

[60] The marginal cost of abatement for each option has not been calculated as 100% renewable electricity is assumed for all options and value for money is considered as a separate criteria.

Treasury CSFs	**Assessment Criteria**	**Description**	**Weighting**
		• Estimated number of jobs created – primarily where there are durable opportunities to grow new industries or support existing industries, but also in the construction phase • Impacts on local communities – this can be positive and negative implications for local services, local amenity, and local businesses • Impacts on recreational activities • Cultural implications and opportunities for partnership.	
	Resilient to shocks and stresses	*The extent to which an option is resilient to stresses and shocks.* This criterion is informed by technical assessments, and project team judgements, and scores each option based on: • Resilience to natural disasters • Resilience to expected changes in climate • Whether the option a single point of failure – i.e. is it centralised or decentralised?[61].	5%
Potential value for money (20%)	Potential value for money	*The extent to which an option provides net monetised national economic benefit.* This criterion is informed by monetised cost benefit analysis and scores each option based on expected Benefit-to-Cost Ratios (BCR)[62]. A key omission from the BCR calculation is the lack of detailed estimate for the cost of shortage applicable to a future highly-electrified society and economy. While average electricity system-wide shortage values are produced in the electricity market modelling, this does not take into account the 'true costs' across the whole economy in a dry year, and are based on current rather than future levels of electrification.	20%
Potential Affordability (5%)	Affordability	*The extent to which an option is expected to be affordable.* This criterion is informed by monetised cost benefit analysis and scores each option based on the expected net present cost (NPC) of each option.[63]	5%
Supplier capacity and capability (10%)	Supplier capacity and capability	*The extent to which an option is able to be delivered by the market in the timeframes required.* This criterion is informed by technical assessments and scores each option based on: • A qualitative assessment of the ability of the market / potential suppliers to deliver the	10%

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[61] Note: HVDC outage risk is included as a probability-weighted and monetized figure in the CBA.

[62] Consideration was given to the use of NPV to compare options, but this was discarded given the view that the cost of the counterfactual is likely an underestimate (given lack of engineering assessment and rigorous commercial testing)."

[63] Note: Detailed affordability considerations (including considerations of revenue generated by each option) are included in the Financial Case.

Treasury CSFs	Assessment Criteria	Description	Weighting
		required services to the quality, cost and timeframes estimated • A qualitative assessment of the availability of feedstock.	
Potential achievability (15%)	Legislative and regulatory impacts	*The extent to which an option is expected to face significant legislative, regulatory, or market implementation challenges.* This criterion is informed by technical assessments, market analysis, and project team judgements, and scores each option based on: • Expected consenting challenges • Requirements for national legislative changes or material changes to National Policy Statements • Ability to satisfy Hazardous Substances and New Organisms (HSNO) requirements • The complexity of integrating the option into the current electricity market.	7.5%
	Environmental and local impacts	*The extent to which an option is expected to create localised environmental impacts.* This criterion is informed by technical assessments, environmental impacts studies, and project team judgement, and scores each option based on impacts to: • Local waterways (including water quality) • Local fisheries, bird, invertebrate, reptile, and other fauna (impacts to threatened species will be considered more significant) • Local flora (including wetlands, specific vegetation types) (impacts to threatened species will be considered more significant) • Protected areas and reserves. Only residual localised impacts are being scored. This means, only those impacts that have not been mitigated as part of the current cost estimates for delivery.	7.5%

2.8.6 Optimism Bias

There is a demonstrated, systematic, tendency for project appraisers to be overly optimistic. To redress this tendency, appraisers should make explicit, empirically based adjustments to the estimates of a project's costs, benefits, and duration.[64]

In the context of NZ Battery, several actions have been taken to limit optimism bias:

- Cost estimates for this project have been derived from a significant body of technical work including engineering, environmental, and geotechnical investigations on Lake Onslow pumped hydro, including environmental, cultural, geotechnical, geological, and hydrogeological fieldwork. Engineering feasibility assessments of the three technologies supporting the Portfolio option has also occurred. For Lake Onslow, this analysis has undertaken parametric cost estimates and quantitative risk assessment to understand

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[64] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/191507/Optimism_bias.pdf

the risk adjusted cost (and schedule) impacts. All cost estimates have also been peer reviewed

- Benefit estimates have a wider spectrum of fidelity – from detailed EMM using two different methods, and different levels of analytical granularity to analyse the same problem; to high level desktop analysis. All assumptions have been transparently made to support these conclusions and are set out in Appendix I
- The MCA analysis has relied heavily on the technical investigations and outputs of EMM. Moreover, the development of different 'personas' has been deployed to test the robustness of the MCA findings
- Finally, sensitivity analysis has been performed on the Economic and Financial Cases to test the findings sensitivity to different assumptions.

2.8.7 Sensitivity testing the MCA

To account for potential variabilities in the way the MCA has been devised, a sensitivity test has been completed. This sensitivity test changes the weightings of the MCA criteria based on five different persona sets that reflect different potential perspectives on the NZ Battery investment. Each persona adds 20 percentage points to the two MCA criteria that the persona might consider most important and evenly downgrades the weightings of the remaining criteria by two percentage points each.

Each persona is outlined below.

- **Favours new / diverse technology**: This persona places greater importance on the 'retaining option value' and 'legislative, regulatory and market risk' criteria. This favours options that provide greater ability for diverse technologies to be used both in the NZ Battery solution and in future, as well as those options which are perceived to be more 'market led'.
- **Minimise local impacts**: This persona places greater importance on the local impacts of the different options. The weightings of the 'localised environmental impacts' and 'socio-economic impacts' criteria have been increased. This favours options that have a smaller environmental footprint and produce larger local economic benefits.
- **Confidence in solution**: This persona favours options with a higher degree of certainty that the option can address dry year risk and be delivered in time. The weightings of the confidence of 'security of supply' and 'supplier capacity and capability' criteria have been increased. This favours options that use mature technology with a well understood delivery pathway.
- **Value for money**: This persona is a more traditional decision-making persona and places greater importance on 'value for money' and 'affordability' criteria. This increases the value of options that have a higher BCR and NPV.
- **Minimise emissions**: This persona is concerned with embedded carbon within the option, emissions associated with the option's operation and the ability of the option to facilitate a pathway to 100% renewable electricity generation. The weightings of the 'reduced emissions' and 'pathway to 100% renewable generation' criteria have been increased. This favours options that have a small embedded and operating carbon footprint, that incentivise additional renewable build out, and support wider decarbonisation goals.

The relevant weightings under each persona are outlined in Table 17 (red figures represent the increased weightings for each persona). Results of the persona analysis are outlined in section 2.8.13:

Table 17: MCA sensitivity table

MCA criteria	Standard weights (%)	Favours new / diverse technology	Minimise local impacts	Confidence in solution	Value for money	Minimise emissions
Confidence of security of supply	20	18	18	35	18	18
Pathway to 100% renewables	5	3	3	3	3	15
Retaining option value	5	20	3	3	3	3
Reducing wholesale electricity prices	5	3	3	3	3	3
Reduced emissions	5	3	3	3	3	15
Socio-economic impacts	5	3	10	3	3	3
Resilience to shocks and stresses	5	3	3	3	3	3
Value for money	20	18	18	18	30	18
Affordability	5	3	3	3	15	3
Supplier capacity and capability	10	8	8	15	8	8
Localised environmental impacts	7.5	5.5	22.5	5.5	5.5	5.5
Legislative, regulatory and market risk	7.5	12.5	5.5	5.5	5.5	5.5

2.8.8 Assessment of cultural impacts

To date, iwi engagement has occurred in relation to the Lake Onslow option. Iwi engagement was commenced in August in relation to the central North Island hydro option. Cultural assessments on other options are challenging at this stage given that the options are location agnostic. Cultural implications have been assessed at a desktop level but without iwi engagement at this stage on the other shortlisted options.

Cultural implications have been considered:

- Through the feasibility assessment
- Through the socio-economic and localised environmental impacts CSFs. All shortlist options have been considered against the potential to generate partnership opportunities for mana whenua, impacts on cultural sites of significance, and impacts on the local environment.

Iwi engagement will be a critical element of the next stage of the project and would be advanced in line with the project iwi engagement plan.

The options advanced will be considered consistently with Te Tiriti o Waitangi.[65] The initial desktop analysis will be followed and strengthened by engagement with mana whenua to understand the range, scope and impact of all options against mana whenua values, rights and interests. Te Arawhiti’s engagement framework will be followed, which provides guidance on how to engage based on the significance of an issue for Māori and its potential impact.

The Management Case sets out the proposed approach to iwi engagement in more detail, including relating Iwi/Māori roles in the Governance structure for the project.

2.8.9 Value for Money

Traditional monetised cost-benefit analysis (CBA) has been applied through the value for money criteria in the MCA. To provide an indication of the items included in the CBA, Table 18 summarises the core inclusions/exclusions for the portfolio and Lake Onslow options – these are set out in more detail in Appendix I. The cost inputs for the value for money metric for the counterfactual option have been derived solely using outputs from the EMM.

The benefits listed below are a feature of the difference that the portfolio and Lake Onslow options have with the counterfactual. As a result, those benefits are not included in the counterfactual assessment.

Table 18: Cost Benefit Analysis of shortlisted options

Costs		Information sources
Construction CAPEX	The expected capital costs associated with constructing the option.	Peer reviewed, Class four cost estimates.
Transmission connection CAPEX	The expected capital costs associated with connection to the transmission grid.	MBIE in consultation with Transpower
Maintenance and renewal CAPEX	The expected capital costs associated with maintaining the option over its lifespan.	Peer reviewed, Class four cost estimates.

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[65] Including Te Tiriti principles of partnership, participation, protection, recognition of cultural values and using mana enhancing processes Te Arawhiti - Engagement

Costs		**Information sources**
OPEX	The expected costs to operate the option and deliver electricity under the selected operating model.	Peer reviewed, Class four cost estimates.
Transmission connection OPEX	Direct and indirect operational costs associated with the transmission grid.	MBIE in consultation with Transpower
System administration	The expected upfront and operating cost of the Government related entity that might manage and / or operate the NZ Battery option.	Input from consultancy studies, high-level estimates.
Resilience	The costs associated with some NZ Battery options being more resilient to failures in other parts of the electricity system than others. Specifically, the extent to which a solution exacerbates the consequence of HVDC failures.	High-level estimates.
Benefits		
Electricity system benefits	The gross economic benefit, relative to the counterfactual, of the avoided electricity system costs from implementing each option. In practice this primarily manifests in avoided fixed capital and operating costs associated with ‘overbuild’ of solar, wind, and green peakers. This category also captures the benefits of reduced electricity system emissions, reduced demand curtailment, and reduced shortage[66].	Outputs from EMM.
Productivity improvements	The productivity improvement for large electricity consumers as result of reduced electricity prices from implementing the NZ Battery option.	High-level estimates using input-output analysis.
Operating revenue	The expected operating revenue from the options *excluding* the net electricity generation revenue. For Lake Onslow there will be no operating revenue, for the Portfolio option this includes the sale of ammonia and un-used biomass feedstock at the end of their storage life.	Peer reviewed information provided in the WSP report.
Economic terminal value	The terminal value of the NZ Battery at the end of the model timeframe (FY65).	High-level estimates.

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[66] Detailed cost of shortage analysis has not been calculated for the options as part of the IBC but has been considered qualitatively as part of the Confidence in Security of Supply assessment. Further quantification of the whole of economy cost of shortage for each option in a future highly electrified society and economy is expected to be developed through the DBC.

2.8.10 MCA result

The options have been evaluated against the assessment criteria described above. The totals have been summed on an unweighted basis, and then on a weighted basis to create a ranking in-line with the established importance of the CSFs.

The conclusion of detailed MCA analysis is provided for each criterion in Table 19 below and a summary is provided in Table 20. What is immediately clear is that no one option scores well across all assessment criteria (including the counterfactual). Therefore, trade-offs are paramount when considering the preferred pathway forward.

- **Option 2:** Lake Onslow is the option that provides the greatest confidence of achieving security of supply objectives on the pathway to 100% renewables. It scores poorly on the value for money and affordability criteria. Further, there are known, significant negative cultural, social, landscape, recreational and environmental effects.
- **Option 3:** The Portfolio option scores positively as a means of providing a credible way of achieving security of supply objectives on the pathway to 100% renewable while also retaining significant option value should newer and more effective technological pathways emerge. However, this option also scores poorly, and slightly worse than Lake Onslow, on the value for money and affordability criteria. It scores better than Lake Onslow in regard to cultural, social, landscape, recreational and environmental effects, however these results are inherently uncertain given the location(s) that might be used for the option are not yet known.
- **Option 1:** The counterfactual is the poorest performing option. Whilst it was seen as having significant flexibility and natural resilience, it is unlikely to credibly mitigate security of supply concerns on the pathway to 100% renewables.

Appendix F provides a detailed account of the MCA scoring.

Table 19: MCA scoring

Confidence in security of supply		
Counterfactual (-1)	**Lake Onslow (2)**	**Portfolio (1)**
EMM indicates that renewable build out will require greater use of green peakers, demand curtailment and system outage[67] *than the other options to manage shortfalls in energy. Green peaker use, demand curtailment and shortage are inherently uncertain in their availability – as they rely on less certain fuel sources, as well as electricity customers' acceptance to reduce demand etc. This uncertainty becomes significantly more pronounced where these are relied upon in greater quantities. By relying more heavily on these items, there is less confidence in the ability for the counterfactual to address dry year risk.* *It is expected that the required level of overbuild of renewable generation would be unlikely to occur without government assistance as it is anticipated that the economic conditions required to justify renewable build out to meet dry year risk would not be present. Further, it is anticipated that renewable build out becomes harder to deliver over time as sites with the best conditions (sunlight hours, wind factors, site characteristics etc.) are built on first and progressively more marginal sites are built on over time. This reduces confidence in the solution's ability to be delivered to the scale required.*	*The size of storage, generation, and speed of energy dispatch make the Lake Onslow option an effective solution to manage dry year risk (as well as shorter term intermittency issues) – this is evidenced by lower system curtailment, green peaker use and demand curtailment metrics than the other options.* *Additionally, Lake Onslow can store and dispatch enough energy to offset extremes of historic hydro variation (the lowest recorded annual hydro inflow year was approximately 5TWhs below average – average dry year electricity shortage recorded is ~3TWh). Lake Onslow's overall size is also expected to allow it to provide additional dry year support where concurrent dry years occur.* *Further, Lake Onslow makes use of mature technology and is considered feasibly deliverable by the mid-2030s.* *There is high confidence about its feasibility, but a score of 2 rather than 3 is applied because it is noted that further geotechnical and design work will be required in the next stage of work.*	*The Portfolio option includes three technologies that were identified by WSP as being the most feasible non-hydro options to provide dry year support – though in practice, the portfolio may involve a different set of technologies in a different combination. When combined in a portfolio, these technologies provide the necessary capacity, energy storage and flexibility to maintain security of supply through long-term variation in hydro inflows, and help to support shorter-term variations in wind and solar generation. However, this option makes use of greater green peaker, system outage and demand curtailment than the Lake Onslow option.* *There are significant uncertainties and risks surrounding the supply chain for biomass and the maturity of technology and markets for hydrogen, reducing confidence in the solution. For example, biomass and hydrogen are expected to have enough storage on hand to provide short – medium term cover. Additional feedstock, although possible to purchase, will be subject to commercial availability (this may be challenging given their potential alternative uses and the depth and existence of markets). Additionally, biomass and hydrogen are expected to have relatively slow recharge rates (biomass is expected to take ~ 2 years to replenish 1TWh of storage). This will reduce the ability for the Portfolio option to be able to cover concurrent dry years.*

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[67] System outage, or shortage, has been assessed qualitatively here but is expected to be quantified through the DBC.

Supports a pathway to 100% renewable generation		
Counterfactual (0)	**Lake Onslow (3)**	**Portfolio (2)**
The counterfactual option is modelled / assumed to achieve the 100% renewables target by 2035. However, due to the lack of a meaningful battery in the system, it is expected that there will be considerable spill – which will reduce total revenue of renewable generators and negatively affect the economic viability of future renewable build out. *While sufficient overbuild itself would deliver a 100% renewable world, it is not considered that the option would itself incentivise or support a pathway to 100% renewable generation.* ***Spill:** The specific amount of 'spill' associated with this option is estimated at (4.34TWh in 2035 – 8.91TWh in 2065). This is considerably higher than the other two options.*	*The Lake Onslow option is anticipated to significantly support the pathway to 100% renewable generation. This support is expected to manifest in the following ways:* *1. **Reduction in volatility:** It is expected that Lake Onslow will help to mitigate wholesale electricity price volatility, by purchasing electricity when prices are low and generating when prices are high. This is expected to provide greater certainty of revenue for intermittent renewable generators and improve the overall quantum of revenue they can expect to receive (generators will have a buyer in times of electricity abundance).* *2. **Derivative products:** In having significant capacity and on demand storage, Onslow has the ability to offer derivative electricity products. For example, Onslow could offer generation options (akin to a call option) to renewable generators to hedge their intermittency exposure. If Onslow operated in this way it is expected that the option could both reasonably reduce the price of derivative instruments (by significantly increasing supply with a low SRMC generation source [hydro]) and improve the economic conditions for renewable generators.*	*The Portfolio option is anticipated to significantly support the pathway to 100% renewables – both as a meaningful contribution to renewable energy sources itself but also in terms of the support it provides to other renewable electricity generators. This support is expected to occur for two reasons:* *1. **Reduction in volatility:** It is expected that the Portfolio option will help to mitigate price volatility – by purchasing electricity when prices are low and generating when prices are high (at full utilisation hydrogen plants in the Portfolio option could purchase ~8.8GWh of electricity per day). This provides renewable generators with greater revenue certainty.* *2. **Derivative products:** Purchasing electricity when prices are low is expected to support total revenue wind and solar generators will receive (incentivising further build out of renewable investments).*

Retaining option value		
Counterfactual (2)	**Lake Onslow (-1)**	**Portfolio (3)**
The counterfactual option does not assume a single significant investment in capacity or storage at one time. Instead, the counterfactual models a staggered build out of smaller scale renewable generation assets over ~40 years. A staggered construction period provides natural stage gates to enable the system to respond to advancements in technology during the build phase (and to pivot or halt planned investments where they become uneconomic). It is assumed that the generation profile will be determined by market forces.	*The Lake Onslow option retains less option value flexibility than the other options for three key reasons:* • ***Fixed costs:** The fixed costs associated with the build out of this option make it difficult to meaningfully stage the build in an economically efficient way – pumped hydro systems have a significant degree of economies of scale associated with them.* • ***Lack of ability to pivot:** Once construction starts, it is difficult to adjust for technological improvements, and once completed, there are very limited opportunities to make material changes.* • ***Technology redundancy / alternate uses:** Were an option to materialise that is better able to manage dry year risk, there are few ways in which Lake Onslow could meaningfully pivot to play a significantly different role in the electricity system. However, it may have alternative uses in other sectors e.g., as a recreational asset, for use as a store of water for agricultural and horticultural resiliency.*	*While it is assumed that this option would be procured at once, the Portfolio option would more likely be built out over time. This would provide stage gates to enable the system to respond to advancements in technology during the build phase (and to pivot or halt planned investments).* *Further, as the Portfolio option is assumed to be acquired through a technology agnostic process , it is assumed this could be scaled up and down over time as needed – this embeds further optionality in the design.*

Reduced wholesale electricity prices		
Counterfactual (0)	**Lake Onslow (3)**	**Portfolio (3)**
Without an NZ Battery solution, the market has less ability to take advantage of periods of high generation / low prices (e.g., when conditions are sunny and windy) and is exposed to periods of low generation / high prices (i.e., when conditions are calm and cloudy). This has the effect of increasing both price volatility and average wholesale price. ***TWAP figure ($/MWh):*** ***2035:*** *76.80 -* ***2050:*** *87.25 -* ***2065:*** *91.11*	*A Lake Onslow pumped hydro scheme would be expected to reduce price volatility in the market with potential flow on benefits for consumers. EMM estimates that the inclusion of Lake Onslow within the electricity market could lead to a roughly 5-6% reduction in average wholesale prices over the modelling period as compared to the counterfactual.* ***TWAP figure ($/MWh):*** ***2035:*** *73.59 -* ***2050:*** *80.67 -* ***2065:*** *83.51.*	*The Portfolio option would be expected to reduce price volatility in the market with potential flow on benefits for consumers. EMM estimates that the inclusion of the Portfolio option within the electricity market could lead to a roughly 5-6% reduction in average wholesale prices over the modelling period as compared to the counterfactual.* ***TWAP figure ($/MWh):*** ***2035:*** *73.95 -* ***2050:*** *80.05 -* ***2065:*** *84.80*

Reduces emissions		
Counterfactual (0)	**Lake Onslow (1)**	**Portfolio (0)**
Emissions related to the counterfactual are expected to be predominantly from the embedded carbon with the generation assets themselves (e.g., within wind and solar assets) and from green peaker use. Although renewable in nature, green peaker assets are expected to make use of fuels that have associated supply chain emissions.	*Lake Onslow is expected to have significant embedded carbon emissions associated with the build of the dam but significantly lower green peaker use than the counterfactual and Portfolio options and no operational emissions (although there will be a very small amount of emission from the lake itself).* *Lake Onslow is expected to have a longer useful life than the generation assets built under the other two options. This reduces the frequency and scale of asset replacement and renewal required to maintain asset effectiveness. A lower asset replacement and renewal profile will improve overall lifecycle emissions (as embedded carbon emissions associated with expected asset renewal will be lower).*	*The Portfolio option is expected to have emissions associated with:* • *Embedded emissions**:** the embedded carbon with the generation assets themselves (e.g., emissions created during the construction of the storage and generation assets). These are anticipated to be greater than the counterfactual but around 50% less than Lake Onslow.* • *Supply chain emissions: From green peaker use, and from the use of hydrogen and biomass to generate electricity. Although renewable in nature, hydrogen, biomass, and green peakers are anticipated to require surrounding supply chains that have associated emissions.* • *Operational emissions: The geothermal component of Portfolio option is expected to release carbon during operations.*

Socio-economic impacts		
Counterfactual (0)	**Lake Onslow (-1)**	**Portfolio (1)**
Because of the significantly greater amount of renewable generation build out required, the counterfactual option has widespread socio-economic impacts (both positive and negative). The key assumption behind the scoring of this criterion is that, when compared to the other options, a distributed (negative) socioeconomic impact is likely better than a concentrated one. *At a high-level the socio-economic impacts associated with the counterfactual are anticipated to be largely neutral (both negative and positive impacts will be felt – on balance these are expected to be similar to the current status quo and considered neutral).*	*As one large solution, the Lake Onslow option will have significant and material localised impacts. Some of these are expected to be positive (in terms of growth in economic activity in the area during construction and the possibility for co-investment with mana whenua) but others will be negative. These include impacts on affected landowners, increased pressure on local services, reduced recreational opportunities, and impacts on significant heritage sites.*	*The distributed nature of the Portfolio option and optionality around location is assumed to reduce the degree of negative localised socioeconomic impacts. This is because where a particular site has specific negative local impacts that others do not, it may be that the site with the least worst impact can be chosen. However, it is still anticipated that all sites will have a range of negative socioeconomic impacts that will still require trade-offs to be made.* *The presence of the opportunity to establish supply chains that surround two of the three portfolio technologies provides potential for meaningful partnership with iwi / Māori as well as durable job creation and growth beyond the construction period.*

Resilient to shocks and stresses

Counterfactual (3)	Lake Onslow (0)	Portfolio (2)
As the counterfactual is distributed across NZ, it is considered highly resilient to shocks and stresses. The individual generation assets are also anticipated to be small to medium in scale and numerous, this further reduces single point of failure and natural disaster risks. Climate change modelling also suggests that wind and solar generation is unlikely to be affected on a net basis.	*The Lake Onslow option is a single dry year solution located in the South Island. This creates a single point of failure risk, and also exacerbates the national electricity system's reliance on the HVDC link. Analysis was undertaken to determine the additional probability weighted cost of HVDC outage with Lake Onslow in the electricity system. This analysis indicated that although HVDC has a significant associated cost of failure (which increases with the inclusion of Lake Onslow) the likelihood of failure is statistically very low. In addition, none of the options completely remove the national electricity system's reliance on the HVDC link. New Zealand's electricity system will still be vulnerable to HVDC link failure regardless of the implementation of any of the options – each option will just impact the degree to which New Zealand is impacted where the link fails.* *Although Lake Onslow increases risks around single points of failure, the Lake Onslow option is not considered at higher risk of natural disasters. For instance, it would be designed and constructed to be highly resistant to seismic shocks.*	*The Portfolio option is a distributed set of storage and generation assets that are anticipated to be spread across New Zealand (although likely predominantly based in the North Island). The distribution of the option and the use of fuels / non weather dependent feedstocks to generate electricity make this option highly resilient to weather-based shocks and climate change related stresses.* *However, many of the fuels used to generate electricity also have alternative uses (both exotic forests and hydrogen have secondary uses and values in other markets). This makes technologies that rely on international markets for fuel, exports, or parts subject to international shocks and stresses. In addition, in making use of woody biomass as feedstock, the biomass option is considered potentially vulnerable to wildfire and biological disease.*

Potential value for money		
Counterfactual (-3)	**Lake Onslow (-3)**	**Portfolio (-3)**
The counterfactual does not have a formal benefit cost ratio given that it generates no additional benefits. However, it is expected to have a material net present cost of PV $1,780.9M. *A key factor impacting the value for money score for the counterfactual is the likely inability to deliver on the Investment Objectives and provide confidence of security of supply in dry years. This is supported by the significant use of green peaking technologies and / or shortage in the EMM results. While the cost of the resulting shortage has not yet been calculated*[68]*, EMM results indicate this would be higher than the other options.* *Additionally, the cost of delivering the counterfactual has been developed using the outputs of the EMM but does not include detailed consideration of the technical and commercial feasibility of delivering the degree of overbuild assumed in the counterfactual. As a result, it is expected that the true cost of implementing the counterfactual is likely understated.*	*The Lake Onslow option has a Benefit Cost Ratio (BCR) of 0.42. This is a poor BCR, but the highest of all options.*	*The Portfolio option has a Benefit Cost Ratio (BCR) of 0.40.*

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[68] Cost of shortage is expected to be developed through the DBC.

Affordability		
Counterfactual (-1)	**Lake Onslow (-2)**	**Portfolio (-3)**
The NPC of the counterfactual is $1.78B. This cost has been developed using outputs of the EMM and does not include a detailed assessment for the technical and commercial feasibility of delivering the degree of overbuild included in the counterfactual. As a result, it is expected that the actual cost of delivering the counterfactual would be higher.[69]	*It is assumed that a Lake Onslow would incur an NPC of $9.59B which is why this option scores a -2. This is the second most expensive option.*	*It is assumed that a Portfolio solution would incur an NPC of $13.55B, making it the most expensive option.*

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[69] Further analysis on the cost of delivering the counterfactual is expected to be developed through the DBC.

Supplier capacity and capability		
Counterfactual (2)	**Lake Onslow (1)**	**Portfolio (1)**
The counterfactual makes use of mature technology with well-established original equipment manufactures, suppliers and delivery pathways. There is confidence that there is sufficient technical expertise within the market to deliver this option. *However, the scale and pace required to build out the amount of additional generation needed under the counterfactual is expected to be challenging for the following reasons:* *1. Availability and ability to consent land* *2. Supplier capacity* *3. Workforce* *The challenge of the build out is exacerbated by uncertainty around the market's ability to provide all required generation without significant fiscal or economic incentive – this is particularly pertinent for otherwise displaced generation required for dry years given this generation is likely to be the least economic.*	*Lake Onslow makes use of mature technologies with-established OEMs and suppliers. Feasibility studies have concluded that Lake Onslow is technically possible to construct and have provided confidence that there would be a contractor market ready to construct this asset. However, the depth of the market and availability for contractors and equipment is currently unknown. Given the size and relative speciality of the technology and works required, availability of international specialists will be key.* *The availability of a local workforce at the scale able to construct Lake Onslow will be subject to local labour markets and maybe difficult given current local employment figures and national infrastructure pipelines.*	*Biomass and geothermal technologies are mature with well-established OEMs and suppliers. However, there is some uncertainty around how much geothermal could realistically be developed by 2035 (given potential resource, consenting, and industry constraints) and the ability to purchase biomass from New Zealand at the scale and price to make this option reasonable (given the competing uses for this biomass).* *The production and storage of green hydrogen at scale is currently immature. However, it is being pursued globally as an enabler to decarbonise hard-to-electrify elements of the energy system and is seeing significant R&D and technology advancement. WSP predicts that by 2027 the scale required for the Portfolio option is expected to be within the manufacturing capability of OEMs. Given interest in hydrogen developments, procurement strategies will be required to ensure the required plant can be secured in line with current project timeframes.*

Environmental and local impacts		
Counterfactual (-1)	**Lake Onslow (-3)**	**Portfolio (-2)**
The counterfactual is location agnostic, and the impacts of the option are not expected to be significantly attributable to one, or a small number of locations. *However, there are expected to be negative local environmental impacts that accrue as a result of construction.*	*The Lake Onslow option has significant localised environmental impacts. Specifically, Lake Onslow is expected to irreparably impact wetlands, threaten local species (including the Teviot flathead galaxias and the Burgan skink), impact local farmland and waterways, and create a significant amount of overburden that must be disposed of locally.* *There are options to mitigate and offset some of these impacts – but many mitigations are complex and costly and require more detailed consideration at DBC stage. On balance, the Lake Onslow option is expected to have a significant negative impact on the immediate local environment.*	*All technologies within the Portfolio option will impact environmental and local amenity through their construction and associated supply chains. In addition, some components of the Portfolio option also pose a hazardous risk to humans (ammonia storage).* *However, as the option is location agnostic (to some degree), the environmental impacts can be potentially mitigated by placing elements of the Portfolio option in locations better suited to handle these risks. However, it is important to note that even better suited sites will face significant environmental degradation as a result of the build out of this option.*

Legislative and regulatory impacts		
Counterfactual (0)	**Lake Onslow (-1)**	**Portfolio (-2)**
The land requirements for the counterfactual pose potential legislative and regulatory risks – i.e., the amount of land required for the counterfactual will be hard to consent and may require changes to consenting processes / legislation. *If locations cannot be found onshore, offshore options may be investigated. This may bring additional legal and regulatory implications, however policy development for offshore renewable energy development is underway.* *Regulatory incentives may be required to ensure the amount of overbuild required. However, delivery of the option may not necessitate any fundamental change to the way the current market operates.*	*There are legislative barriers that will need to be overcome to implement the Lake Onslow option, which may require specific enabling legislation (e.g., exemptions to consenting legislation).* *It is also anticipated that a significant policy and regulation process would be required to ensure successful integration into existing electricity market structures. This is likely to require complex and bespoke regulation, as well as enforcement and monitoring tools.*	*There has been limited analysis done on the legislative and regulatory impacts of the Portfolio option. However, it is expected that significant legislative and regulatory interventions would be required in order to minimise:* *1. **Market integration risk.** The manner in which the option would be delivered needs to be explored in greater detail. However, it is expected that procuring of services that support mitigation of dry year risk, or the establishment of a capacity market, would be a significant regulatory and market facing exercise and could require complex regulatory oversight.* *2. **Physical risk.** There are potential hazardous effects that hydrogen and ammonia storage could have on both people and the environment without oversight and, potentially, regulation to manage risk.*

Table 20: Summary of MCA results

Treasury CSFs	Assessment Criteria	Weighting	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
Strategic fit and business needs (50%)	Confidence of security of supply	20%	-1	2	1
	Pathway to 100% renewables	5%	0	3	2
	Retaining option value	5%	2	-1	3
	Reducing wholesale electricity prices	5%	0	3	3
	Reduced emissions	5%	0	1	0
	Socio-economic impacts	5%	0	-1	1
	Resilience to shocks and stresses	5%	3	0	2
Value for money (20%)	Potential value for money	20%	-3	-3	-3
Affordability (5%)	Affordability	5%	-1	-2	-3
Supplier capacity and capability (10%)	Supplier capacity and capability	10%	2	1	1
Potential achievability (15%)	Localised environmental impacts	7.5%	-1	-3	-2
	Legislative, regulatory and market risk	7.5%	0	-1	-2
Unweighted total		100%	**1**	**-1**	**3**
Weighted total		100%	**-0.48**	**-0.25**	**-0.20**
Rank			**3**	**2**	**1**

2.8.11 Sensitivity analysis

Use of the MCA approach has demonstrated significant sensitivity to adjustments in assumptions and inputs. A range of sensitivities have been applied to test the outcome above.

2.8.12 NZAS stays sensitivity

A core assumption underpinning the EMM and productivity benefit calculations that inform the conclusions above is that NZAS exits the market early in the modelling period. Changing this assumption to include NZAS and its associated demand (or a similarly high load asset in the South Island) during the modelling period has an impact on the overall BCR numbers for each option.

With NZAS included, the BCR for the Lake Onslow and Portfolio options is 0.66 and 0.54 respectively. Applying this sensitivity results in the following outcome.

Table 21: MCA with NZAS included

	Weighting	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
Unweighted total	100%	**1**	**0**	**4**
Weighted total	100%	**-0.48**	**-0.05**	**0.00**
Rank		**3**	**2**	**1**

2.8.13 Persona impacts

As noted in section 2.8.7 above, the MCA has also been run by applying altered weights based on different personas or perspectives according to which the NZ Battery project could be assessed.

Table 22: MCA scoring – Persona impacts

Persona	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
Standard weights (%)	-0.48	-0.25	-0.20
Favours new / diverse technology	-0.16	-0.47	0.11
Minimise local impacts	-0.67	-0.81	-0.53
Confidence in solution	-0.53	0.18	-0.02
Value for money	-0.98	-0.83	-0.98
Minimise emissions	-0.50	0.25	-0.02
Average	**-0.55**	**-0.32**	**-0.27**
First persona rankings	0	3	4
Second persona rankings	3	2	2
Third persona rankings	4	2	1

The persona analysis indicates that although the MCA results are sensitive to MCA criterion weighting, all MCA personas indicate a preference towards a battery solution.

2.8.14 All of the shortlisted options generated a cost benefit score of less than 1

This section presents the results of the cost-benefit analysis (CBA) which have been applied in value for money criteria of the MCA. To help frame the results, it is important to reiterate that:

- These costs and benefits are economic values. They are real, and discounted, and should not be interpreted to represent the financial costs and benefits of the project. Rather, these enable a determination of whether a project represents economic value for money and a comparison of options on equivalent grounds
- A Benefit Cost Ratio of above '1' represents good value for money in that there are net benefits for every dollar spent. The inverse holds true for a BCR less than '1'
- The counterfactual has served as a comparator for the electricity system benefits and productivity improvements benefit categories. Accordingly, it does not derive any gross (or net) benefits in this CBA. It does however incur gross costs which are captured
- There are a range of potential economic benefits that have not been quantitively captured in this analysis including:
    - The contribution of a reliable electricity system to wider economic outcomes. For example, the costs of electricity shortage and demand curtailment to the economy, the impacts of a reliable electricity system on business immigration, and the need for decarbonisation
    - The consumer surplus associated with consumers who would be willing to pay more than the demand curtailment and shortage price thresholds assumed in the EMM.

A summary of the costs and benefits for each shortlisted option is presented below. All costs and benefits are presented on a P50 and base schedule basis.

Table 23: Cost Benefit Analysis of shortlisted options

NPV (5% discount rate) (NZDm)	**Option 1: Counterfactual**	**Option 2: Lake Onslow**	**Option 3: Portfolio**
Costs			
Construction capex	1,780.9	7,811.4	7,819.9
Transmission capex		465.1	205.3
[redacted]		[redacted]	[redacted]
[redacted]		[redacted]	[redacted]
[redacted]		[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

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[70] Note, while the system administration costs for the counterfactual option would be greater than zero, it is considered that they are immaterial and therefore have not been investigated in detail by the project team.

NPV (5% discount rate) (NZDm)	Option 1: Counterfactual	Option 2: Lake Onslow	Option 3: Portfolio
Benefits			
Commercial Information			
BCR	**n/a**	**0.42**	**0.40**

A core conclusion of the value for money analysis is that **no option has a BCR above 1.** This implies that for every dollar spent, there will be 40-50 cents of public value returned.

As noted above, for the “NZAS stays” sensitivity, the Lake Onslow option BCR improves significantly to 0.66, with the Portfolio option improving to 0.54.

A modest BCR or a BCR of less than 1 is not unusual for many infrastructure investments, particularly given that infrastructure investments typically have characteristics whereby significant capital costs are incurred up-front, but benefits are annualised, and disproportionately accrue in outyears. Moreover, it is worth noting that there are a range of potentially monetisable benefits that have not been quantified in this IBC. Where possible, these should be quantified for the DBC.

2.8.15 Value for Money Sensitivities

For the purposes of the CBA presented above, a single number was selected for all underlying assumptions in the detailed model. However, the underlying inputs realistically fall within a range. Sensitivity analysis has also therefore been performed on higher and lower discount rates.

2.8.15.1 Discount rates

A discount rate represents the rate at which society is willing to trade off present benefits and costs against future benefits and costs, thus capturing the time value of money. In this context, a NZ Battery solution would be providing long-term well-being benefits to current and multiple future generations. Given this long-term focus and the added fact that NZ Battery is contributing to decarbonisation efforts which, again, are assumed to have long-run benefits for multiple future generations, there is an argument that a lower discount rate should be employed.

To reflect this preference to favour long-run benefits, a lower bound discount rate of 2% has been used to sensitivity test the central findings. 2% has been chosen as the advised sensitivity in Treasury CBAx guidance.

Where a 2% discount rate is applied, the Lake Onslow option has a BCR of 0.75. Under this scenario Lake Onslow represents significantly better value for money but is still below a ‘break even’ investment for those costs and benefits that can be monetised.

Table 24: Lake Onslow Cost Benefit Analysis for various discount rates

Lake Onslow NPV (NZDm)	2% discount rate	5% discount rate	8% discount rate
Commercial Information			
BCR	**0.75**	**0.42**	**0.25**

Table 25: Portfolio Cost Benefit Analysis for various discount rates

Portfolio NPV (NZDm)	2% discount rate	5% discount rate	8% discount rate
Commercial Information			
BCR	**0.54**	**0.40**	**0.30**

2.9 Two preferred options have been identified for further investigation

As noted above, the results of the MCA and CBA have identified that:

- Both NZ Battery options are more effective than the counterfactual at addressing the dry year problem and better balance the competing objectives of the NZ Battery Project. Specifically, when compared to the counterfactual both battery options:
  - Provide greater confidence in their ability to address dry year risk. When modelled, both options rely less on demand curtailment, shortage and green peaker use to meet demand than the counterfactual
  - Provide a more credible pathway to 100% renewable generation. By acting as a load sink in times of energy abundance both options improve the economic incentives for renewable generation investment
  - Reduce the cost of wholesale electricity prices. Both options reduce TWAP prices over the modelling period
  - Reduce the total level of renewable generation required to be built to transition to 100% renewable generation.
- The MCA identifies the Portfolio option as narrowly ahead of Lake Onslow as the option that best meets the competing objectives of the NZ Battery Project. The Portfolio option has a range of positive elements that make it an attractive option in theory. It provides a credible way of achieving security of supply objectives on the pathway to 100% renewable generation while retaining option value should newer and more effective technological pathways emerge. Like the Lake Onslow option it has a poor BCR but has the greatest net present cost of either option. Further, there are uncertainties surrounding the supply chain for biomass, technology and markets for hydrogen, and the delivery model, which reduce confidence in its ability to be delivered.

- Despite scoring marginally worse than the Portfolio option, Lake Onslow is considered the option that provides the greatest confidence to achieving security of supply objectives on the pathway to 100% renewables. While acknowledging that there are significant cost implications, it demonstrates slightly better value for money and affordability characteristics than the Portfolio option. In addition, more work has been undertaken to understand the cost implications of the Lake Onslow option, this provides greater confidence that the cost estimates are robust when compared with the Portfolio option which is comparatively less understood. However, Lake Onslow will have significant cultural, social, landscape, recreational and environmental effects.

Despite both battery options outperforming the counterfactual in the MCA, neither battery option significantly outperformed the other. As a result, both options have been advanced to the Commercial, Financial and Management cases.

2.10 Next steps

During the IBC several options are explored at a high level of detail resulting in a wide range of benefits and costs in the CBA and MCA. To narrow the range and better understand each option, the following steps should be prioritised during the next phases of the project.

- **Further refine and define the Portfolio option:** This should include:
    - Further optimisation of the scale and configuration
    - Consideration of potential operating and delivery models
    - Alignment with broader energy strategy / transition and policy work underway
    - Engagement with the market.

This would lead to a better indication of the expected economic costs and expected impacts.

- **Improving cost certainty for the Lake Onslow option:** This includes several activities:
    - More extensive investigations and greater design
    - Optimised configurations
    - Further develop the ownership, operating, and funding models
    - Perform more detailed analysis on power system integration costs
    - Better define the expected system administration costs, post FID
    - Greater consideration of Transmission Pricing Methodology (TPM) implications.[71]

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[71] The new TPM implementation is only just being finalised by Transpower, so to date we have only been able to make high level estimates of this.

- **Complete a ‘cost of shortage’ study** to better understand the benefits of a large-scale battery investment to address the dry year risk, compared with the true economic cost of ‘doing nothing’. This should include an assessment of the full costs of prolonged non-supply. This information would enable the adjustment of the assumptions used in the EMM, in particular around demand curtailment / shortage bands and their economic costs.
- **Improve the accuracy of price impact estimation:** Estimating market prices in a different electricity system from today’s is challenging. However, possibilities for improving or supplementing the EMM approach to provide better estimates of the price impacts of different options should be investigated.
- **Expand, and undertake more detailed, benefits assessment** to better understand:
    - Productivity improvements
    - Impacts of the options in stimulating demand across the economy (possibly through computable general equilibrium modelling)
    - The contribution of the options to the wider NZ economy decarbonisation goals.
- **North Island pumped hydro:** Depending on the outcome of iwi engagement, the next steps would be to undertake electricity market modelling of the option. This would involve Stochastic Dual Dynamic Programme modelling on how the scheme would interact with the Tongariro Power Development. This will provide a far better understanding of the market interactions and electricity system gross benefits of the option. In turn this will inform whether it genuinely poses an option worth investigating further.

3. Commercial Case | Options for Ownership, Operation and Procurement

Summary

There are feasible operating, ownership and procurement models for the Lake Onslow option; and the use of market instruments (RFPs) or regulation could be deployed to support implementation of the Portfolio option.

For the Lake Onslow option

For the IBC, work has focused on investigating the ability for the market to deliver such a large-scale complex infrastructure project, who is best placed to own the assets once delivered, and how it might operate / interact with the current electricity market.

Delivery: Due to the scale, cost, and complexity of the Lake Onslow scheme, the following delivery models are considered the most feasible: Pure Alliance, Competitive Alliance, Two-stage Early Contractor Involvement moving to Engineer Procure Construction (i.e., an ECI moving to an EPC) and Engineer Procure Construction Management. This is predominately because they both allow for innovation and risk to be appropriately allocated as well as providing time certainty / a shorter time to FID.

Ownership: Full Crown, hybrid, and mixed ownership models are considered the better ownership models for Lake Onslow as they would provide financing, risk allocation and flexibility advantages over more private ownership models.

Operations: Given the cost of the Lake Onslow scheme, operational models that maximise market interaction and benefits (while minimising potential negative second order effects) are preferable to those that restrict operations to security of supply only. Negative second order impacts refer to the accumulation and use of market power for the benefit of the asset operator at the expense of the nation.

Based on research conducted on the impacts of storage options on the electricity market, there are feasible operating models that could achieve this.

For the Portfolio option

There is less certainty about how a Portfolio option would be delivered, however, three options have been identified:

- Crown directly procures reserve capacity generation assets
- Crown procures contracts for reserve capacity
- Development of a reserve capacity market.

These delivery models have not yet been fully assessed for their impact on market incentives in terms of investment or market operations. Comprehensive assessment of these delivery models will be required to better understand market impacts and whether they align with the NZ Battery objectives.

The next stage of work should develop preferred models for delivery of the Lake Onslow and Portfolio options

Investigations in the next phase of work will confirm the delivery strategy for both the Lake Onslow option and Portfolio options. For both, a DBC would need to consider in detail the regulatory settings required to enable a market with battery assets or services to function effectively.

3.1 Purpose

The purpose of this Commercial Case is to provide decision makers with an indication of:

- The availability of viable commercial models for the preferred investment options – this includes consideration of operating and ownership models – and to rule out unviable options
- The availability of viable delivery models for the preferred investment options – this includes considering how the options could be procured and delivered in a way that suits the ownership and operating models and meets government procurement rules.

In most business cases, this assessment is limited to the viability of procurement options. However, given the size and potential impact of the NZ Battery Project, additional work is required. Specifically, the IBC needs to consider:

- The market's ability to build (or deliver the services required for) the preferred option, and
- The electricity market's ability to absorb and operate effectively with a battery function in the market.

This Commercial Case is structured around these two elements and what they would look like under the two preferred options – the Lake Onslow and Portfolio options. The greater depth of the available evidence base means that analysis is predominantly focussed on the Lake Onslow option. However, elements of the work undertaken for the Lake Onslow option are also applicable to the Portfolio option. For example, where both options contemplate the build of hard infrastructure specific assets. However, the work is less applicable to the Portfolio option where the Crown would not procure the assets itself. Further work will need to be undertaken to investigate delivery models for the Portfolio option in greater detail.

3.2 Lake Onslow option

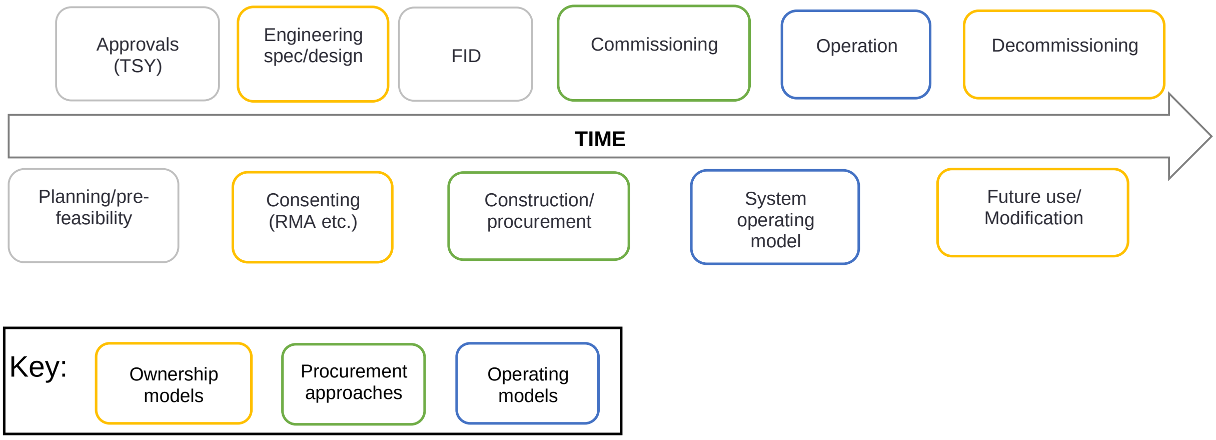
3.2.1 Our approach

In order to make the required commercial viability assessment, for Lake Onslow, the Commercial Case establishes a framework for evaluating the risks, benefits and implications of each model. As noted, aspects of this may be equally applicable to the Portfolio option. The key components to be explored are:

1. The asset lifecycle of the preferred options
2. The required services of the preferred options
3. Assessment of the ownership models able to deliver the preferred options
4. Commercial considerations of the operating models (e.g., market power and revenue generation)
5. Assessment of the range of procurement approaches that are suited to the available ownership and operating models.

This assessment looks across the asset lifecycle to consider the risks associated with each phase. Figure 22 presents the asset lifecycle as a high-level overview of the different stages that the preferred option will pass through to get from the completion of this IBC to final investment decision (FID), commissioning and operations, and eventual decommissioning. This diagram is appropriate for the Lake Onslow option but is less relevant for the Portfolio option delivery models where the Crown is not a direct owner of infrastructure.

Figure 22: Asset lifecycle diagram showing where in the commercial case these risks will be discussed



The asset lifecycle above illustrates how the ownership, operating model and procurement approaches interact with each step in the asset life cycle. The Commercial Case will break down each of the risks across the lifecycle under each of the corresponding model headings to allow these to be discussed in the context of the choices on ownership, operating model and procurement.

3.2.1.1 Services procured

The Lake Onslow option is a single pumped hydro asset constructed as a single programme of work. The services potentially provided by this asset are:

- Dry year generation cover
- Peaking generation / intermittent firming cover.

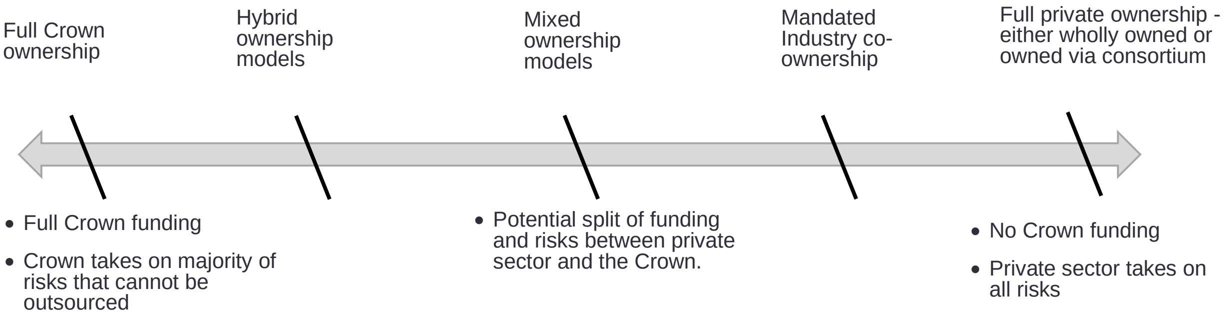
The discussion in this section therefore examines how to procure the construction of the Lake Onslow option that delivers these services, ownership options for this asset and the commercial implications of how this asset will operate in the market.

3.2.2 Full or partial Crown ownership models is likely to be most appropriate

The question of ownership is important because it has implications for the potential procurement and operating models – and has flow on implications for the Financial Case.

The range of ownership models is provided at a high level below[72] with an assessment of the options presented in Appendix J. It should be noted that in all cases the entity that owns the physical asset could be different to the entity that operates the asset (plant operator) and the entity that controls when it operates (system operator).

Figure 23: Ownership model spectrum



- **Full Crown ownership:** This describes a model of direct Crown ownership. This could be achieved through a range of different Crown entity types and corporations (e.g. Crown agents, Autonomous Crown Entities, and Independent Crown Entities). This ownership model would best allow the achievement of non-profit driven considerations.
- **Hybrid ownership models:** This describes an ownership model that is Crown owned but has characteristics of private ownership e.g., a greater degree of autonomy and a profit motive. An example of this model is a State-Owned Enterprise.
- **Mixed ownership models:** This is an ownership model that has a profit motive and allows for multiple different ownership groups (this could include private parties, the Crown, Regional Councils, or iwi).
- **Mandated, industry co-ownership:** This option represents a mandated ownership model (through empowering regulation or legislation) that requires key industry players to hold shares in an entity holding the assets of the option.

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[72] This is not an exhaustive list of all available ownership structures that could possibly be considered to deliver the preferred investment option or Lake Onslow option. Instead, this list is illustrative of a high-level range of options that fall across the ownership / risk / funding spectrum.

- **Full private ownership:** This is private ownership of the option's assets. This could be achieved through a range of different structures e.g., trust, company, or partnership.

The assessment of the above models showed a preference for ownership models that have an element of Crown ownership (Crown, Hybrid and Mixed Ownership models). The key reasons for this assessment were:

- Crown ownership will maintain future flexibility where market conditions change, or a change in asset size and capability is required
- Due to the scale of the asset, the acquisition of land and consenting may be contentious and Crown ownership may allow enabling regulations to be enacted with greater ease
- Crown ownership may be perceived more favourably in terms of the asset delivering a national benefit
- Based on the potential return profile, private owners may be reluctant to fund the asset. This issue may be addressable through severing the link between legal asset ownership and control over the operations of that asset to create an annuity asset (as outlined below). However, it is worth noting this could significantly increase the overall project cost depending on how it is structured.

The assessment of ownership models included an assessment of risk allocation for key risks (such as consenting, asset failure and decommissioning) to ensure the ownership model appropriately assigned risk across the lifecycle. Details of this assessment are included in Appendix J. All short-listed ownership models would need to be considered in greater detail in the DBC.

3.2.3 Procurement approach

There is a range of procurement options that could be used to design and build the Lake Onslow option, ranging from a traditional (design, bid, build) model to more collaborative models like the Alliance model used by the Stronger Christchurch Infrastructure Rebuild Team.

An implementation report completed by Mott MacDonald informed the critical procurement model drivers for the Lake Onslow option. These have been considered and refined to assess the different procurement models and identify a short list of options which would require further refinement for the DBC. Through the IBC the aim has been to establish that there are feasible procurement approaches available for the construction of Lake Onslow. Therefore, analysis focusses on assessing which models best fit with the procurement objectives. A preferred option is not selected.

For the DBC and later phases, a preferred delivery model, considering packaging (how the required services are bundled together into related contracts), sourcing strategy and procurement plan would be developed.

3.2.3.1 Services required

The Lake Onslow project would comprise a series of civil, mechanical, and electrical works packages to deliver the dam, powerhouse and tunnel of the pumped hydro scheme and supporting enabling works. This would comprise a wide range of services.

The DBC would select the preferred procurement model and investigate the procurement strategy. The strategy would also involve a more in-depth consideration of how the different services might be packaged. Packaging of services can offer advantages over contracting individual services – including:

- Bundling of contracts can generate significant value for money. In instances where there are services that make sense to bundle, this can result in several savings owing to a better alignment of risk and a reduction in interfaces between contractors (which can be a source of delay and cost)
- Generating 'larger' procurement opportunities may incentivise more parties to engage in the procurement process, and hence drive competitive tensions on price and quality of responses
- Larger contract sizes may also attract international firms who can bring innovation and global best practice to New Zealand
- A streamlined tender process could lower costs for government and the market as fewer contracts will lower administration costs rather than many small contracts
- There is potential to leverage replicable Requests for Proposal (RfPs) and other procurement documentation. Similar to the above, this can result in cost efficiencies in the development of procurement material.

Key considerations for packaging services include the following:

- **The timing of the procurement:** Where functionally similar, or related, roles are required at the same time, there may be an opportunity to package
- **Technical skills:** Where services have overlaps / similarities which could be delivered by one provider
- **Risk:** Where services share a particular risk there may be advantages to a single contractor managing this risk.

High-level service packaging options have been noted in Appendix K but a comprehensive service packaging strategy should be developed as part of a DBC.

3.2.3.2 Procurement model evaluation criteria

The following evaluation criteria has been used to assess the procurement models and identify a short list for further consideration in a DBC.

As the purpose of the work at the IBC stage is to screen out unsuitable procurement models, the work that has been completed to date by Mott MacDonald is more detailed than that required at the IBC stage. For the purposes of the IBC is has therefore been refined to the evaluation criteria listed in Table 26. The process of building the evaluation criteria from the Mott MacDonald drivers is presented in Appendix L.

Table 26: Procurement model evaluation criteria

Criteria	Definition	Relevance to Lake Onslow option
Time certainty (at FID)	The extent to which a procurement model provides a high level of certainty for the time of completion.	One objective of this project is to enhance or facilitate investment and transition to renewable energy. Uncertainty in the timing of the project's completion may potentially reduce or delay private sector investment in renewable energy.
Shortest time (to FID and from FID to completion)	The extent to which a procurement model delivers the shortest total time to completion.	Delivery of the project relatively quickly will enable the project objectives to be realised early.

Criteria	Definition	Relevance to Lake Onslow option
Flexibility	The extent to which a model provides flexibility to address external and strategic direction changes and deliver increased value.	As a major public works programme the government may wish to exercise significant control over certain elements of the project. With more prescriptive contract models exercising these controls may be more costly/time consuming. This is also a function of the delivery entity used and a function of flexibility for change. The problem definition for the project and external factors may change during project delivery. The facility to manage this change within the procurement framework without major barriers would minimise change friction.
Cost certainty (at FID)	The extent to which a model provides confidence regarding the ability to deliver the project against budget.	Cost certainty is key to ensuring that project objectives are met overall and that funding institutions can have confidence in project budgets and economics.
Lowest cost (at FID)	The extent to which a procurement model delivers the lowest total cost for the project.	Lowest cost is key to ensuring that project objectives are met overall, this has a trade-off with quality and risk transfer.
Innovation and incentives	The extent to which a model incentivises innovations that can assist in delivering desired outcomes with the delivery entity to release value and realise upsides.	Innovation and value release through the engagement of contractor and consultants should achieve a higher whole of life value than independent development. Achieving a high whole of life value / cost effective solution is key to achieving the highest downward pressure on energy costs as the costs for the project are likely to be borne via the NZ electricity/energy market either directly or indirectly.
Risk transfer	The extent to which a model supports effective risk management by transferring, allocating and / or incentivising risks to the parties best placed to manage them	Allocating the “right” risks to the constructor means that the constructor will accept the risks and the client is only managing the risks appropriate to their role.

A further criterion relating to how well the option allows for partnering with Mana Whenua was also considered. However, Iwi/ Māori partnership is a non-negotiable for the project. As a result, it has been treated as a mandatory feature, to be negotiated into any of the delivery models, rather than a screening criterion.

The selected procurement model should, as a minimum, aim to achieve the NZ Government’s 5% Māori procurement spend target and align with the Government’s broader outcome target of increasing NZ businesses’ access to government procurement, including that of Māori and Pasifika businesses. To achieve this, the DBC should look to identify a range of Māori suppliers to deliver the project.

The DBC should also identify the secondary outcomes sought through procurement spend and in alignment with supplier diversity approaches (e.g. utilising local suppliers, local employment, sustainability and waste minimisation). Supplier diversity, as defined by Amotai (Supplier Diversity Aotearoa), is the strategic business process set in place to proactively engage and support indigenous, minority and women-owned businesses and social enterprises within business-to-business (B2B) supply chains to provide fairer access to consumers and markets.

3.2.3.3 Procurement model summaries

Eight potential procurement models were identified for delivering the Lake Onslow option, as follows:

- Traditional
- Design and Construct
- Engineer Procure Construct
- Engineer Procure Construction and Management
- Two-stage Early Contractor Involvement into an EPC
- Alliancing
- Design Construct Maintain Transfer
- Public Private Partnerships

These are summarised in Table 27, with a more detailed summary of each procurement model included in Appendix M.

Table 27: Summary of procurement models

Model description	Risk allocation	Use
Traditional (Design, Bid, Build) The client is responsible for design up to a detailed level of definition and then issues for bidding to which the constructor must deliver the works. They are typically contracted on a lump sum basis.	The client carries almost all risks of design, ground conditions, interface management, overall performance, while the contractor only carries risks for items that should have been accounted for by a competent contractor (productivity etc.). A main constructor takes on the responsibility for as-built design and construction. Quantity risk sits with the constructor under a lump sum, however some traditional contracts permit a re-measurable quantity where risk sits with the Client for items that are not as per the detailed design.	Traditional or Design, Bid, Build procurement is typically used for tightly specified, fully designed solutions with limited complexity. With this model there is limited opportunity for constructor involvement in innovation due to the late appointment of the constructor, so the designer and client are responsible for innovation. The traditional procurement model was applied to the International Thermonuclear Experimental Reactor (ITER) project in France, as detailed further in Appendix N (Reference Projects).
Design and Construct (D&C) The Project Partners seeks tenders to provide a (typically) fixed price for design and construction. In principle design and construct contracts are fixed price lump sum where the constructor accepts and manages the majority of risks having been fully informed during the single stage tender process and contract negotiation.	The client is responsible for designs up to a developed level of definition against which the constructor must deliver the works. As the design is defined to a greater degree the responsibility for the overall performance rests to a greater degree with the client. The contractor is able to provide innovation during the bid stage, but once the contract is awarded the scope for innovation is reduced and the contractor is focussed on delivering against the contract design. A main constructor takes on the responsibility for both detailed design and construction and interfaces within their scope.	A design and construct approach is commonly used for well-defined projects, including large scale complex projects. Design and construct contracts are typically used where there is limited scope for change after contracting and as such there is limited flexibility for changing or directing the project function. The Design and Construct model was also applied to the International ITER project, as detailed further in Appendix N.

Model description	Risk allocation	Use
Engineer Procure Construct (EPC) The client is responsible for designs up to a concept or preliminary level of definition and a performance specification against which the constructor must deliver the works. These requirements are occasionally defined as a minimum functional/performance specification to reflect that the constructor's responsibility is widened from that of a design and construct model. A main constructor takes on the responsibility for both developed and detailed design, interfaces and construction.	An EPC approach is similar to a D&C option however generally reflects a greater degree of design responsibility and risks allocated to the Constructor. In addition to productivity, price escalation and detailed design, under an EPC contract selection, procurement of long lead items and overall performance (time/efficiency) are typically the responsibility of the constructor. Risk for the developed and detailed design sits with the constructor as does the solutions performance that is built based on compliance with the Principals Requirements. The contractor is able to provide innovation during the bid stage, but once the contract is awarded the scope for innovation is reduced and the contractor is focussed on delivering against the contract design.	Infratec's Alpine Energy Battery Storage Trial in Timaru, New Zealand, was procured under an EPC procurement model, resulting in the installation of a 36kW, 142kWh lithium ion battery energy system.
Engineer Procure Construction and Management (EPCM) The EPCM approach provides for a professional services consultant to act as Management Consultant to manage the engineering design, procurement process and the various construction, supply, and installation contracts. The managing consultant, owner, designer and (to a lesser degree) each package constructor, all contribute to the buildability and optimisation of designs allows for significant innovation.	A Managing Consultant takes on, with the owner's input, the responsibility for: • Developed and detailed design • Constructability, logistics and scheduling • Procurement and contract management • The integration of various equipment supply and constructor packages Risk for the detailed design and performance sits with the Managing Consultant as does the solution that is built based on compliance with the Principal's Requirements. With this model ground-based risk will likely rest with the client as it would not fully transfer to the Managing Consultant.	This approach has been used primarily in the resources, mining, oil and gas sector in order to deliver large complex projects. Both the New Zealand Nga Awa Purua 138MW Geothermal Power Plant and Kawerau 100MW Geothermal Power Plant, and their associated Steam Separation Systems, were procured under an EPCM procurement model.

Model description	Risk allocation	Use
Two-Stage Early Contractor Involvement into an EPC While not a procurement contract in the strictest sense the 2 stage ECI is a mechanism for enhancing Traditional, D&C or EPC contracting. A two Stage ECI approach involves the procurement of either a single or multiple constructors to develop a fully scoped and priced solution in collaboration with the client. The client will advance the design requirements to the point necessary for the constructor to prepare an optimised bid.	The client is responsible for designs up to an initial preliminary design and performance requirements (initial Principal's Requirements) against which the client further develops in the first stage of the ECI with input from the constructor into a developed functional and technical performance requirements (final Principal's Requirements). A main constructor takes on the responsibility for both detailed design and construction. Involvement from a constructor into the buildability and optimisation of designs allows for significant innovation, schedule development and time certainty. Risk for the detailed design sits with the constructor as does the solution that is built based on compliance with the developed Principals Requirements as per a D&C or EPC.	The two-stage ECI to an EPC procurement model was applied to Snowy 2.0, Kidston and Coire Glas pumped hydro projects across Australia and the UK, as detailed further in Appendix N.
Alliance (Pure and Competitive) An Alliance relationship is formed between key project participants, which include the Project Partners and non-owner participants (eg designer, constructor, other key stakeholders, etc). The relationship must be collaborative for the Alliance to be effective. The Alliance forms a consortia Interim Project Alliance to develop the design and agree a final Target Out-turn Cost (TOC), in the case of the pure alliance this includes the client. In a competitive alliance multiple consortia to produce Target Out-turn Cost (TOC) and bid for the final Project Alliance. Involvement from a constructor, client and designer into the buildability and optimisation of designs allows for significant innovation. The Alliance delivery entity takes on the responsibility for developed design and construction.	The client is responsible for designs up to a Preliminary / Reference level of design functional and technical performance requirements (Principal's Requirements) to which the Alliance must deliver the works. Risks for the project sits with the Alliance which may package the works and pass that risk through to sub-contractors.	Typically used in high-risk projects where it is difficult to effectively define and transfer risk and there is uncertainty around scope definition, design complexity, delivery complexity, and complex interfaces which will influence design and construction outcomes. The model provides early collaboration of the designer and contractor in the project, providing opportunities to access construction expertise in the development of the design, definition and construction programming. Alliancing procurement models have been applied to the City Rail Link and Waterview Connection projects in New Zealand, and the Heathrow Terminal 5 project in the UK, as detailed further in Appendix N.

Model description	Risk allocation	Use
Design Construct Maintain (Build Own Operate / Transfer– BOO/T) The design construct maintain or build own operate (BOO) model is a long term contract for the delivery of works and operating services to the client, based upon the provision of an asset or facility, which is typically transferred at the end of a contracted period. It is substantially similar to the PPP model below aside from that the finance for the project is provided by the client and that the specification of the works are more prescriptive.	The client is responsible for designs up to a concept or preliminary level of definition and a performance specification against which the constructor must deliver the works and maintain the service. These requirements are occasionally defined as a minimum functional/performance specification to reflect that the constructor's responsibility is widened from that of a design and construct model.	As this model allows government entities to assign a private sector party the responsibility to finance, design, construct, own and operate a project for a specified number of years, the BOOT structure is often used to build power stations, water treatment facilities and sewage facilities. For example, this procurement model has been applied to the large Wathba 2 Wastewater Treatment Plant (WWTP) located in the UAE.
Public Private Partnership (PPP) The PPP models is a long-term contract for the delivery of a service to the client, based upon the provision of an asset or facility, which is typically transferred at the end of a contracted period. Finance is provided by the PPP by via the private sector.	The client is responsible for specifying the service required of the asset and the minimum functional specification of the works to be handed over to meet the services requirements.	The PPP procurement model was applied to the Transmission Gully Motorway project in New Zealand, as detailed further in Appendix N.

3.2.3.4 Four procurement models were assessed as viable for Lake Onslow

The potential procurement models were assessed against the evaluation criteria to identify a short list for further consideration in a DBC. Evaluation was focused on the extent to which each procurement model helped to achieve the criteria in the context of the Onslow option with reference to the project objectives. Any procurement models given a red rating against an evaluation criterion have been ruled out with the evaluation shown in Table 28.

This assessment was undertaken using model procurement options and was agnostic of packaging. The procurement context, investment objectives, procurement drivers and procurement options will need to be considered again during the development of the procurement strategy at DBC to ensure they are up to date for the Project as it progresses in development.

The following models were determined to be compatible with the procurement drivers:

- Pure Alliance
- Competitive Alliance
- Two-stage Early Contractor Involvement to Engineer Procure Construction (i.e. ECI moving to an EPC)
- Engineer Procure Construction Management (EPCM).

It is recommended that these options are taken through for consideration in the DBC stage of the project.

The Management Case provides information on the indicative programme activities and durations[73] for the probable procurement options up to FID for:

- Pure Alliance
- Competitive Alliance
- ECI moving to an EPC.

A programme has not been developed for EPCM as the programme for this work is considered to be between the Alliance options and ECI moving to EPC in duration. Hence the timeframe for the work would be between these two options and does not need to be considered in detail in the IBC.

More detailed procurement model option timelines that take into account the need for multiple procurement activities for different service packages would need to be developed once a procurement strategy is sufficiently progressed.

The evaluation has informed the costs to FID for the project and the mid-case estimate for a Competitive Alliance has been used in the Financial and Economic Cases of this IBC. In addition, the owners team information and structure has informed the Management Case of this IBC.

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[73] Based on *the construction programme included within the Feasibility Study Report completed by Te Rōpū Matatau, dated September 2022.*

Table 28: Procurement model evaluation

Procurement Model	Evaluation criteria							Comments
	Time certainty (at FID)	Shortest time (to FID and from FID to completion)	Flexibility	Cost certainty (at FID)	Lowest cost (at FID)	Innovation and incentives	Risk transfer	
Traditional	🟥	🟥	🟩	🟨	🟨	🟥	🟥	The model did not align with the time, innovation and risk criteria and therefore will not be considered further.
D&C	🟨	🟥	🟥	🟨	🟩	🟥	🟥	The model did not align with the shortest time, flexibility, innovation and risk criteria and therefore will not be considered further.
EPC	🟨	🟨	🟥	🟨	🟩	🟨	🟨	The model did not align with the flexibility criterion and therefore will not be considered further.
EPCM	🟨	🟨	🟨	🟨	🟨	🟩	🟨	The model allowed all criteria to be met and therefore will be further considered in the DBC.
Two Stage ECI to EPC	🟩	🟨	🟨	🟨	🟩	🟩	🟩	The model allowed all criteria to be met and therefore will be further considered in the DBC.
Alliance (Competitive and Pure models)	🟩	🟩	🟩	🟨	🟩	🟩	🟨	The model allowed all criteria to be met and therefore will be further considered in the DBC.
Build Own Operate/ Transfer (BOO/T)	🟨	🟥	🟥	🟩	🟨	🟥	🟩	The model did not align with the flexibility, shortest time and innovation criteria and therefore will not be considered further.
PPP	🟩	🟥	🟥	🟩	🟩	🟥	🟩	The model did not align with the flexibility, shortest time and innovation criteria and therefore will not be considered further.

Key:

Rating	Description
🟥	Does not allow criterion to be met – **procurement model is eliminated**
🟨	Allows criterion to be met
🟩	Performs strongly against criterion

3.2.3.5 An initial market assessment suggests there is market interest and capacity to build the Lake Onslow option

If progressed, the Lake Onslow option would be one of the largest infrastructure projects to be constructed in New Zealand. It is assumed that it will require at least one large-scale international constructor to mobilise to service the project.

To gain an understanding of how the market may respond, an initial market assessment of potential suppliers and reference projects has been undertaken. This is to provide information for consideration in advance of the detailed market sounding and preparation of case studies which will be required as part of the procurement strategy and DBC.

The type of contractors who may have interest in helping deliver the project range from international large-scale constructors, EPCM managing consultants, and Australian / New Zealand constructors. Key equipment suppliers have also been considered as the design, manufacture, and supply of key equipment from the original equipment manufacturers (OEMs) is a significant component of the project and will need to be considered in any future procurement approach. The following list summarises the types of contractors who may be involved in project delivery and demonstrates that there is capability in the market to deliver this and it should be an attractive project to the wider market.

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A market sounding exercise including targeted interviews with all types of suppliers is recommended during the preparation of the procurement strategy to fully understand the market capacity, capability, and interest in the project.

An initial desktop assessment of reference hydro and pumped hydro projects and more broadly applicable large scale, one-off projects has been completed. The output of this assessment can be seen in Appendix N. This demonstrates that the probable delivery options that were determined through comparing procurement options and procurement drivers is aligned with current market procurement.

This scan is cognisant of:

- Comparable project governance: Government delivered infrastructure projects, particularly in New Zealand, or projects that are intended to be transformational to the market
- Comparable asset class: Large scale energy projects with either underground works or projects that are discrete assets with significant ground / geotechnical challenges
- Comparable locations: Australian projects that are likely to share supply chain constraints with the national market or local projects
- Comparable client capability: One-off projects delivered by organisations with limited to large scale construction project procurement
- Understanding the market approach to managing risks particularly for what is likely to be a project tendered prior to consents being granted.
- Projects with large projected economic gains / broader project outcomes for local communities.

A case study exercise including targeted interviews with the owners of the projects is recommended during the preparation of the procurement strategy to fully understand why specific procurement approaches, risk allocation approaches and timeframe decisions were taken.

3.2.3.6 Key procurement risks and mitigations have been identified

An approach to risk management that is aligned with MBIE’s existing risk management approach, and Te Waihanga guidance, will be adopted (this is outlined further in the Management Case). MBIE’s understanding and management of these risks will evolve as the project progresses.

Risk allocation from a delivery model perspective should be considered during the development of a procurement strategy at the DBC stage. This may impact both the Option’s ability to achieve Investment Objectives and decisions around procurement options. These considerations include:

- Conformance to government rules of sourcing
- Market capability
- Market capacity and interest
- Concurrent and competing projects
- Desire to have New Zealand contractors included in delivery
- Supply chain constraints
- Client-side resource constraints
- A fair and transparent process
- Consenting risk and who is best placed to take and manage this risk.

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[redacted]

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3.2.4 Indicative consenting strategy

Te Waihanga, in its Infrastructure Strategy, notes the challenges with gaining consent for infrastructure projects and the need for change to enable these to progress in the future. It notes the significant time and cost impact of infrastructure consenting processes on the industry currently. Early planning has been completed for a consenting strategy and responses to these challenges for the Lake Onslow option.

At the IBC stage, the consenting strategy seeks to identify the issues that would need to be addressed in a DBC in terms of obtaining the necessary resource consents and designations required to authorise the construction, operation, and maintenance of the asset throughout its lifespan.

The Government is currently drafting new legislation, which will repeal and replace the current Resource Management Act (RMA). The Government has indicated the future Natural and Built Environments Act (NBA) will be the first Act (of three) to be operative and is expected to be passed in 2023. At the time of developing this IBC, the process under the NBA is not known and untested, but a board of inquiry process may be required if this process was used.

Given the scale and complexity of the Lake Onslow option, enabling legislation to authorise the project may be better suited to ensuring that the effects of Lake Onslow are considered holistically. For the purposes of the indicative consenting strategy, it is assumed that the Lake Onslow option would be authorised under enabling legislation.

The consenting strategy would need to be developed fully in a DBC. Consideration would need to be given to the resourcing of the consenting strategy as well as the timeframes required to effectively consult with stakeholders and develop any required enabling legislation.

Negotiations

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

- [redacted] Negotiations

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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Negotiations

[redacted]

[redacted]

[redacted]

[redacted]

Negotiations

[redacted]

[redacted]

[redacted]

3.2.7 Operating model commercial considerations

This section summarises the work undertaken by Dr Grant Read to identify options for how a Lake Onslow option might operate within the NZ electricity market. It draws on examples from other jurisdictions like the Columbia River Basin and identifies mechanisms for enabling the Lake Onslow option to participate in the market and minimise as far as possible the risk of market distortions.

The commercial arrangements would need to be developed further as part of a DBC process. This section is not intended to provide a roadmap to implement different operating model options but does cover key considerations to be explored further.

The Grant Read report identifies three models and the high-level arrangements needed to enable these to work to operate the storage and generation associated with the Lake Onslow option. These are outlined in Table 30 below. These market operating models would likely require regulatory oversight to ensure:

- The asset achieves its core objective – coverage of dry year risk.
- Fairness and transparency around operation.
- Negative impacts on the wholesale electricity market are minimised.

Table 30: Operating model options and rules required

Market Operating Model	Operating Model Infrastructure required	Rules required
National benefits optimisation model: This describes the operation of the facility by one party in accordance with a formal reservoir management model that uses a net national benefit “objective function” to determine buy / sell offers in spot / hedge markets.	• Oversight of model construction and operation • Independent review processes to avoid undue influence by one party • Periodic review of model outcomes to identify issues and improve performance	Definition of how national benefit is assessed and then optimised through buy / sell offers.
Virtual slicing offer model: This would involve the virtual slicing of the storage, generation and pumping capacity of Lake Onslow and auctioning slices to different market participants. This option would conceptually split Lake Onslow into several mini pumped hydro assets.	• Auction process and rules • Registry of holders’ rights • Periodic review and oversight of auction outcomes	Limits on purchase to ensure market power is controlled (both in terms of the absolute limit on purchases and the purchases in the context of the rest of the purchaser’s energy generation Portfolio) Determining the price of slices at auction where there is insufficient participation to have efficient price discovery. The role of an operator in terms of how the slices are offered to the market, how buy / sell orders are executed and how the role is funded
Hybrid model: This is a combination of the above two operating models. For example, the facility could be split into separate slices, of which a portion is provided to a single operator that is using a national benefits optimisation model and the remainder is auctioned. Alternatively, a single operator could manage the pumping of the facility and the storage and generation capacity could be auctioned.	As above for both options.	As above for both options.

All three options require an independent operator to run the facilities transparently and in accordance with operational rules. This could be achieved similar to how Transpower, as system operator, currently dispatches and operates the national power system.

In addition, the asset operator would likely require oversight from an independent industry regulator to:

- Monitor and report on the efficacy of the facilities and the conduct of the operator and participants. This would be similar to how the Electricity Authority currently works in the wider electricity market to set market participation rules and manage service provider performance
- Set maximum return thresholds on the asset operator (and potentially facility owner) to ensure market power is not being exploited to make excessive profits. This could involve similar oversight of returns to that provided under Part 4 of the *Commerce Act 1986*.

The creation of this system may require the amendment or creation of legislation to implement it.

As outlined, there are some pre-existing operators and market regulators who perform similar roles in the wider electricity market that might be suitable to provide services to monitor and call upon both options. Whether these same bodies can or should be used, and the design and scope of any legislation required would need to be considered in detail.

3.2.8 Next steps for Lake Onslow

To inform a DBC, the following activities will need to be undertaken:

- **Development of the procurement strategy, involving:**
    - **Market Sounding:** engagement directly with all types of market suppliers and Te Waihanga to understand capacity, capability, constraints, and risk appetite for the Project - this should include consideration of Māori suppliers and NZ Government targets on Māori procurement spend
    - **Competing projects scan:** an analysis of infrastructure pipeline and the impact on the supply chain. This will include engagement with Te Waihanga to leverage their transverse view of infrastructure capabilities in the NZ market.
    - **Lessons Learned:** direct engagement with other client entities of similar projects to understand their procurement and wider decision making
    - **Workshops:** wider engagement on procurement drivers and procurement option assessment is recommended including decision makers, industry experts and potentially external client advisors.
- Negotiations

[redacted]

- **Policy work to investigate operating models, including:**
    - **Electricity market participation engagement:** to examine the potential market impacts and the implications of potential operating models; regulatory changes that might be required; and market interest.

3.3 The Portfolio option

The NZ Battery work at the IBC stage has defined the Lake Onslow option in detail. The Portfolio option has been developed as a comparative solution with equivalent services, but is yet to be developed to the same level of detail. For example, there is a range of physical assets that could feasibly deliver these market services and further work, including market engagement is required to understand what a true Portfolio option could look like. Instead, work on the Portfolio option has focused on establishing that viable delivery models exist.

The Portfolio option has been defined in the Economic Case as a combination of the following technologies to provide similar dry year and peaking cover (reserve capacity) as the Lake Onslow option:

- Flexible geothermal[74]
- Biomass
- Hydrogen.

More information about the specific technologies and the risks associated with each is available in the work undertaken by WSP on these options.

The ownership and delivery of the reserve capacity services from these assets, or other similar energy storage and generation assets, could be provided through different delivery models or a combination of models. These are explored below.

3.3.1 Portfolio option delivery models

Three options for delivering a portfolio of reserve capacity assets of services have been identified. Full examination of these will need to be undertaken during the next phase of work leading to the DBC. The following delivery models have been identified at a feasibility level for the purposes of the IBC.

It is acknowledged that the dimensions of the Portfolio option modelled for the purpose of the IBC are illustrative. As delivered, the option would be unlikely to match these dimensions.

Identification of the delivery models has been guided by the Investment Objectives identified in the Strategic Case. The delivery model will need to deliver an outcome that:

- Provides security of supply during a dry year that is no worse than today in a 100% renewable electricity system

- Provides for more affordable electricity, compared to a future without NZ Battery, in a 100% renewable electricity system

- Accelerates emissions reduction through increased renewable share of energy.

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[74] Noting that geothermal may have limited ability to run as peaking capacity from an economic perspective.

For a Portfolio option to deliver on the Investment Objectives, the delivery model will need to allow for either:

- Direct Crown intervention to ensure the necessary assets and services are in place within the desired timeframe, or
- The creation of incentives to ensure the necessary assets and services are in place within the desired timeframe, or
- A combination of these approaches.

One or a combination of these models could be employed:

1. **Crown procures reserve capacity generation assets** – this would involve direct procurement of the generation assets themselves, which would be similar in approach to the Lake Onslow option. The mix and dimensions of assets to be built would need to be determined before going to market to procure them. In contrast to the Lake Onslow option, the procurement would be for a series of lesser scale generation assets managed as a Portfolio of reserve capacity. Once the shape of the Portfolio is determined, the ownership options set out in section 3.2.2 would need to be considered.

2. **Crown procures contracts for reserve capacity** – this would involve the procurement of reserve capacity on long term contracts that obligate the owner to hold generation fuel and capacity available for use in dry year or peaking events. Each contract would be related to specific assets held (or to be built) by the contract holder. Such contracts could also apply to demand response options whereby a major electricity user contracts to reduce demand at a specified time in the market. A combination of testing, incentive and penalty regimes would be required to ensure that the generation or demand reduction capacity was available at the contracted time. This model could be achieved by the Crown:

    a. Providing funding for the build / extension of an asset and then procuring services from it

    b. Providing funding for services but being agnostic to the means of them being provided.

    The option assumes wholly or predominantly private ownership.

3. **Development of a reserve capacity market** – this would involve procurement of reserve capacity for specified periods of time through an open market. The contracts auctioned in the market would pay the owner of generation capacity to hold generation capacity available for specified market services (peaking or dry year risk) for a specified period. Such contracts could apply to demand response options whereby a major electricity user contracts to reduce demand at a specified time in the market. Penalties would apply if the generation capacity was not available at the contracted time. There would be no obligation on generation capacity owners to bid into the market. Capacity markets are used in a number of electricity markets in place of the ‘energy only’ model[75] used in the NZ market. Belgium and Sweden operate capacity markets specifically for strategic reserves of electricity. The capacity markets supplement a core real-time energy market comparable to ours.

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[75] An ‘energy only’ market refers to an electricity market where participants are paid to generate electricity. No payments are made to hold capacity available. The NZ market is an energy only market. While Transpower does contract with generators for frequency keeping and black start services these are very minor contracts in terms of revenue and are of a very different nature to wholesale market sales.

During the IBC, the option to regulate existing market participants was also considered. Unlike the reserve capacity market option described above, the regulatory option would require electricity market participants to hold sufficient reserve capacity or firm energy for dry year and peaking cover. This would be a substantial change for the NZ electricity market. Initial consideration is that it is unlikely to be feasible for the following reasons:

- The option would likely be contentious, creating an uncertain pathway for implementation
- The costs of the reserve capacity would be able to be passed through unchecked to consumers, which could increase electricity prices to an unaffordable level contrary to Investment Objectives
- Such a significant change may create a perception of instability in market rules potentially leading to an erosion of investor confidence in the NZ renewable generation market. This would undermine Investment Objectives aimed at encouraging renewable generation investment
- Compliance with regulation would be costly and potentially difficult to monitor due to the interplay between commercial electricity generation and the reserving of capacity for specified market conditions.

3.3.2 Further work is needed to investigate the models

Ownership and operating model considerations for these delivery models would need to be examined in detail. However, at this stage private ownership is assumed for options 2 and 3. Consideration will also need to be given to the extent to which these delivery models might impact the incentives or ability of electricity market participants to invest in new renewable generation at the right pace to meet the 100% renewable electricity imperative and projected future demand.

There is a risk that the delivery models do not adequately incentivise participation or do so in a manner that materially increases electricity prices. This risk could take the form of insufficient bids for an auction or a lack of credible counterparties for a concession regime. While increasing the contract price would encourage further reserve capacity to offer into a market, these bids could be artificially high as a rent-seeking response to the lack of bids – further escalating cost. Where this occurred, the resulting costs would undermine the Investment Objective aimed at reducing wholesale electricity costs.

All Portfolio delivery models will involve some change to current electricity market operations. There may be a need for different regulator roles, such as a market operator, or enhanced technical capabilities, such as assessing the adequacy of reserve capacity on an ongoing basis. These changes would require full assessment to inform a DBC.

3.3.3 Next steps for the Portfolio option

Given the challenges of the delivery models noted above, it will be important to fully examine each during the next phase of the project. Moreover, the potential impost on electricity market stakeholders of these solutions will necessitate significant consultation with electricity market participants to prepare the industry for these changes, further understand the design options, and identify risks. The next steps for this option are therefore:

- **Options scanning**: Further options scanning of markets in other jurisdictions to build out and refine the option
- **Design:** Further indicative design work to support discussions with market participants
- **Engagement:** Industry Engagement with electricity market stakeholders to get feedback on the potential changes and input on potential scheme and market design choices. Consideration will be given to combining with proposed Lake Onslow (and possibly North Island pumped hydro) consultation to minimise the burden on industry.
- **Policy:** Indicative regulatory impact assessment work to understand the scale and impacts of the changes.

4. Financial Case | Understanding the Financial Impact

Summary

The financial costs of both the Lake Onslow option and Portfolio option have been quantified over a period of 42 years. Both are expected to be significant investments with multi-generational costs and revenues.

The total project expenditure and funding envelopes for each over that period are as follows:

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A range of potential funding, financing, and cost recovery mechanisms have been explored in this IBC and most appear feasible – depending on the eventual option selected and the fiscal objectives that should be pursued. It is proposed that these matters are explored and defined in the DBC.

4.1 Purpose

The purpose of the Financial Case is to:

- Quantify and outline the cost of the selected options which will need to be funded over the near-term (to DBC), mid-term (to FID), and long-term (Post FID) and required funding envelope to be met by the Crown
- Outline and summarise potential funding and financing options available to the Crown to deliver and operate the options over their lifetime
- Discuss the overall affordability of the selected options.

4.2 Introduction

While the Economic CBA includes the effects on all sectors of the economy, the Financial Case only focuses on the fiscal impacts to the government sector. In the context of NZ Battery this means the Financial Case only considers the relevant investment made by the Crown. The key implications of the Financial Case and how it differs from an Economic CBA are as follows:

- The Financial Case includes escalation, resource transfers, and accounting items such as depreciation and a capital charge. In contrast, the Economic CBA reflects real resource use
- Sunk costs are included in the Financial Case but are excluded in the Economic CBA

- The Financial Case considers all potential sources of funding available to the Crown to fund the gap between existing funds already committed to the option and the total cost. The Economic CBA does not consider funding methods.

4.3 Preferred options

As noted elsewhere in this IBC, there is considerably more available and certain information about the Lake Onslow option than the Portfolio option at this point in time. As a result, it is not possible to explore the financial considerations for the latter to the same extent as the Lake Onslow option. This information asymmetry is reflected in this Financial Case. Further work would be needed in the next phase of the project to better understand the potential costs and revenues of a Portfolio option.

4.4 The Lake Onslow option

4.4.1 Assumptions

The project team has delivered a cost estimate (AACE Class 4), including P50 and P90 estimates, reflecting current understanding of risks events. Statistically, P50 and P90 represent the confidence level of a cost not being exceeded. A P50 value has a 50% probability that it will be exceeded, whereas, a P90 has a 10% probability of being exceeded. All figures presented throughout this case are based on P50 and base schedule.

As part of the Economic CBA, a comprehensive financial model was built to forecast all relevant costs and benefits over the lifespan of the investment. As for the Economic Case, the Financial Case has been undertaken on one potential configuration for Lake Onslow of 5.0TWh, 1,000MW and lower storage capacity of Commercial Infor at Negotiations The optimised configuration for the Lake Onslow would be selected through further detailed design work.

Table 31 provides a summary of the assumptions relevant to the Financial Case where they differ from that which is included in the Economic CBA. See Appendix I for a detailed explanation of the Economic CBA assumptions.

Table 31: Lake Onslow Financial Case Assumptions

Item	Assumption	Source
Timeframe	42 years to (1) align with the EMM (as per Economic CBA), (2) represent roughly half of the asset life and (3) balances time value of money considerations.	Team assumption.
Escalation	The escalation assumption adopted aligns with TRM where the following profile was applied: CY22: 6% CY23: 5% CY24: 4% CY25 (onwards): 3% It is noted that because the model is on a financial year basis, the above has been adjusted from calendar year to financial year.	TRM reports
Construction CAPEX	The expected capital costs associated with constructing the NZ Battery option	Peer reviewed, Class four cost estimates. Please refer to

Item	Assumption	Source
	including a 30.8% contingency applied to all capex categories.	TRM reports (Appendix K – Basis of Costing and BoQ)
Transmission connection CAPEX	The expected capital costs associated with transmission connection of the NZ Battery option. It is noted that for the Economic Case the $286m cost associated with increasing the capacity of the transfer from Roxburgh to Waitaki was classified as CAPEX as this is the economic cost to New Zealand. For the financial case it is classified as OPEX due to Transpower recovering the cost from NZ Battery through the TPM.	Performed by MBIE based on information supplied by Transpower
Renewal and replacement CAPEX	The expected capital costs associated with maintaining the NZ Battery option over its lifespan and reflects a 30.8% contingency applied to all categories.	Peer reviewed, Class four cost estimates. Please refer to TRM reports (Appendix K – Basis of Costing and BoQ).
OPEX	The expected costs to operate NZ Battery and deliver electricity under the selected operating model	Peer reviewed, Class four cost estimates. Please refer to TRM reports (Appendix K – Basis of Costing and BoQ)
Transmission connection OPEX	The expected direct operating costs associated with transmission assets. Furthermore, this also includes NZ Battery’s contribution to overall, NZ wide system transmission costs.	Performed by MBIE based on information supplied by Transpower
System administration	The expected upfront and operating cost of the government related entity that will manage and / or operate the NZ Battery option.	High-level Project Team estimates.
Resilience	Excluded, not financial cost	n/a
Operating revenue	The expected operating revenue from the NZ Battery option (i.e. generation revenue less electricity consumed during periods of pumping)	Outputs from EMM.
Electricity system benefits	Excluded, not a financial benefit.	n/a.
Productivity improvements	Excluded, not a financial benefit.	n/a.
Terminal value	Excluded.	n/a
GST and Tax	Excluded.	Treasury BBC guidance.
Capital Charge	Treatment of capital charge is not included in the IBC and will be considered at DBC.	n/a.

4.4.2 Lake Onslow Financial cost

During Phase 1 of the NZ Battery Project, the project team has worked to understand and quantify the potential risks if the project is to move beyond the feasibility phase. The cost estimate has been informed by:

- A feasibility engineering, geotechnical and environmental investigation into the feasibility of pumped hydro at Lake Onslow focusing on identifying the most feasible scheme design options
- A programme of geotechnical investigations, including drilling for rock samples, in and around Lake Onslow and the Teviot Valley to support the findings of the investigation above, and to identify any fundamental geotechnical risks
- A risk-based cost estimate, which:
  - Quantifies risk into the project base cost estimate – recognising risks as threats and opportunities that can cause variability to the base cost estimate.
    - Clearly articulates the whole scope of cost – including contingency, escalation, enabling works (roading, etc) and transmission upgrades.
- International best practice by using the Association for the Advancement of Cost Engineering (AACE) cost, schedule and risk estimates. Class 4 – P50 and P90
- Transmission costs (Class 4) have been developed by Transpower, utilising their extensive expertise
- Relevant benchmarking of key project elements (i.e., dam and tunnel) with similar large scale national and international projects is underway and nearing completion.
- Independent external expert review of cost, schedule and risk by specialist firm, Turner and Townsend.

Table 32 below provides a summary of the total P50 CAPEX and OPEX on the base schedule required to pursue Lake Onslow and how the total costs are incurred over the 42-year model timeline. It is noted that the life span of Lake Onslow is estimated to be 80 years and therefore the figures presented do not present a whole of life picture. See Appendix H for a detailed analysis of the source and research that informs the below costings.

Table 32: Total estimated financial costs to build a pump hydro dam at Lake Onslow ($'m, 42yrs, nominal)

Lake Onslow expenditure items *(*Negotiations*, 1.0GW, 5TWh,* Commercial Informa	**Estimated financial cost** ($'m, 42 yrs, nominal)
Construction CAPEX	15,493.3[76]
Transmission connection CAPEX	614.56[77]
Commercial Information	[redacted]

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[76] This figure excludes $190.3m of CAPEX which is scheduled to occur pre-FID (this is instead included in system administration costs below). Where pre-FID CAPEX was included, the Construction CAPEX figure would total $15,684m.

[77] This figure includes $25m for improvements to grid protection schemes in the South Island (to improve grid stability when Onslow is pumping) and $416.5m for a new substation at Onslow (connected to the three local 220kV lines), these costs have then been escalated for inflation to reach $614.56m.

Note, this figure excludes $286m (un-escalated) for a double-circuit 220kV line from the new Onslow substation to Benmore, plus duplexing of the Aviemore-Benmore line (to improve grid capacity between the Roxburgh region and Waitaki Valley) as these costs are expected to be paid through annual TPM payments. These costs have been included in transmission connection OPEX figures.

Lake Onslow expenditure items Negotiations *1.0GW, 5TWh,* Commercial Informa	**Estimated financial cost** ($'m, 42 yrs, nominal)
Commerci	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
Commercial Information	[redacted]

Note: Based on P50 costs and base schedule. Due to rounding the sum of parts may not equal the total

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[redacted]

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[78] NZ Battery Project Procurement and Implementation Assessment, Mott McDonald, September 2022.

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4.4.4 Current funding and revenue for Lake Onslow

At the beginning of the NZ Battery Project, MBIE received approval for a $100.008m appropriation. This was intended to fund the assessment of options to address New Zealand’s dry year problem in sufficient detail for Cabinet to make a decision on the selection of an option and to take it through to FID. To date, $30m of this appropriation has been tagged to phase 1 with the remaining $69m being available for DBC and FID.

The scope of the appropriation aligns with the expenditure items outlined above and is therefore assumed to be able to be drawn down in full to cover the forecast expenditure. It is noted that the appropriation expires 30 June 2025.

Based on EMM performed during the feasibility phase, the net operating revenue for 89 hydro inflow futures is calculated for 2035, 2050 and 2065. As part of the Economic CBA, the net operating revenue is assumed to be the average across all 89 futures and linearly interpolated between the years.
An average was taken as:

- Weather events are very unpredictable
- No one year of water inflows from 1932 to 2019 is more or less likely to occur in the future (i.e. each has equal probability of occurring).

Based on these assumptions it is estimated that the net operating revenue of Lake Onslow is Commercial Information

4.4.5 Funding gap for Lake Onslow

The funding gap describes the total cost of the project (net of revenue) required over its lifecycle. The size of this gap is also subject to how the Crown chooses to fund the project and recover costs e.g., should a levy option be chosen it could be designed to fully recover the cost of capital reducing the funding gap to nil. This is described in greater detail in section 4.7.2 below.

In addition, there are a range of key decisions expected to be made following the submission of this IBC. This includes final decisions on potential operating and commercial arrangements for each option. The outcomes these decisions will also materially impact the funding requirements for each option.

In lieu of these decisions and actions being completed, analysis has been done on the funding gap assuming that Lake Onslow will operate to arbitrage the market whenever economically viable (subject to minimum storage constraints required to maintain security of supply).

Table 34: Funding gap to build a pump hydro dam at Lake Onslow ($'m, 42yrs, nominal)

Lake Onslow expenditure items Negotiations, *1.0GW, 5TWh,* Commercial Inform	**Estimated financial cost** ($'m, 42 yrs, nominal)
Construction CAPEX	15,493.3[80]
Transmission connection CAPEX	614.6[81]
Commercial Information	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

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[79] Lake Onslow generates net operating revenue through pumping and storing water when wholesale prices are low and releasing that water to generate electricity when wholesale prices are high (i.e., the higher the volatility in wholesale prices, the higher the net operating revenue). However, the presence of a large pumped-hydro scheme will reduce volatility of wholesale prices and thus lower the potential net operating revenue Lake Onslow earns. The commercial attractiveness of Lake Onslow will therefore reduce over time. This means operating revenue is potentially overstated in later years as it does not take this into consideration.

[80] This figure excludes $190.3m of CAPEX which is scheduled to occur pre-FID (this is instead included in system administration costs below). Where pre-FID CAPEX was included, the Construction CAPEX figure would total $15,684m.

[81] This figure includes $25m for improvements to grid protection schemes in the South Island (to improve grid stability when Onslow is pumping) and $416.5m for a new substation at Onslow (connected to the three local 220kV lines), these costs have then been escalated for inflation to reach $614.56m.

Note, this figure excludes $286m (un-escalated) for a double-circuit 220kV line from the new Onslow substation to Benmore, plus duplexing of the Aviemore-Benmore line (to improve grid capacity between the Roxburgh region and Waitaki Valley) as these costs are expected to be paid through annual TPM payments. These costs have been included in transmission connection OPEX figures.

Lake Onslow expenditure items Negotiations *1.0GW, 5TWh,* Commercial Informa	**Estimated financial cost** ($'m, 42 yrs, nominal)
Commercial Information	

It is worth noting two things about this analysis:

- The funding gap is demonstrated for the model lifetime and will therefore be different to the funding envelope over the asset lifetime (which could be upwards of 80 years). It is assumed that a longer modelling period would reduce the funding gap as it would include additional years of net operating revenue
- While the funding gap roughly equates Commercial Information, it is noted that this might be different to any funding request. For example, it is likely that all CAPEX, plus initial OPEX and maintenance costs, will be sought upfront, with a portion of this paid back through surplus operating revenue (and potentially a levy or equivalent). The specific terms of this arrangement will be considered in the DBC.

4.5 The Portfolio option

4.5.1 Assumptions

In a similar manner to Lake Onslow, a comprehensive financial model was built to forecast all relevant costs and benefits over the lifespan of the investment. Table 35 provides a summary of the assumptions relevant to the Financial Case where they differ from that which is included in the Economic CBA.

Table 35: Portfolio Financial Case Assumptions

Item	Assumption	Source
Timeframe	42 years to align with the EMM	Team assumption
Inflation	The inflation assumption adopted aligns with Lake Onslow (TRM reports) where the following profile was applied: • CY22: 6% • CY23: 5% • CY24: 4% • CY25 (onwards): 3% It is noted that because the model is on a financial year basis, the above has been adjusted from calendar year to financial year.	Aligned with Lake Onslow, TRM reports
Construction CAPEX	The expected capital costs associated with constructing the NZ Battery option and reflects contingency applied to all CAPEX categories	Class four cost estimates. Please refer to WSP reports

Item	Assumption	Source
Transmission connection CAPEX	The expected capital costs associated with transmission connection of the NZ Battery option.	Performed by MBIE based on information supplied by Transpower
Renewal and replacement CAPEX	The expected capital costs associated with maintaining the NZ Battery option over its lifespan and reflects contingency applied to all categories	Class four cost estimates. Please refer to WSP reports
OPEX	The expected costs to operate NZ Battery and deliver electricity under the selected operating model	Class four cost estimates. Please refer to WSP reports, and separate calculation performed by MBIE for Transmission costs
Transmission connection OPEX	The expected direct operating costs associated with transmission assets. Furthermore, this also includes NZ Battery's contribution to overall, NZ wide system transmission costs	Performed by MBIE based on information supplied by Transpower
System administration	The expected upfront and operating cost of the government related entity that will manage and / or operate the NZ Battery option	Class four cost estimates. Please refer to WSP reports. The System administration costs are highly dependent on the delivery model implemented.
Resilience	Excluded, not financial cost	n/a
Operating revenue	The expected operating revenue from the NZ Battery option (i.e. generation revenue, export of by-products, less electrolyser costs).	Outputs from Electricity Market Modelling
Electricity system benefits	Excluded, not a financial benefit	n/a
Productivity improvements	Excluded, not a financial benefit	n/a
Terminal value	Excluded	n/a
GST and Tax	Excluded	Treasury BBC guidance
Capital Charge	Treatment of capital charge is not included in the IBC and will be considered at DBC	n/a

4.5.2 Financial cost

Table 36 below provides a summary of the total CAPEX and OPEX required to pursue the Portfolio option and how the total costs are incurred over the 42-year model timeline. It is noted that the life span of the Portfolio option is estimated to be 40 years and therefore the figure captures the whole of life costs and revenues.

Table 36: Total estimated financial costs to build out a Portfolio option ($'m, 42yrs, nominal)

Portfolio *(Biomass, Geothermal and Hydrogen)*	**Estimated financial cost** ($'m, 42 yrs, nominal)
Construction CAPEX	13,275.8
Transmission connection CAPEX	363.7

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4.5.3 Current funding and revenue

As for the Lake Onslow option, there is $69m available from existing appropriation for DBC and FID.

Based on EMM performed the net operating revenue of the Portfolio option is Commercial Information reflecting the following:

- Electricity sales net of electrolyser costs
- Export of used biomass material and ammonia (by-products of biomass and hydrogen generation)

4.5.4 Funding gap for the Portfolio option

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Portfolio *(Biomass, Geothermal and Hydrogen)*	**Estimated financial cost** ($'m, 42 yrs, nominal)
Construction CAPEX	13,275.8
Transmission connection CAPEX	363.7

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4.6 Funding and financing options

4.6.1 Lake Onslow option

This section outlines a range of possible financing options for Lake Onslow and highlights the indicative impact of each on Crown accounts. Financing options for the Portfolio option are set out in section 4.6.1.2.

This section does not assess the viability of the different financing options – this is left to the DBC when more would be known about the NZ Battery investment options, market appetite, and expected delivery models. The DBC would also include more explicit application of Te Waihanga's Infrastructure funding and financing principles for the preferred option.

Table 38: Infrastructure funding and financing principles

Te Waihanga: Infrastructure funding and financing principles	
Principle 1	Those who benefit pay - Infrastructure services should be paid for by those benefiting from the services (the benefit principle) or creating a need for the service (the causer principle).
Principle 2	Intergenerational equity - Funding and financing arrangements should reflect the period over which infrastructure assets deliver services and be affordable for current and future generations.
Principle 3	Transparency - There should be a clear link between the cost to provide infrastructure services and how services are funded. Wherever possible, prices should be service-based and cost-reflective.
Principle 4	Whole-of-life costing - Funding requirements should include the ongoing costs to maintain and operate an infrastructure asset and the cost to renew or dispose of it at the end of its life as well as the up-front cost to construct or purchase it
Principle 5	Administratively simple and standardised - Administrative costs for both providers and users should be minimised unless there are clear benefits from more complex funding and financing arrangements.
Principle 6	Policies for majority of cases - Funding and financing policies should be written to work for the majority of cases. If needed, alternative or supplementary mechanisms should be added to provide flexibility and ensure fairness.

Source: Rautaki Hanganga o Aotearoa – NZ Infrastructure Strategy 2022

4.6.1.1 Ownership model

As outlined in the Commercial Case, there is a spectrum of potential ownership models for Lake Onslow, including:

- Full Crown ownership
- Hybrid ownership
- Mixed ownership models.

As set out in the Management Case, further work needs to be done to confirm the exact ownership structure / entity for Lake Onslow. However, to give effect to the ownership preferences outlined in the Commercial Case and preserve flexibility of mixed or sole ownership models, the Financial Case has been advanced on the assumption that Lake Onslow's generation and storage assets would be held in a Schedule 4A company (S4A).[82] As a result, this section considers high-level financing implications from the Crown's perspective on the assumption that the Crown holds at least a majority shareholding in Lake Onslow storage and generation assets.

A DBC would explore whether holding Lake Onslow assets through an S4A company would allow for on or off-balance sheet recognition of revenues, costs, assets and liabilities etc.[83] For the purposes of the following analysis, it is assumed that all impacts are off-balance sheet.

4.6.1.2 Funding options

Where Crown ownership of Lake Onslow were through a S4A, the Crown would need to provide at minimum 51% of the equity to fund its construction and operation. However, the value of this investment is not 51% of the total funding required. The total value of the Crown's equity position would depend on the capital structure and gearing ratio of the S4A. The remaining equity stake, and or debt, that made up the eventual capital structure of the entity could then be provided by the Crown or by private investors.

Private investment

The EMM and the assessment of the Economic CBA confirm statements made by the CCC that Lake Onslow would not be commercially viable without government intervention.[84] Modelling shows that generation revenue would cover operating revenue and create an operating surplus (on average) over the lifetime of the asset. However, this surplus would be insufficient to pay back and provide a commercial return on capital likely required for private investment.[85]

Therefore, to meaningfully fund a S4A with private sector capital, the Crown would likely be required to provide additional commercial incentives. This could be achieved by either:

1. **Increasing the revenue of the S4A:** This could be provided by top up payments to the S4A by the Crown to enhance the operating surplus of the S4A (enhancing the return on investment for co-investors or private debt holders).
2. **Providing cheap (or no interest) debt or equity funding:** This would work to reduce financing costs of the S4A, improving the return that co-investors receive on their capital. This could be achieved via low or no interest debt or by providing investors with a class of investment that receives a greater share of the operating surplus.
3. **Guarantying debt payments to private debt investors or commercial banks:** This could facilitate the issuance of bonds or taking on of commercial debt by the S4A in lieu of Crown funds.

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[82] S4A company refers to a non-listed company (detailed in Schedule 4A of the Public Finance Act 1989) in which the Crown is a majority or sole shareholder.

[83] It is important to note that the structure in which assets are held is not determinative of whether they are held on or off balance sheet (for example, simply holding assets through an S4A would not be determinative in of itself). Accounting advice is required to confirm Crown balance sheet treatment.

[84] When commercial discount rates are applied as part of a discounted cash-flow model net present value figures are significantly negative.

[85] The BCR provided in the Economic Case is significantly below 1 at standard Crown discount rates. This value only approaches 0.75 where a discount rate closer to 2% is employed. At the time of writing 2% is significantly lower than both current 30-year government bond yields and expected commercial rates on debt.

Each financing option above includes several sub-options within them (e.g., debt financing could include various gradations of rate, security arrangement and subordination, etc.). These sub-options would be explored further in a DBC.

Alternatively, the Crown could fully fund the entity to avoid any additional payments to cover returns of private investors.

The way in which the Crown would fund the Lake Onslow option would determine:

1. The type and degree of ownership or security interest the Crown has in the generation and storage assets
2. How the funding is classified and recognised by both the recipient and the Crown, and
3. The level and timing of Crown funding required (and the ability of the Crown to fund this with or without additional government borrowing).

The Pros and Cons of each, and a high-level assessment of their impact on Crown accounts, are indicated in the table below:

Table 39: Funding mechanism impacts

Funding mechanism	Pros	Cons	Crown impacts
1. Full Equity investment or the provision of concessionary debt financing	Full equity investment would likely be the cheapest option for the Crown as it would not have to pay additional funds to support the returns of private investors. Full ownership would provide full control over the asset.	This would require significant upfront investment from the Crown likely requiring additional government borrowing. This may have implications on the accounting treatment of the entity that holds Lake Onslow (i.e., whether it would sit on or off whole of Crown balance sheets). This may limit the Crown's ability to fund competing priorities.	The likely required additional government borrowing, may conflict with the Budget Responsibility Rules. However, the Crown may be able to recoup the cost of the investment over time through a levy or other recovery mechanism. See section 4.7 below.
2. Provide commercially favourable debt or equity financing	This would allow for private investment to reduce the total investment by the Crown.	This would require significant upfront investment from the Crown likely requiring additional government borrowing. By providing debt or equity at below market rates, the Crown will be effectively paying the private sector a return on investment.	The likely required additional government borrowing, may conflict with the Budget Responsibility Rules. However, the Crown may be able to recoup the cost of this investment over time through a levy or other recovery mechanism. See section 4.7 below.

Funding mechanism	Pros	Cons	Crown impacts
3. Make top-up / capacity payments / guarantee of private sector debt	This allows the Crown to spread the cost of investment over time and between private and public sectors.	The Crown would effectively be paying the private sector a return on investment. The Crown would still be required to fund 51% of the equity invested in Lake Onslow. However, this could effectively be reduced by the S4A taking on greater levels of debt in lieu of equity and increasing capacity payments.	Depending on the size of the payments, this may be able to be funded through OBEGAL surplus or rearrangement of budget priorities. Alternatively, this could be covered by levy payments made by consumers. See section 4.7 below.

4.6.2 The Portfolio option

As established in the Commercial Case, the Portfolio option could have a very different commercial model than Lake Onslow. In general, it is expected, given the size of the portfolio components and their characteristics (i.e., likely reduced market power when compared with Onslow, smaller upfront CAPEX requirements for individual parts of the portfolio, etc.), that the Portfolio option could include greater private sector involvement in construction, operation, and financing.

The three main delivery options identified in the Commercial Case have been reoutlined below, alongside their impacts on Crown accounts:

1. **Procurement of reserve capacity generation assets:** This is the direct procurement of the generation and storage assets by the Crown. Under this option, the Crown would be expected to fund upfront CAPEX through equity or debt financing. This would have the same impacts outlined in point 1 of Table 39 above.
2. **Development of a long-term capacity contract:** Procurement of reserve capacity on long term contracts that obligate the owner to hold generation capacity available for use in dry year or peaking events. Each contract would be related to specific assets held by the concession holder. As this option includes a capacity payment to top up operational revenue from the Portfolio option, this will have the same impact as a capacity payment by the Crown for the Lake Onslow option. See point 3 of Table 39 above.
3. **Development of a Reserve Capacity Market:** Procurement of reserve capacity for specified periods of time through an open market. The contracts auctioned in the market would pay the owner of generation capacity to hold generation capacity available for specified market services (peaking or dry year risk) for a specified period. As this option includes a capacity payment to top up operational revenue from the Portfolio option, this would have similar impacts as a capacity payment by the Crown for the Lake Onslow option. See point 3 of Table 39 above.

4.7 Recovery of funds

Recovery of funds could range from full recovery of all Crown investment, debt or capacity payments over time through to no recovery.[86] The degree to which the Crown seeks recovery of funds for any investment, or capacity payments made, would be determined by the appetite of decision makers to do so.

Recovery of funds would require the imposition of additional charges (or taxation) on electricity users, market participants (who would likely pass this through to consumers through higher priced generation), electricity consumers, or taxpayers.

4.7.1 User pays philosophy

In general, New Zealand has a long history of applying taxation and levies to pay for services and infrastructure based on a user pays philosophy. Common examples of this can be seen in the transport sector which often applies levies on road or rail users to cover investment. E.g., toll roads to fund expansion or upgrades of significant roads, track user charges on rail investment, road user charges, fuel excise tax, etc.

4.7.2 Tax or levy

A user pays philosophy lends itself towards recovery of funds by a levy on either electricity consumers or electricity system participants. However, when considered from an economy wide basis, an investment in a large-scale energy storage intervention could be seen to benefit all New Zealanders. This benefit is realised through a reduction in electricity system emissions, the provision of a more resilient electricity system, and an acceleration in the decarbonisation of the wider economy. In this way, an increase in general taxation to recover costs could also be seen to be in keeping with a user pays philosophy.

Yet, the imposition of a levy on electricity consumers may undermine the Investment Objectives that underpin a NZ Battery solution as it would work to increase the price consumers pay for electricity.

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[86] Commercial Information

[87] This is calculated as the nominal funding gap for Lake Onslow divided by total electricity demand over the modelling period.

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[redacted]

4.8 Next steps

In addition to items confirmed in the Economic Case that will provide greater fidelity of cost and revenue estimates, engagement with Treasury and other stakeholders will be required to:

- Confirm proposed **capital structure** of the entity which would hold the asset or assets for each option
- Undertake market sounding to determine whether there is **market appetite** for debt/equity investment
- Confirm the proposed **cost recovery mechanism**
- Complete **accounting treatment** analysis of the preferred option.

5. Management Case | Managing the Delivery of the Project

Summary

- Delivery of the project will differ depending on which option(s) decision-makers choose to advance.
- In all scenarios, the next stage will require a greater emphasis on policy work to confirm matters including:
  - The trade-offs relating to and deliverability of the Portfolio solution technologies
  - How a technology agnostic portfolio solution might be either procured by the Crown or delivered through a market mechanism
  - The possible operating models for the Lake Onslow option and relative market impacts.
- This work will need to be supported by enhanced policy capabilities within the project team and industry and stakeholder engagement.
- In its design of next steps, TRM has broken delivery of the Lake Onslow option into several key phases:
  - Phase 2A – ‘Getting to DBC’: this would include further investigations, advice, and engagement to confirm the preferred way forward, including ensuring this is aligned with Ministerial objectives.
  - Phase 2B – ‘Procurement and FID’: refining the preferred way forward and preparing and procuring the services for on-the-ground delivery.
  - Phase 3 – ‘Implementation’: this would include construction and eventually operation.
- The next phase of the project continues to require a high degree of Ministerial oversight, as well as continuity from the current feasibility phase. It is proposed that the DBC preparation should therefore continue to be led by MBIE, though with additional capabilities recruited and procured in accordance with the stage of the project and the broader range of workstreams and activities to be completed.
- Depending on end of year decision-making, the current NZ Battery project team of approximately 9 FTE may need to be expanded to up to 22 to 25 FTE to take the project through to DBC.
- Substantial work has been done on what would be required to take the Lake Onslow option through to FID and construction. If this option is to advance beyond DBC, it is anticipated that later phases of the project would need to be migrated to a body that appropriately reflects the resourcing, capability, flexibility, and authority needs for project delivery. Further information on what this entity could look like would be provided in the DBC.
- Consideration of the DBC and FID provide clear decision points for Cabinet to consider continuity of the project. Several important decisions need to be made following IBC approval. These include:
  - At what stage, and based on what level of understanding, the options should be narrowed, and which options should be further advanced
  - If work on Lake Onslow advances, confirming the preferred design, as well as the consenting strategy and the procurement approach.

5.1 Purpose

The purpose of the Management Case is to describe the arrangements that will be put in place for the successful delivery of the NZ Battery Project, from the phase immediately following this IBC, through to conclusion of the project.

This management case includes assessment of the:

- **Delivery framework:**
    - Project timeline, key activities, and decision points
    - Who should deliver the project
    - Project structures and governance
    - Partnership and engagement
- **Project management:** The methodology for managing the project, including change, risks, benefits, and the approach to engaging with and managing stakeholders
- **Reporting and assurance:** The approach to project reporting, evaluation, and assurance.

Delivery of the NZ Battery Project will differ depending on which of the two preferred option(s) decision-makers choose to advance. The range of possibilities, if the project proceeds to DBC, are that either:

1. Work on Lake Onslow will advance
2. Work on Lake Onslow will advance alongside work to better understand the potential for a Portfolio solution
3. Work on a Portfolio solution will advance.

The approach to managing the project, including the right delivery framework, expertise, level of authority and autonomy, and project structure necessarily will need to develop as decisions are made. Each of these options are addressed in this Management Case, however, as for earlier cases within this IBC, there is considerably greater understanding of the Lake Onslow option at this stage of the project. The Management case reflects this.

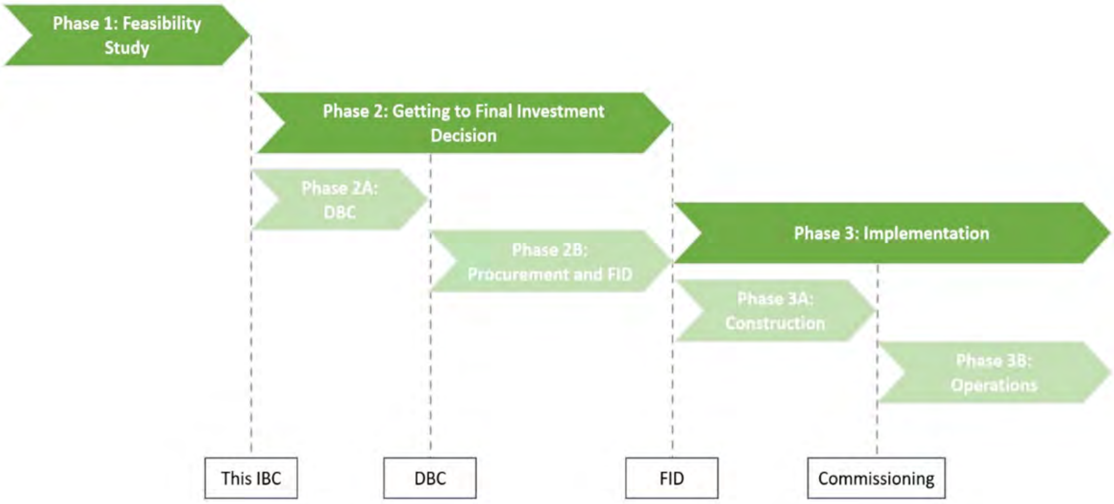
Experience and best practice from both international and New Zealand infrastructure projects have shown that achieving the right expertise, authority, and level of autonomy would be essential for delivering an infrastructure project of the complexity and scale of pumped hydro at Lake Onslow.

5.2 The Lake Onslow option

5.2.1 Project timeline, key activities and decision points

Advancing work on Lake Onslow can be broken down into three main phases and several sub-phases, as shown in Figure 28. The next stage would involve the project focussing on detailed investigations into delivery and construction, funding and implementation. This would inform a DBC (delivered at the end of phase 2A) and would ultimately result in a FID (delivered at the end of phase 2B). This would then be followed by phase 3 which would involve construction through to operation of the pumped hydro scheme.

Figure 28: NZ Battery high-level project phases



- The project is coming to the end of Phase 1 (‘Feasibility Study’). To date, the project has been delivered by a small, dedicated team within MBIE’s Building, Resources, and Markets (BRM) Group. For the Lake Onslow option, the next phases of the project would involve an increasingly broad range of activities requiring a correspondingly broad range of capabilities, and the project team make up would need to change over time to reflect this.
- The key workstreams within Phase 2 (‘Getting to FID’) include:
- Preparation of a DBC that outlines the strategic, economic, commercial, financial, and management components for Lake Onslow and confirms through Ministerial decision-making the preferred way forward for delivery of the project
- Further detailed investigations and development of its technical design
- Continuing environmental, social, and cultural assessments, in partnership with iwi / Māori
- Obtaining access to and undertaking acquisition of land as needed to support delivery and further investigations
- Ongoing policy work, economic analysis, and stakeholder engagement to determine the operating model and market impacts
- Confirmation of the consenting pathway for the project, including the development of legislation if needed
- Design and establishment of the delivery entity.

The DBC and the ultimate investment decision would need to be supported by substantial advice across a broad range of topics, from land use planning and technical engineering, through to market design, commercial, legal, and funding.

These activities would need to be supported by fit-for-purpose project governance that supports decision making and project management capabilities suited for the project's size, complexity, range of workstreams and inputs. Overall, the 'Getting to FID' phase would incorporate a significantly greater range of activities than Phase 1. This would require correspondingly greater capability and capacity than is currently in place.

As an illustration, Figure 29 provides an overview of the workstreams and range of activities within Phase 2, based indicatively on a competitive alliance procurement approach.[88]

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[88] The progress and timing of Phase 2 set out in the Management Case are based on work starting early in 2023. All timings will need to be adjusted depending on decision-making timeframes and funding decisions. The technical and delivery activities and timing are also dependent on the procurement and delivery model, particularly during Phase 2B, after approval of DBC. Note, that this is only one indicative timeline - the choice in procurement model has been estimated to have an impact on the timing of the FID by approximately one year. Key considerations for decision-makers in determining timing preferences will include the trade-offs between pre-FID spend and time and the potential savings, certainty, and risk mitigation that this would bring.

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5.2.2 The technical and delivery activities and timeline would be finalised once a procurement model has been selected

The Technical and Delivery activities and timing set out in this case are dependent on the procurement model, particularly during Phase 2B, after DBC approval. Detailed timelines are provided below for the Technical & Delivery workstream for each of the probable delivery models. As shown in the below figures, the choice of procurement model is expected to impact the timing of a FID on Lake Onslow by approximately one year.

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Current construction assessments have indicated that it would take between 7 and 9 years to complete all construction works required for Lake Onslow from FID, these assessments have estimated the length time for each of the main construction stages and provided indicative completion dates.

5.2.3 Delivery timeline assumptions

The delivery timeline remains uncertain and dependent on confirmation of the preferred option, as well as the preferred procurement model, particularly for activities after the DBC. Some key assumptions underpinning the timeline provided above include:

- **Work advancing on Lake Onslow only:** advancing both Lake Onslow and the Portfolio solution to DBC will have an impact on timeframes, as set out later in the Management Case
- **Commencement of DBC work as early as possible in 2023**: this will be dependent on clear and efficient decision making, and having project, governance, and procurement structures in place as quickly as possible
- **Consenting:** The consenting strategy will be confirmed before DBC, but the working assumption is that bespoke consenting legislation will be required for the Lake Onslow option
- Negotiations
- **Design:** Early design development is required to inform further options refinement, the DBC, environmental impact assessments, consenting, land acquisitions, and procurement.

Development of a detailed programme and costing is required in Phase 2a to confirm current high level budget allocations are appropriate, and for any potential 'early start' to pre-implementation. This will be dependent on decision making at the end of 2022 regarding timing and budget. If the current budget allocation is not appropriate this could be mitigated during delivery of the pre-implementation phase, but this has not yet been considered.

5.2.4 Project ownership would need to evolve over time

Getting the structure right for planning and delivering pumped hydro at Lake Onslow would be critically important to its success. Te Waihanga has released guidance on Major Infrastructure Project Governance, outlining best practices for governing the delivery of infrastructure projects with a whole of life cost greater than $50 million.[89] The guidance outlines a set of essential elements for successful delivery of such projects:

- Setting a clear strategic purpose and a mandate to achieve that purpose
- Having clear roles and responsibilities that separate governance and management (i.e. distinct allocation and delegation of decision-making rights)
- Involving the right people, with the right mix of skills, to deliver the project
- Investing in effective relationships with stakeholders
- Being clear about accountabilities and transparent about performing against them
- Managing risks effectively, and ensuring good information, systems, and controls are available to inform decision-making.

Te Waihanga's guidance highlights that procuring entities (like MBIE) do not always allow for these elements to be met, and infrastructure delivery is not always aligned with their core business. However, in addition to the above, other important factors for the success of the Lake Onslow option also include:

- Maintaining momentum, and allowing for continuity of skills, knowledge, and relationships across the project's phases
- Ensuring clear hand-over points between phases, aligned with the shift in focus, from policy and strategic direction to procurement and delivery, and eventually through to construction
- Attracting the right capabilities to deliver the project
- Ensuring strong stakeholder engagement and credibility to negotiate and transact in the market.

MBIE has a diverse range of policy and service delivery responsibilities, with around three-quarters of MBIE's role relating to designing and delivering regulatory systems across a broad range of interests[90]. This experience and the ability to maintain the momentum of the project, makes MBIE a good fit to lead the policy and regulatory components of the NZ Battery project through phase 2A. However, it would not be as well placed to lead the project through the core infrastructure delivery activities in Phase 2B. As a result, it is assumed that delivery of the project would transfer from MBIE to a different delivery entity after Phase 2A of delivery of Lake Onslow.

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[89] Te Waihanga / New Zealand Infrastructure Commission – Major Infrastructure Project Governance Guidance, October 2019

[90] Ministry of Business, Innovation, and Employment – Pūrongo ā-tau – Annual Report 2018/19

5.2.5 Four potential entity forms could be suitable for delivering the Lake Onslow option

The Project could be delivered by either existing entities or a new entity. In principle, an existing entity would be a more straightforward option because systems, processes, and some capabilities are already in place and can be immediately leveraged.

A new entity would require time and resources to establish. However, it could be set up to be solely focused on meeting the project’s needs, functions and provide the required balance between operational autonomy and Ministerial oversight. It could also adapt as the project evolves. Whatever type of entity is used, it is acknowledged that there will be challenges in securing the requisite capability and capacity.

Machinery of Government guidance (set out in Figure 33) outlines the choices to be made around what form of organisation is best placed to deliver on certain functions. These are assessed based on the two project phases in Table 42.

Figure 33: Machinery of Government – Organisational design choices

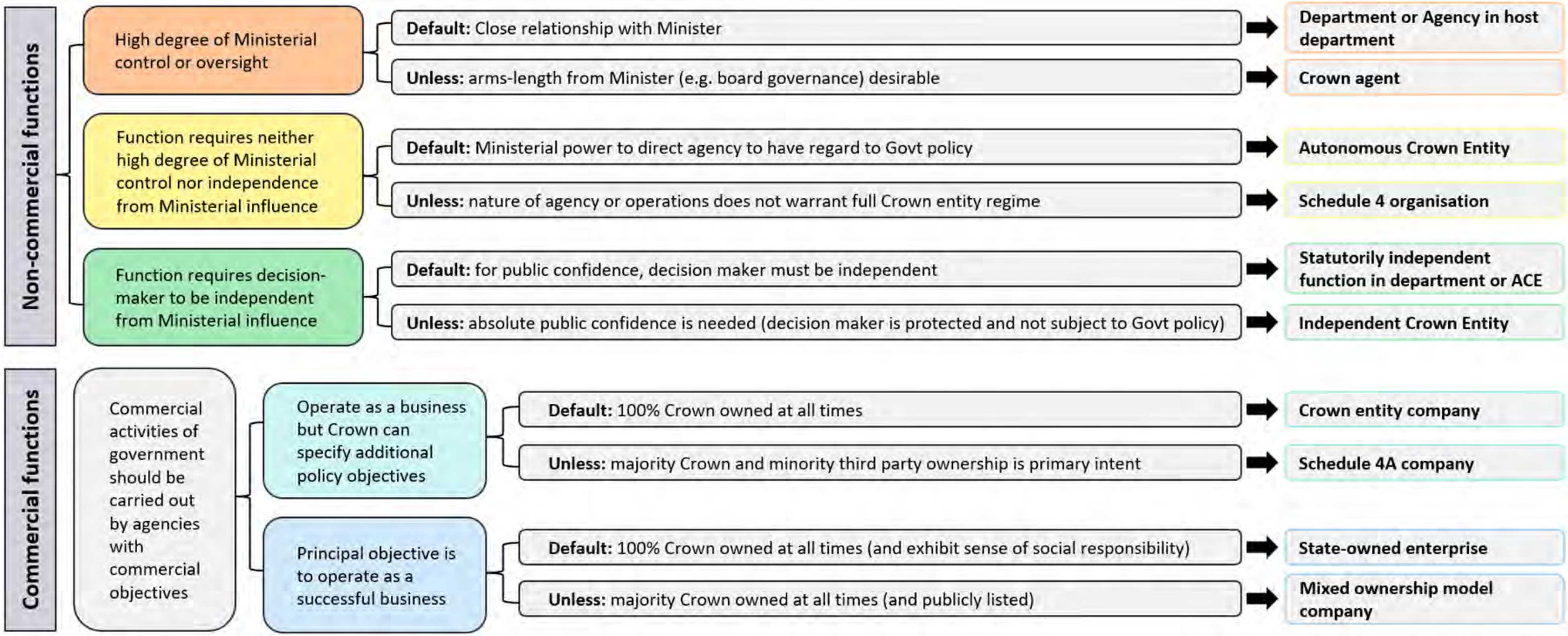

Table 42: Organisational form analysis

	Phase 2A organisational forms		Phases 2B and 3 organisational forms	
	Department / Departmental agency	**Crown agent**	**Crown entity company**	**Schedule 4 company**
Description	Function established as a team or business unit within an existing Department or as a departmental agency.	The Crown Agent is a non-company legal entity wholly owned by the Crown. The Crown Agent is governed by a board who is accountable to the primary Minister. The board has responsibility for the entity's performance and appoints the Chief Executive. Ministers appoint board members to Crown agents.	Crown entity companies are established and owned by the Crown to further certain policy objectives. Crown entity companies are registered as companies and are subject to the Companies Act 1993. They are also subject to relevant provisions of the Crown Entities Act 2004. Minister appoints board members.	A S4A is a non-listed limited liability company that is typically used when outcomes are required within a clearly defined scope, often with a mixture of commercial and social objectives. It is subject to the provisions of the Crown Entities Act 2004, Companies Act 1993, Public Finance Audit Act 2001, Official Information Act 1982, and the Ombudsman Act 1975. The Crown is always the majority shareholder, but this structure allows for joint ownership with other parties.
Accountability	The department's Chief Executive would be accountable to a Minister for the department's performance for the project.	Governance Board.	Company Board.	Company Board.

	Phase 2A organisational forms		Phases 2B and 3 organisational forms	
	Department / Departmental agency	**Crown agent**	**Crown entity company**	**Schedule 4 company**
Independence	Provides for high degree of ministerial oversight and direction. Ministerial power to direct regulator to give effect to policy. Must give effect to whole of government approach if directed by Ministers of Finance and State Services. Can be given statutory independence for its functions.	Governance board provides some independence from Ministers. Entity must "give effect to" policy that relates to the entity's functions and objectives if directed by the responsible Minister. It must also “give effect to” whole of government approach if directed by Ministers of Finance and State Services. Can be given statutory independence for its functions.		Operationally independent and guided by its constitution.
Establishment	Cabinet agrees to establish.	The Crown Entities Act 2004 requires separate legislation to establish a new Crown Agent (can be the same legislation that sets out specific powers). Alternatively, primary legislation can specify an existing Crown Agent to carry out the functions.		A S4A company is relatively fast to establish, requiring an Order in Council rather than specific legislation to be developed. Despite this, a S4A company would still take some time to establish. For example, City Rail Link Limited was established in approximately nine months, while Ōtākaro Limited took around six months to establish.
Examples		Accident Compensation Corporation, Earthquake Commission, Kāinga Ora.	Radio New Zealand Ltd, Television New Zealand Ltd, and Crown Irrigation Investments Ltd.	City Rail Ltd, Ōtākaro Limited Crown Infrastructure Partners Limited.

5.2.6 Organisational design considerations for getting to DBC

Table 43 outlines the organisational design considerations for advancing the Lake Onslow option prior to DBC, including in its current feasibility phase.

Table 43: Organisational design considerations for getting to DBC

Consideration	Phase 1: Feasibility	Phase 2A: DBC Development
Purpose	Advise on feasibility of Lake Onslow.	Confirm a preferred design and prepare a DBC and procurement strategy for delivery of that option, to inform a definitive decision on a preferred way forward.
Function	Primary function is to ensure the NZ Battery Project is aligned with, and implements, Government policy and social and environmental objectives.	Primary function is to ensure the NZ Battery project continues to be aligned with, and implements, Government policy and social and environmental objectives, through to confirmation of the preferred way forward.
Ministerial Oversight	A high level of Ministerial control and close relationships with Ministers are desirable to ensure preferred option will deliver on government policy and objectives.	A high level of Ministerial control and close relationships with Ministers are desirable to ensure preferred option and way forward for delivery will deliver on government policy and objectives.
Capabilities	Technical, policy and commercial capabilities to a sufficient level to develop the IBC.	Technical, policy, commercial and engagement capabilities to support development of the DBC. Increasing infrastructure delivery capabilities is needed to support DBC development.

Until the DBC is endorsed and the preferred way forward is confirmed to be in line with Government policy and Ministerial expectations, a department, like MBIE, remains an appropriate home for the project through until DBC. This will enable continuity, momentum, and access to systems and capability already established in the NZ Battery team. However, the increasing range of activities in Phase 2A, will require a larger team than is currently dedicated to the NZ Battery Project to provide the necessary capabilities and capacity.

5.2.7 Organisational design considerations post-DBC

Following the DBC the Lake Onslow option would transition further away from policy delivery towards technical and commercial delivery functions. Table 44 outlines the considerations for the delivery phases of the NZ Battery Project, following DBC ('Procurement and FID' and 'Construction').

Table 44: Organisational design considerations for getting to commissioning on the Lake Onslow option (post-DBC)

Consideration	Phase 2B: Procurement and FID	Phase 3A: Construction
Purpose	Further develop the design, procure, and enter into a delivery agreement for the preferred option, and confirm the details for the implementation phase.	Construct the preferred option.
Function	Once a decision has been made on the preferred way forward, the function is solely to manage, deliver, and complete the delivery of the preferred option. Commercial flexibility is required to adapt to different funding / financing and procurement models.	
Ministerial Oversight	Reduced Ministerial control is desirable to provide a level of operational autonomy that ensures perceived market credibility and negotiating power. A clear framework for ministerial oversight of project progress will still be needed.	
Capabilities	Project delivery, commercial, technical, financial, and investment competencies of an independent governance board, as well as similar capabilities within the delivery team.	
Ownership	Keeping the opportunity open for a non-Crown stake in ownership is desirable (e.g. iwi or local government).	

If the Lake Onslow option were to be advanced, post-DBC there would be a significant change in the nature and complexity of the functions and so too in the capabilities required to deliver the project. The size of the project team would need to grow considerably. Retaining the team within a policy branch in MBIE beyond Phase 2A creates project risk as the particular operational and governance structures required for delivery will be significantly different from existing structures and because of the possible dilution of focus. Some policy work would still be required, but the majority of policy alignment and settings would be completed by DBC, and there would be a significant shift of emphasis towards delivery. As a result, it is expected that the functions will require a comparatively lesser degree of Ministerial oversight.

It is recommended that the project transition to a dedicated delivery entity as soon as possible after DBC. To achieve this, further work to determine the form of a delivery entity would need to be undertaken early in Phase 2A of the project.

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Broad engagement should be undertaken on the choice and design of the delivery entity with the involvement of The Treasury, Te Waihanga and the Public Service Commission.

Design of the entity will need to consider:

- Its functions, scope, and powers
- The range of existing entities that could deliver the project as well as new entity options
- Funding mechanisms for the delivery entity
- Governance arrangements from transition to the new entity
- Transition.

5.2.8 Governance arrangements

Governance is the provision of project leadership, strategic direction, control, and accountability. A key objective of governance is to make decisions efficiently, effectively, and transparently. As the NZ Battery Project moves between phases and responsible entities, as outlined above, the appropriate governance arrangements will change.

To date the project has reported to the Minister of Energy and Resources. Governance has been provided by an internal MBIE Steering Group.

A Technical Reference Group has also provided the NZ Battery Project with independent expertise, sector knowledge, and advice. Members of the Technical Reference Group represent a range of backgrounds and areas of expertise across electricity and energy, iwi / Māori, climate and environment, commercial and investment, engineering, and community sectors. The Technical Reference Group does not have a decision-making role but reviews and provides input to proposals and analysis provided by the project team. Ultimate accountability and decision-making power sits with the Minister of Energy and Resources.

This model has been broadly fit for purpose at the early stages of the project but needs to be significantly enhanced to ensure successful delivery of the next phase. How this structure needs to change as the project moves to Phase 2A and beyond is outlined in the sections below.

5.2.9 Current governance arrangements will need to expand

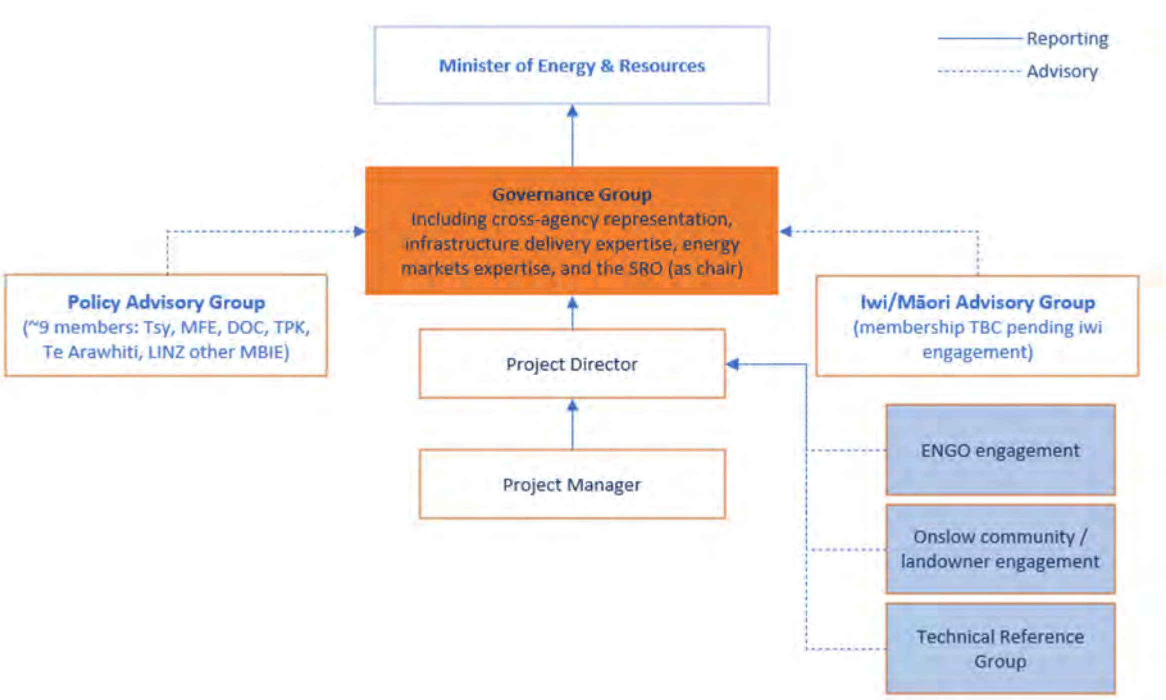
Delivery of the Lake Onslow option will have a range of significant challenges and implications:

- Technical and market design implications
- Environmental and ecological impacts
- Impacts and opportunities for mana whenua
- Cross-agency policy implications, including MBIE (Energy and Resources, Skills and Employment), The Treasury, Department of Conservation, Ministry for the Environment, Te Waihanga
- Fiscal and infrastructure delivery implications
- Local social and economic impacts.

Governance and advisory arrangements need to deliver an appropriate level of skills, knowledge, and experience to test, advise, and steer the delivery of the project and represent the breadth of these challenges.

With this in mind, Figure 35 outlines a potential governance structure for the NZ Battery project during the development of the DBC.

Figure 35: Potential governance arrangements - Phase 2A (Getting to DBC)



A description of the potential responsibilities of the roles presented in Figure 35 is provided in Table 45.

Table 45: Governance roles - Phase 2A (Getting to DBC)

Role	Responsibility
Ministerial oversight	Provide oversight and make interim decisions regarding NZ Battery Project delivery to ensure the project maintains momentum and risks are appropriately managed, within the context of Cabinet decisions. Some delegated decision-making power may assist with momentum and efficiency in advancing the project.
SRO	The SRO has overall accountability for the success of the project. As the chair of the Governance Group, the SRO is responsible for delivering the agreed outcomes and benefits, optimising value, managing risk, ensuring timely delivery to schedule, meeting project performance requirements, and determining remedial action should the project not perform to plan. For others in the project, the SRO provides leadership on culture and values, makes timely decisions, obtains required resources, upholds probity principles, and manages relationships. **Ministerial requirements:** The SRO will be responsible for providing project updates as well as escalating issues and risks to the Minister and seeking Ministerial direction in response.
Governance Group	Ensure the NZ Battery Project will achieve its strategic and investment objectives. The project will have strong technical and policy directives which may at times be challenging to reconcile. The Governance Group is the mechanism for having the trade-off conversations between technical and policy advice with a singular focus on achieving the best outcomes for New Zealand. Incorporating iwi / Māori representation at this level is

Role	Responsibility
	important to ensure decision-makers are aware of and delivering on iwi / Māori expectations. Given the status of the project, a DCE-level project steering group is proposed, combining government, energy sector, technical and iwi / Māori representation.
Iwi / Māori Advisory Group	The representation on the Iwi / Māori Advisory Group will be dependent on the preferred option and location. Establishing the Iwi / Māori Advisory Group will require engagement with impacted iwi to confirm an appropriate structure, methodology for appointment, focus, and terms of reference for the group.
Policy Advisory Group	The Policy Advisory Group will act as a clearing house for senior policy officials to ensure the policy workstream for NZ Battery is sensible, connected, and consistent with the wider government priorities. Manager / Director level membership is proposed.
Technical Advisory Group	The role of the Technical Reference Group is to test and challenge the robustness and practicalities of the technical advice developed to inform the final investment decision.
Project Director	The single point of operational accountability, reporting to the SRO and Steering Group for the project as it progresses through the DBC phase.
Project Manager	Ensures the project is well planned, sequenced, resourced, and managed to deliver on the project's physical solution.

Key points to note about the proposed structure

- Use of advisory groups to support the Governance Group - Key areas of risk that will need particular oversight have been identified as ensuring the policy work is connected across government, recognising the importance of ensuring the voice of iwi is heard and ensuring the advice stays abreast of best practice and technical developments in the electricity and energy sectors.
- Confidentiality [redacted]

Non-governance assurance and engagement

There are three other key aspects of project input, all relating to stakeholder engagement. All of these are integral to project success, but it is not proposed that they form part of the formal governance structure.

- **Stakeholder engagement:** In addition to the interests and perspectives represented in the proposed structure above, there will be a need for engagement with three particular groups:
    - **Affected landowners:** Engagement with affected landowners will be critical to advancing the project. We propose to explore the best means of engaging with those people after Cabinet has made its decisions on next steps. This could involve the establishment of landowner and/or community groups. Our approach

to this will be set out in our revised engagement plan but we do consider this a form of project governance

  - **Industry stakeholders:** Engagement with industry will be essential to understand potential market impacts of the Battery Project in the next phase. While there needs to be electricity sector expertise on the governance group, we propose this being fulfilled Free and frank opinions with market engagement to be addressed in our engagement plan
  - **Environmental NGOs:** Similarly engagement with ENGOs is critical to the next stage and to informing decisions on a range of aspects of the project but will, similarly be addressed in our engagement plan, rather than as an aspect of governance.

- **Technical Reference Group:** The project has been ably assisted by its Technical Reference Group to date. The role of the Group is to test and challenge the robustness and practicalities of the technical advice developed.

5.2.10 Governance arrangements post-DBC

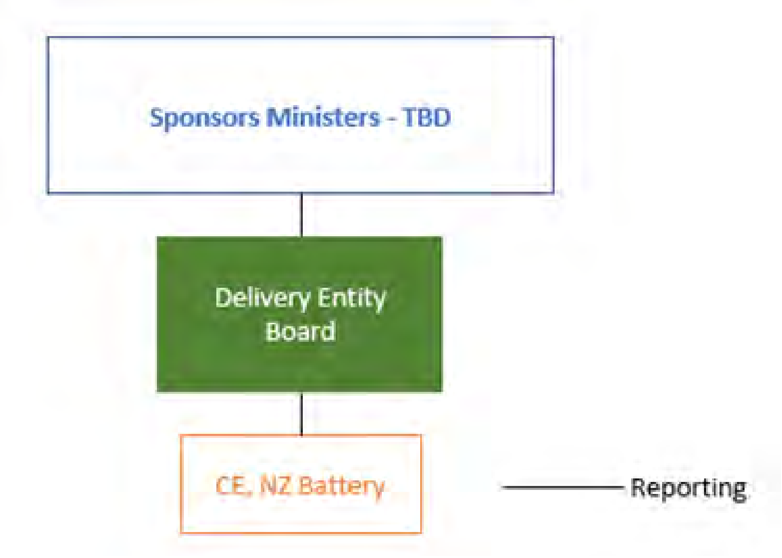
Governance arrangements for Phases 2B and 3 of the project will be dependent on the delivery entity selected. Identification of the new delivery entity will require confirmation of the overall governance framework as part of the DBC, including the sponsoring Ministers and additional non-Crown sponsors and partners, such as iwi and / or local government entities.

The delivery entity should be guided by an independent board of directors who provide the single point of responsibility for delivery. The board should be skills-based and operationally independent but be accountable to the Ministers / sponsors. Decision-making representation of iwi / Māori through this phase of the project can occur via appointment(s) to the delivery entity board, as well as through a potential sponsorship role.

It may be beneficial to establish a Transition Board prior to formal establishment or transition to the Delivery Entity. The Transition Board would be focused on establishing the new entity, including the appointment of a chief executive and ensuring decisions relating to the delivery phase are appropriate for a large infrastructure project.

The Delivery Entity governance structure, sponsoring ministers and other parties, board structure, and need for a Transition Board will be explored through the Delivery Entity workstream during Phase 2A. However, potential governance arrangements are shown below *(Note: Ministerial Group illustrative only)*:

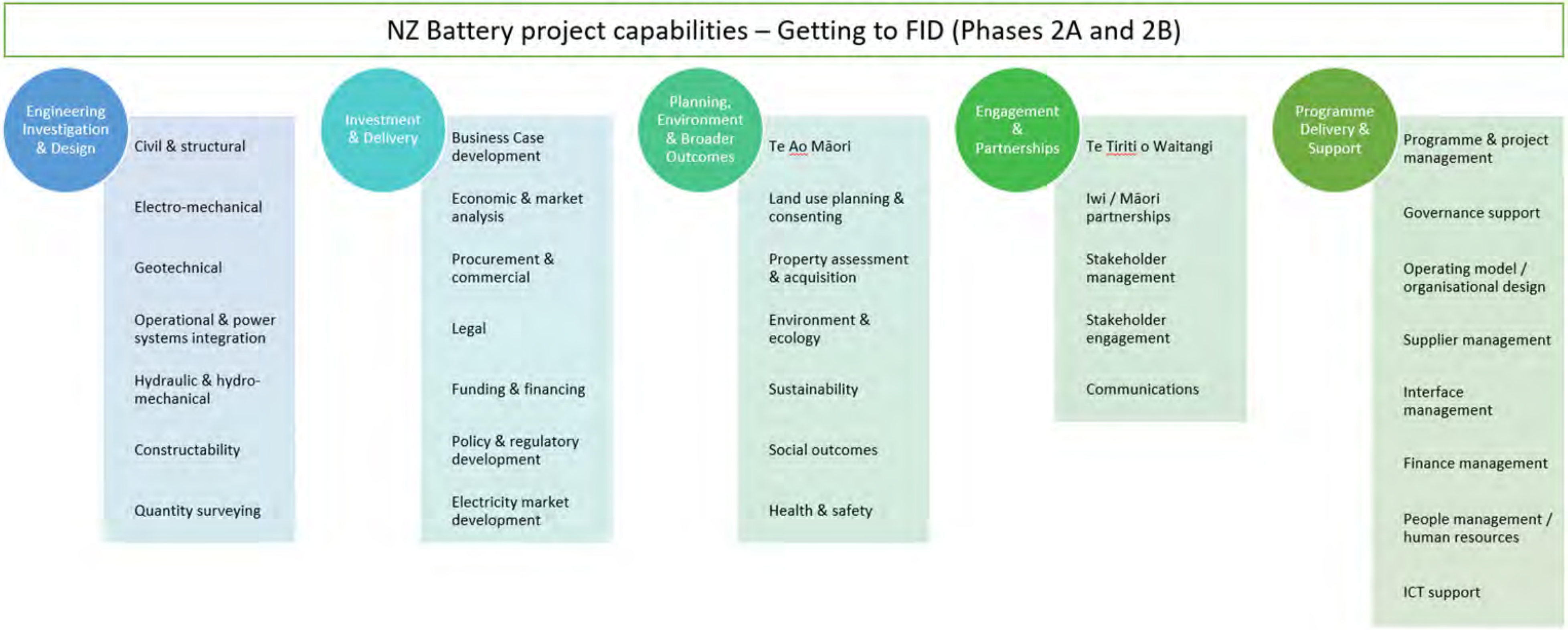
Figure 36: Governance arrangements



5.2.11 Delivery Team

Given the broad range of activities that would need to occur in the following phases of the Lake Onslow option, a correspondingly broad range of capabilities would be required to deliver the project through these phases. The capabilities required for Phase 2 ('Getting to FID') are shown in figure below.

Figure 37: Capabilities required for Phase 2 of the Lake Onslow option ('Getting to FID')

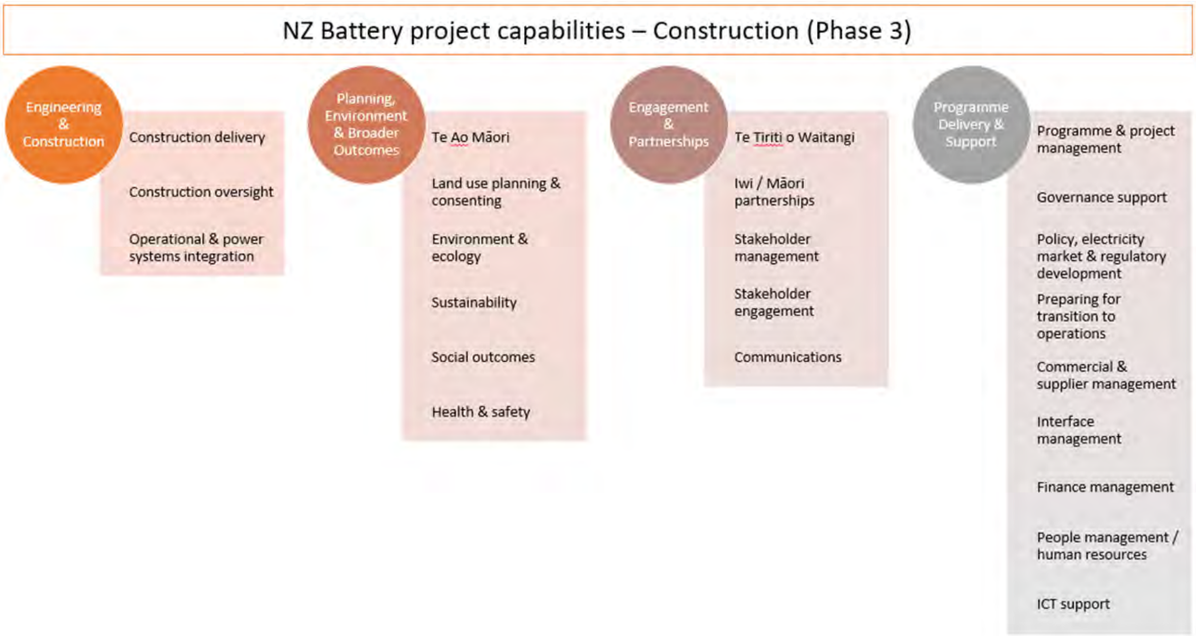


NZ Battery project capabilities – Getting to FID (Phases 2A and 2B)

Engineering Investigation & Design	Investment & Delivery	Planning, Environment & Broader Outcomes	Engagement & Partnerships	Programme Delivery & Support
Civil & structural	Business Case development	Te Ao Māori	Te Tiriti o Waitangi	Programme & project management
Electro-mechanical	Economic & market analysis	Land use planning & consenting	Iwi / Māori partnerships	Governance support
Geotechnical	Procurement & commercial	Property assessment & acquisition	Stakeholder management	Operating model / organisational design
Operational & power systems integration	Legal	Environment & ecology	Stakeholder engagement	Supplier management
Hydraulic & hydro-mechanical	Funding & financing	Sustainability	Communications	Interface management
Constructability	Policy & regulatory development	Social outcomes		Finance management
Quantity surveying	Electricity market development	Health & safety		People management / human resources
				ICT support

The capabilities required for construction (Phase 3) are highly dependent on the preferred option and the procurement model, but indicative capabilities required for this phase for a major infrastructure project like Lake Onslow, are shown in Figure 38. Depending on the procurement model, these capabilities may sit within the lead delivery organisation or may be procured services. However, some capability is likely to be required across all these areas within the lead organisation to enable management and coordination of each associated workstream and activity.

Figure 38: Indicative capabilities required for Phase 3 ('Construction') of the Lake Onslow option

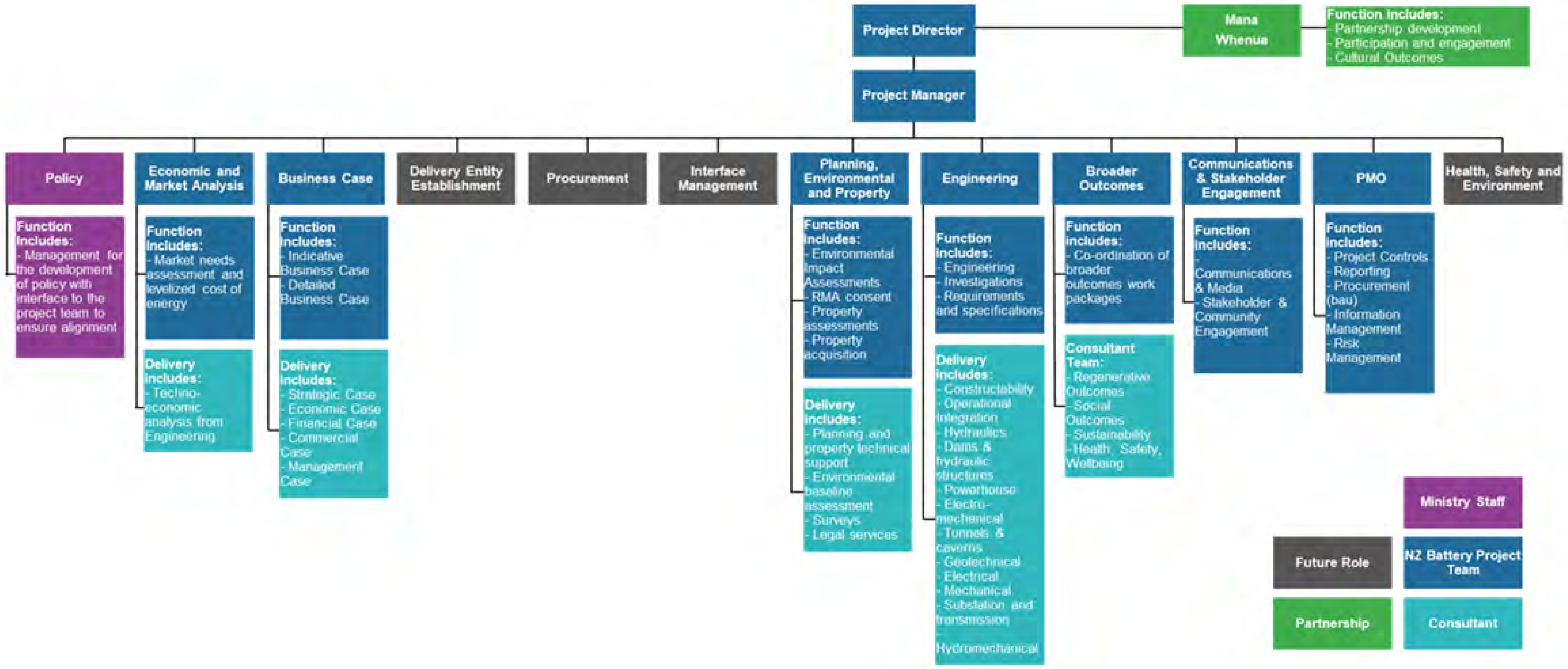


5.2.12 Organisational structure – Phase 2A (Getting to DBC)

The current NZ Battery Project team is small (approximately 9 FTE). The team is primarily resourced internally, within MBIE, supported by some contracted resource. The project will require greater resource and a broader range of capabilities to support development of the DBC than is currently in place.

It is anticipated that an expanded team of 22 to 25 will be needed to take the project through to DBC. A potential organisational structure is set out in Figure 39.

Figure 39: Potential Lake Onslow organisational structure - Phase 2A (Getting to DBC)



Further information on these teams is provided in Table 46.

Table 46: Team roles, responsibilities, and resourcing type - Phase 2A (Getting to DBC)

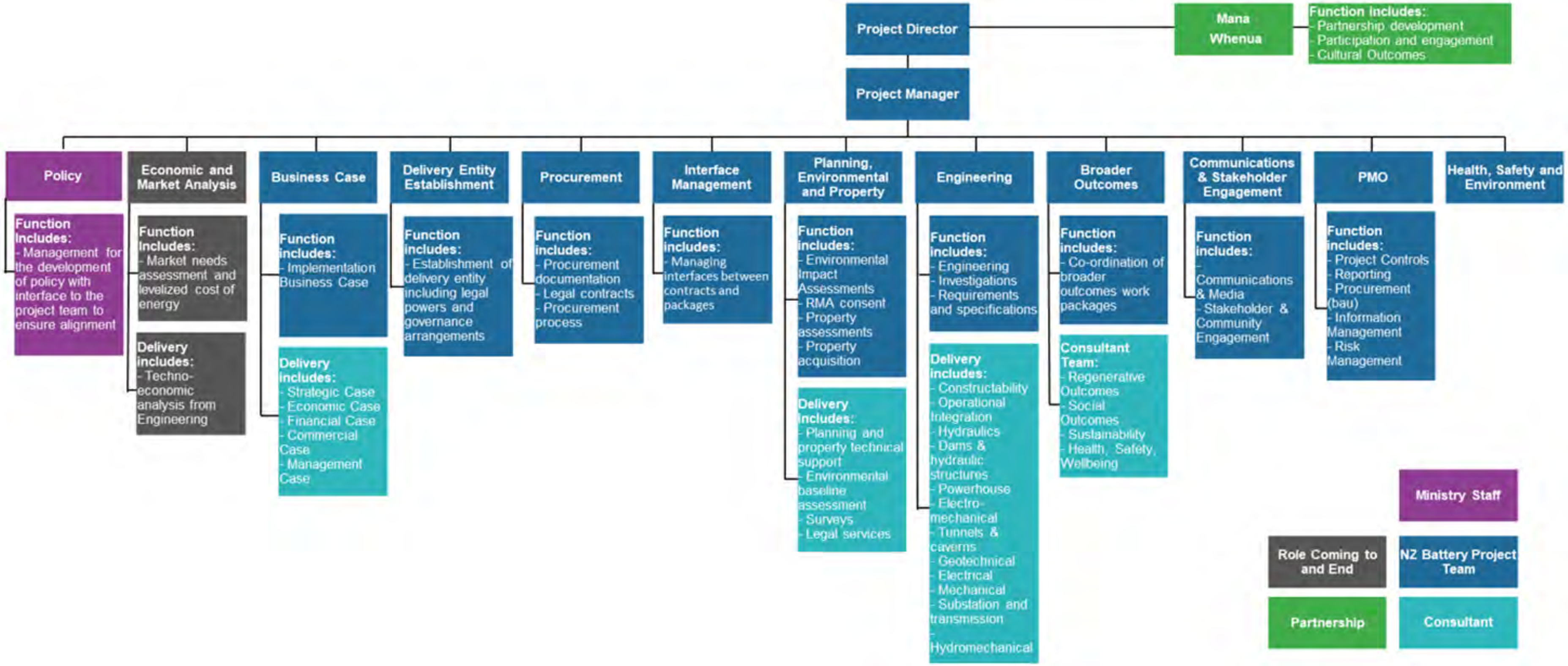
Team	Function
Policy	Developing advice on the settings needed to ensure the intended outcomes are achieved with the preferred option. This includes developing policy advice and any statutory changes to enable the delivery entity to be established and deliver as intended in the electricity market.
Project Management Office	Project management office services like project planning, reporting, risk management and practice. The corporate support activities include finance, human resources, and corporate reporting requirements. Where possible this entire function would be dedicated resources which would shift over to the new entity once it is established. This would also include BAU procurement activities.
Communications and Stakeholder Engagement	Development of meaningful and enduring relationships with communities and stakeholders impacted by the preferred option. This team also includes media and communications functions.
Iwi / Māori Partnership	Development of a collaborative partnership approach with iwi and Māori groups impacted by the preferred option, and leading integration of iwi / Māori perspectives and positive cultural outcomes into the project. This includes establishing the preferred model for iwi / Māori representation at all levels of the project.
Business Case	Development of the DBC, utilising inputs from across the different workstreams.
Economic and Market Analysis	Assessment and economic analysis of market needs and how Lake Onslow would operate in the market.
Planning, Environmental and Property	Developing the consenting strategy and pursuing the consent, if required for the option. This includes undertaking environmental impact assessments, as well as property assessments and acquisitions to support delivery of the preferred option. In the implementation phase, this transitions to a focus on Health, Safety, and Environment management in delivery. This would also include access for pre-FID geotechnical investigations and field work.
Engineering	Engineering investigations, requirements, specifications, and design development across constructability, operational integration, hydraulics, electro-mechanical, tunnels, geotechnical, and hydromechanical.
Broader Outcomes	Coordination of broader outcomes work packages, including regenerative outcomes, social outcomes, and sustainability.

5.2.13 Organisational structure – Phase 2B and Phase 3A

It is anticipated that upon establishment of the delivery entity for the Lake Onslow option, much of the NZ Battery Project team would be ‘lifted and shifted’ to the new entity. This will enable project momentum to be maintained, with continuity of skills and knowledge across the project phases, and the ability to sustain meaningful relationships with iwi / Māori and stakeholders.

A potential organisational chart for the delivery phases post-DBC is shown in Figure 40 below.

Figure 40: Indicative organisational structure – Phase 2B and Phase 3A



Negotiations

[redacted]

5.2.15 Resourcing strategy

Resourcing the project with the appropriate skills, capability, and experience is essential for successful delivery. Currently, New Zealand is facing a historic workforce shortage across all aspects of infrastructure delivery (as are some other countries, including Australia).[91] A key principle for resourcing the project should therefore be to ensure a legacy of capability that is enduring and can be leveraged for the future energy sector and other infrastructure projects.

If the Lake Onslow option were advanced it would be one of New Zealand's largest infrastructure projects in history, with significant scale and complexity, and involving design and construction methodologies not commonly used in New Zealand. This means it would need to attract highly capable resources from both domestic and international markets. Delivery of the Lake Onslow option would be a massive world class project that may be attractive for international expertise. The approach will be to engage international resources to supplement and complement high calibre local expertise.

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[91] Te Waihanga / the Infrastructure Commission – New Zealand Infrastructure Strategy

As noted, resourcing requirements will incorporate an increasingly broad range of capabilities as the project moves towards and through delivery. Retention of key personnel through the different phases and organisational structures of the project will assist in providing continuity and positive momentum. The preferred resourcing approach is therefore to recruit permanent resources, with a view to attaining consistency on the project for the long-term.

5.2.16 Project management

The NZ Battery Project will continue to utilise MBIE's existing project management methodology, tools and controls. Additional dedicated project management and corporate support staff would be recruited to manage the project through to DBC.

Appropriate project management methodologies and tools will be identified and/or developed for later stages of project delivery as decisions are made on the preferred way forward, and this will be presented in the DBC.

5.2.17 Change management

The transition of the project from the current phase to Phase 2A (developing the DBC) will not result in a significant level of change, as the project structure and delivery framework will remain largely consistent.

However, later stages of the project may be associated with more significant change, which could include:

- Internal organisational changes as the project model, structure, and governance transitions
- Changes to the electricity sector and market as a result of the project
- Changes in delivery scope, timeline, cost, and/or quality.

Further information on the above changes and strategies and plans for managing these changes will be provided in the DBC.

5.3 The Portfolio option

Advancing work on the Portfolio option would involve a different work programme. To date, the project has acquired a strong understanding of the technical requirements of the three technologies identified that could form the option.

The work programme would need to be designed to reduce the existing uncertainties about the option. This would involve developing a greater understanding of:

- market deliverability
- any trade-offs, impacts and opportunity costs inherent in the technologies
- how a technology agnostic portfolio solution might be either procured by the Crown or delivered through a market mechanism

The skills required for this phase would require enhanced policy and electricity sector expertise, with additional capacity to manage industry consultation. Organisation considerations would be those set out in Table 48 below.

Table 48: Organisational considerations for further assessing the Portfolio option

Consideration	Narrowing uncertainty about the option
Purpose	Enhance understanding of deliverability, trade offs and impacts and confirm delivery mechanism through policy development, industry and stakeholder engagement and procurement approach design.
Function	Ensure the project continues to be aligned with and implements Government policy and social and environmental objectives, through to confirmation of the preferred way forward.
Ministerial Oversight	A high level of Ministerial control and close relationships with Ministers are desirable to ensure the preferred option and way forward will deliver on government policy and objectives.
Capabilities	Enhanced policy capabilities to investigate, design and advise on Portfolio option.

The approach to delivery entity, project structure and governance would not materially change if both Lake Onslow and the Portfolio solution were to be developed during phase 2A. However, considerably more policy work would need to be undertaken during the period before DBC.

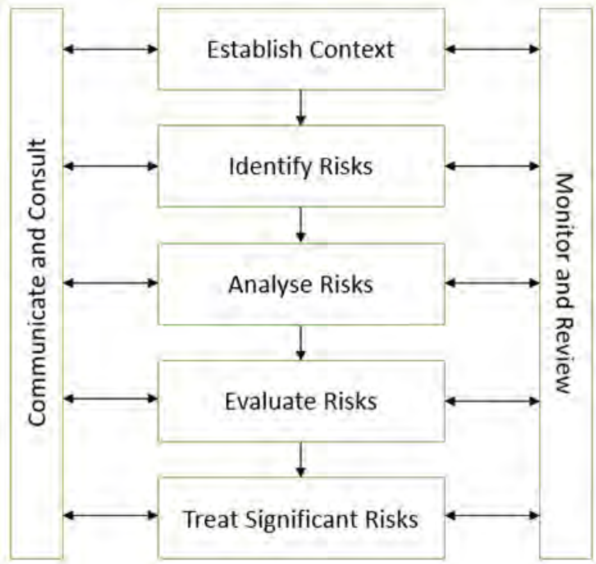
While consultation is required to ensure market participants are prepared for the implementation of the NZ Battery, there is a risk of consultation fatigue if both options were progressed in parallel. This is because the same market participants would be consulted on two different market designs and project options. Careful planning of consultation will be required to ensure continued engagement.

If work were to be advanced on both options, the earliest that the project could advance to DBC would be mid-2024. [redacted] Negotiations

5.4 Risk management

The NZ Battery project will use a risk management approach that is consistent with International Risk Standard AS/NZS ISO 31000 and MBIE's existing risk management approach. Risk identification and assessment will be used to make informed decisions, taking into account the consequence and likelihood of risk events. Figure 41 provides an overview of the general risk management approach to be used for the NZ Battery project

Figure 41: Risk management approach for NZ Battery project, based on AS/NZS 31000



The key potential delivery risks that have been identified at this stage, with a particular focus on Phase 2A are shown in Table 49. The DBC is expected to provide an updated risk management structure and risks to get to FID.

Confidentiality

[redacted]

Confidentiality

[redacted]

The Project’s risk management practices will be further developed to manage the NZ Battery Project risks, including an assessment of each risk’s impact and likelihood and, where relevant, the associated treatment approach. This will include a combination of the risks included in this IBC, risk registers currently in use by the team, and those completed by both WSP (for the Portfolio option) and TRM (for the Lake Onslow option).

The risk management process is the responsibility of appointed risk staff within the Project Management Office, who will own the NZ Battery Project risk register and ensure it is kept up to date. A risk reporting and escalation approach will be developed to ensure all parties at all levels are informed of risk progress and the consequences of any changes.

The Project Steering Group will review the risk register regularly. A risk that materialises will no longer be managed as a risk, but instead as an issue that requires direct management action. The level of management action will be dependent upon the assessment of the issue's impact.

5.5 Partnership, engagement, and stakeholder management approach

The NZ Battery Project is of significant interest to a broad range of stakeholders. Best practice communications, engagement, and relationship management is essential to maintain collaborative relationships with stakeholders and to generate widespread understanding of the project.

The NZ Battery Project Communications and Stakeholder Engagement Plan outlines the specific stakeholders and interests. This analysis is included in Appendix R. The approach to stakeholder engagement and partnership will evolve with the project, particularly as relevant stakeholders and partners evolve along with the preferred option. The plan and approach will therefore be continually updated as the project progresses.

Enduring partnership with iwi on this significant, multi-generational project will be essential. The project will work with iwi to define how they may wish to be involved. For example, iwi may wish to be represented in project governance as shown in Figure 35, and a dedicated iwi advisory group would allow broader integration of te ao Māori into the project.

This is a unique project from a communication and engagement perspective, because it involves:

- Delivering highly technical advice to Cabinet on an issue of national significance
- Potential implications for New Zealand's electricity system and all associated stakeholders
- Interest from and input by a range of energy sector stakeholders, environmental interest groups, and community stakeholders
- Uncertainty among external stakeholders fuelling speculation and requiring management of expectations and concerns
- The need to coordinate communications with other work underway on the transition to a highly renewable electricity system and overall climate change and energy workstreams
- The project has benefits for all of New Zealand, while impacting local communities and stakeholder groups
- The project is of significant interest to iwi / Māori and has genuine partnership opportunities.

The objectives for the NZ Battery communications and engagement approach include:

- Create wide-spread understanding of the challenges faced by New Zealand due to the dry year problem, and how the NZ Battery project is seeking a solution to resolve this problem
- Engage early and regularly with Treaty partners
- Ensure stakeholders receive regular project updates and can provide constructive feedback to the project

- Ensure target audiences and stakeholders consistently feel well-informed about the rationale for the project and how it is being delivered
- Provide clear and concise information regarding the project's development, planning processes, and how people can be involved
- Provide clarity about how engagement will inform outcomes and provide feedback to stakeholders
- Build trust with landowners and stakeholders in specific study locations, and achieve access for fieldwork required
- Ensure there is a coordinated communications approach with project delivery partners and contractors to ac]hieve best practice outcomes
- Position the NZ Battery team and project delivery partners as having the expertise to deliver high quality, best practice advice
- Demonstrate that environmental, social and cultural outcomes are taken into account from the onset
- Celebrate and promote project milestones
- Maintain flexibility and adaptability in the engagement approach.

5.6 Iwi engagement

Engagement with iwi / Māori will follow Te Arawhiti engagement guidelines. The level of engagement should be determined through advice from Te Arawhiti and by engaging directly with Treaty partners. According to the Te Arawhiti guidelines, there is a spectrum of engagement, in terms of who is engaged and how, based on the significance of the issue. The Crown's Treaty Partners have an important role in the implementation of this project, and the engagement approach should be guided by Te Tiriti o Waitangi and its principles and align with Māori rights and interests.

Because the NZ Battery Project objectives are nationally significant, there is a need to engage iwi at a national level, and to ensure that mātauranga Māori and cultural values are included within the project's design and outcomes. There is also a need to coordinate iwi engagement with broader energy and climate change work underway.

There are a range of rights and interests for iwi / Māori intersecting with the NZ Battery Project including ownership, governance, ability to exercise kaitiakitanga, benefit distribution and commercial investment. 'Who' has rights and interests typically depends on if the 'battery' solution falls within their rohe (tribal area).

For example, Lake Onslow lies within the takiwā of Ngāi Tahu. Te Rūnanga o Ōtākou identify as Mana Whenua for the area, and Hokonui Rūnanga and Kāti Huirapa Rūnanga ki Puketeraki have also expressed an interest. An initial indication of the groups to be engaged with and the approach to engagement for Lake Onslow is outlined in Table 50.

Table 50: Initial iwi / Māori engagement approach for Lake Onslow

Iwi / Māori group	Broad interests	Engagement approach
1. Whānau / hapū • Te Rūnanga o Ōtākou • Hokonui Rūnanga • Kati Huirapa ki Puketeraki	• Capturing mana whenua values for the Lake Onslow area • Approach to kaitiakitanga • Economic opportunity • Impacts and benefits • Legacy • Upholding Te Tiriti o Waitangi principles	• Kanohi ki kanohi hui • Relationship with Ōtākou as mana whenua • Ōtākou to facilitate meeting with other two runanga • Aukaha to deliver cultural values assessment
2. walwi • Te Rūnanga o Ngāi Tahu	• Mātauranga Māori and cultural values are included within the project • Mana whenua for each area of interest are engaged	• Advice to be sought from Te Arawhiti on how best to approach workstream
3. Māori collectives / business • Murihiku Regeneration	• Potential interest in hydrogen workstream, as Tiwai Point is within their area of interest	• To be engaged on wider NZ Battery Project, particularly hydrogen workstream • Kanohi ki kanohi hui

Table 51 is an example of engagement approaches that would be taken for the Lake Onslow option. Other locations may be defined for alternative options in a Portfolio solution, In that scenario, mana whenua, as well as other iwi / Māori groups with interests in the project, will continue to be identified and engaged as these other geographic locations are proposed for the NZ Battery Project.

5.7 Benefits realisation

A benefits realisation plan will be developed in the DBC phase. Benefits realisation is the approach used to identify, define, track, and optimise the realisation of project benefits. An initial view of the NZ Battery Project's benefits has been outlined in the Strategic and Economic Cases. To ensure the project benefits are realised, the NZ Battery Project will embed a benefits management framework as part of the project management processes to be implemented by the Project Management Office.

Guiding principles for the benefits management approach include:

- Benefits are the quantifiable improvements the investment will achieve, and must be directly attributable to the investment
- Benefits can be dynamic and may change, but changes to benefits need to be documented.

A Benefits Realisation Plan (BRP) will be developed for the project during the next phase, following these four phases. The BRP will outline:

- Benefit descriptions (with weightings)
- Benefit owners
- Key performance indicators (KPI) / measures for each benefit (with weightings)

- KPI baseline and target values and realisation dates
- Assumptions, dependencies, risk, and issues impacting benefit realisation.

The BRP will be a live plan for the Project Management Office and benefit owners to own and continuously refine as the project progresses.

Some of the benefits of the NZ Battery Project will be challenging to measure, particularly as, in some cases, the benefit is in comparison to a future that does not yet exist. The approach to monitoring benefits realisation needs to differ by benefit area. It also needs to incorporate the different responsibilities that the various parties have in relation to delivering on the outcomes sought through the NZ Battery Project, and therefore who and how they will be measured.

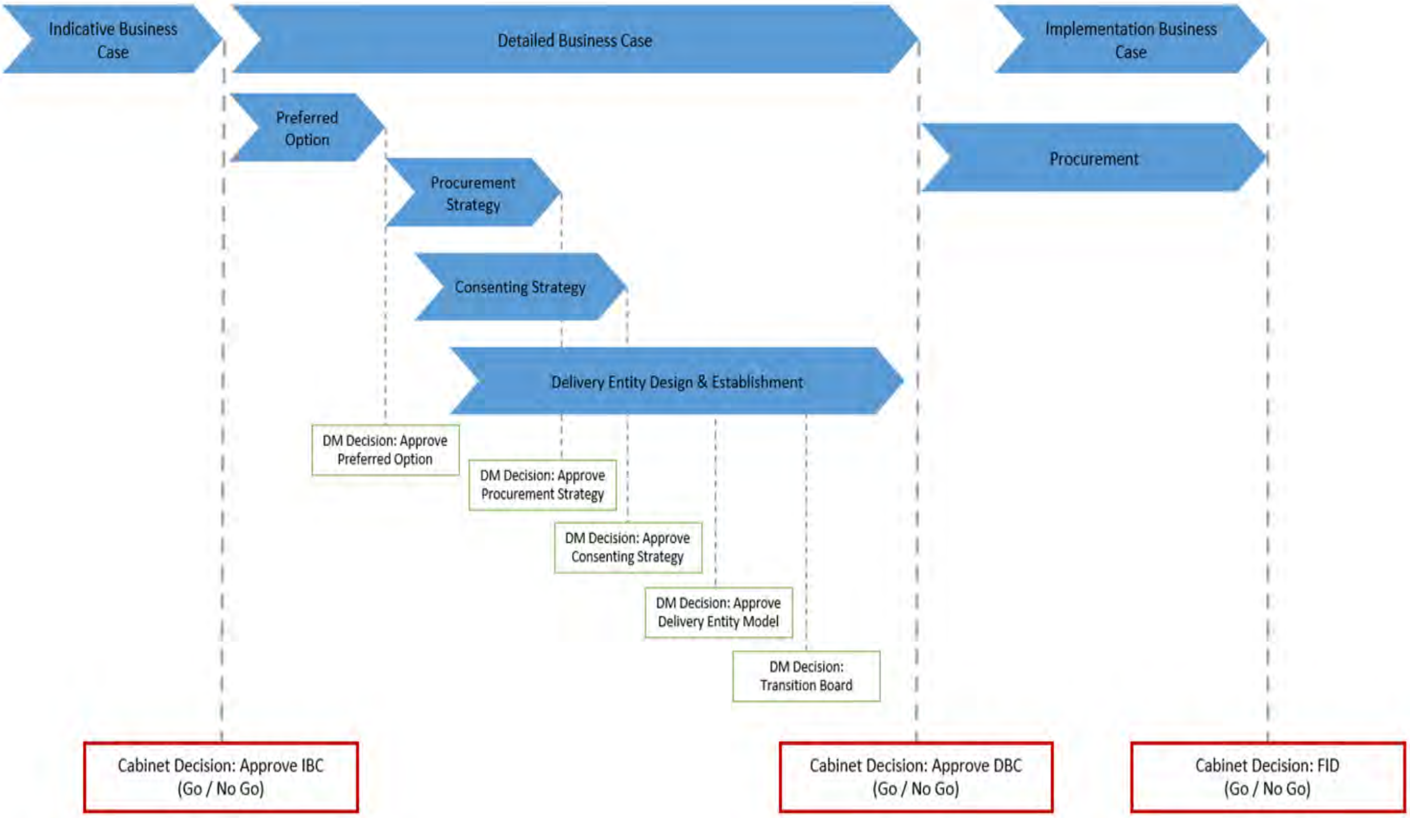
5.8 Reporting and assurance

The NZ Battery investment proposal is high risk, due to the scope, scale, and complexity of the project. An appropriate reporting and assurance approach is needed to provide assurance that the project is on track to deliver the intended outcomes. The approach to assurance for the project is outlined in Table 51. These approaches will evolve as the project progresses, and further detail will be provided in the DBC.

Table 51: NZ Battery quality and assurance approach

Mechanism	Description
Gateway reviews	Due to the high risk of the project, the NZ Battery Project is required to undergo reviews by Treasury at strategic points through the life of project ('Gateway reviews'). The first of these reviews has occurred during the development of this IBC, and subsequent reviews will occur during the following project phases.
Internal monitoring, reporting, and assurance	Project and workstream status reports will be regularly provided to project governance and management. The Project Director and Project Management Office will be responsible for centrally coordinating delivery and escalating risks and issues to governance as required.
Technical peer review	Given the significance of the project, technical peer review is proposed on all material pieces of technical advice. To date this has included cost, feasibility, and scheduling considerations.
Independent Quality Assurance (IQA)	An IQA is proposed to be conducted to provide assurance that the project is appropriately planned, managed, and controlled, and that governance supports the project effectively. The timing for the IQA will be confirmed following IBC approval and establishment of the project framework to 'get to the DBC' phase.
Post-project evaluation	Upon completion of each phase of the NZ Battery Project, and final completion of the project, an evaluation process will be undertaken of how successfully the planned objectives and outcomes have been met. This will include assessment of the effectiveness of project management and governance, management of risks and issues, and realisation of expected benefits. This will provide lessons learnt for future similar projects.

Figure 42: NZ Battery key decision points offramps



5.9 Next steps

The following next steps should be progressed early in phase 2A to continue the Project's momentum and to ensure its success:

- Confirming **delivery structure for MBIE** (Phase 2A) and begin **recruiting appropriate staff** for expanded project team
- Engage with MBIE procurement to **commence procurement of necessary services in Phase 2A**, including but not limited to:
    - Project Development (design, investigations etc)
    - DBC
    - Market shortage study
    - Land access/acquisition (if necessary).
- Confirm **governance arrangements, including:**
    - Confirming the membership make up of each group
    - Appointment process, which is likely to be different for each group
    - Developing terms of reference, and
    - Developing and delivering an induction for each group.
- Commence **stakeholder engagement** in line with IBC and proposed stakeholder engagement plan.
- Confirm **key decisions with Cabinet** relating to:
    - Funding
    - Timeline
    - Reporting
    - Delegations framework.
- Review and update project and risk management processes to reflect the focus of proposed Phase 2A activities.

Te Kāwanatanga o Aotearoa
New Zealand Government

NZ Battery Project
Indicative Business Case Appendices

FEBRUARY 2023

PREPARED BY ERNST & YOUNG

MINISTRY OF BUSINESS,
INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Te Kāwanatanga o Aotearoa
New Zealand Government

**MINISTRY OF BUSINESS,
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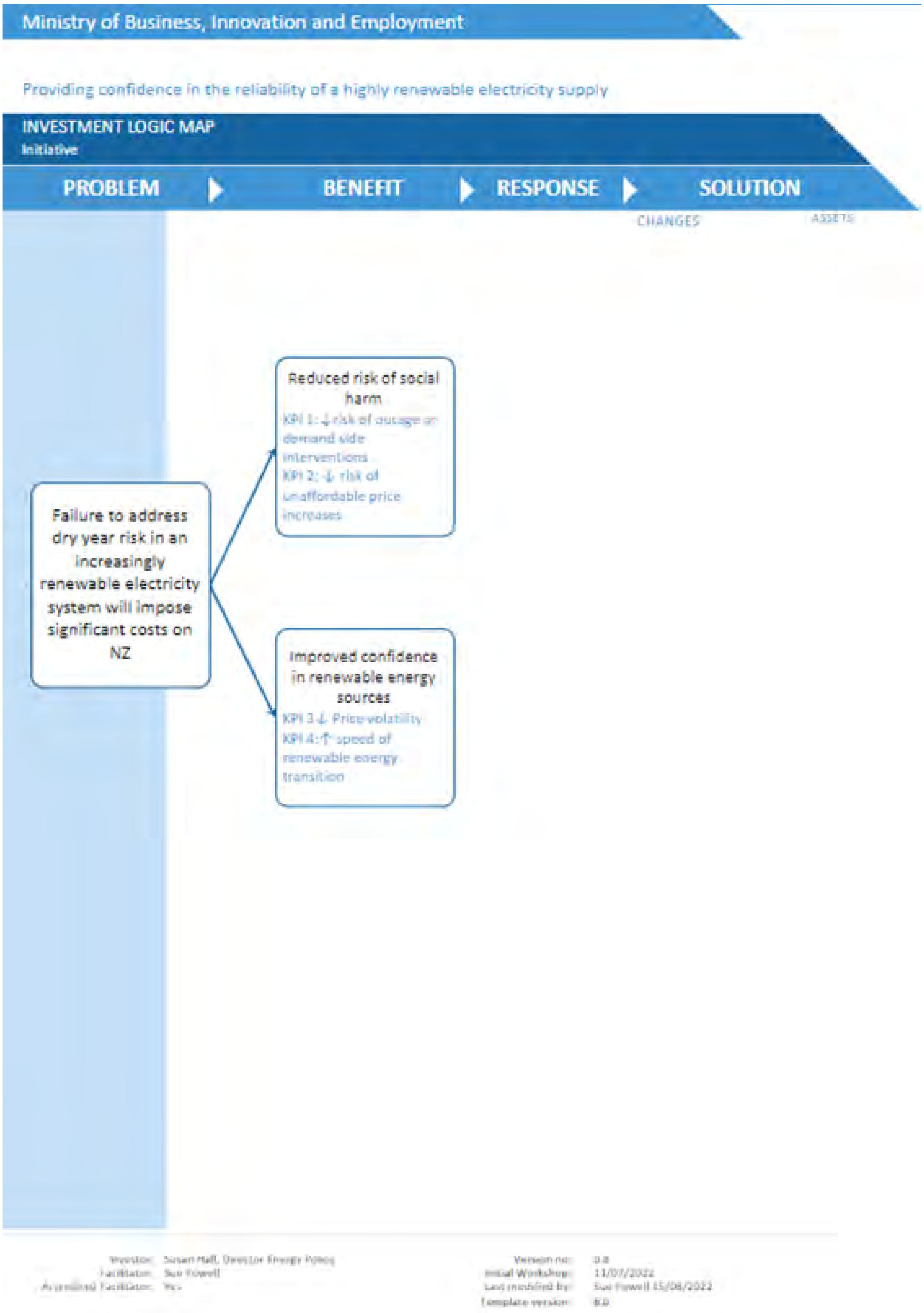
Appendix A Technical advice provided for the NZ Battery project

Document title	Provided by	Date
Workstream 1: Pumped Hydro at Lake Onslow		
NZ Battery Project – Lake Onslow Pumped Storage Scheme & Technical Appendices.	Te Rōpū Matatau	Sep 2022 (draft)
NZ Battery Project – Procurement and Implementation Assessment	Mott McDonald	Sep 2022 (draft)
NZ Battery Analysis & Appendices	Transpower	Dec 2022 (draft)
Capital Cost Estimate, Schedule and Risk Assurance Review: NZ Battery Project, Lake Onslow Pumped Storage Scheme MBIE	Turner & Townsend	Nov 2022 (draft)
Hydrology, water quality and ecology of the lower Clutha	NIWA	Jul 22
Assessment of Lake Onslow climate, hydrology and ecology	NIWA	Mar 22
Assessment of conservation values at Lake Onslow: New Zealand battery project - Lake Onslow option	DOC	Jun 22
Baseline ecological assessment of Lake Onslow and Teviot River for the New Zealand battery project	Cawthron Institute	Mar 22
An investigation into Lake Onslow brown trout spawning habitat availability at increased lake heights	Fish & Game	Jul 22
Lake Onslow hydro storage project: a desktop assessment of archaeology and heritage	New Zealand Heritage Properties	Nov 21
New Zealand battery project: landscape & visual assessment	Blakely Wallace Associates	Aug 21
Evaluation of terrestrial indigenous biodiversity features and values at Lake Onslow and adjacent vegetation and habitats	Wildlands	Jul 22
The Lake Onslow option: cultural values statement for the New Zealand battery project	Aukaha	Aug 22
Aotearoa/New Zealand battery project: interim assessment of social impacts for Lake Onslow pumped hydro scheme option	Nick Taylor & Associates	Jul 22
Workstream 2: Other options to expand hydro storage		
Identifying potential sites for large-scale Pumped Hydroelectric Storage (PHES) in New Zealand	NIWA	Sep 2021
Other Pumped Hydro and Other Hydro Options Initial Desktop Screening Study	Stantec	Mar 2022
Workstream 3: Other technologies for energy storage		
Technical memorandum on MBIE's screening of long list approaches for other technologies scope in the NZ Battery Project	Arup	Sep 2021
Other technologies feasibility study – Options analysis report and feasibility study	WSP	May 2022

Other technologies feasibility study – Feasibility assessment report	WSP	Sep 2022-
Capital Cost, Schedule and Risk Review: NZ Battery - Other Technologies MBIE	Turner & Townsend	Sep (2022) (draft)
Workstream 4: Market integration and economic analysis		
Estimated gross benefits of NZ Battery options	John Culy Consulting & Concept Consulting	May 2021
NZ Battery – electricity market study, Problem 2: Market Interaction	Sapere	May 2021
Climate change impacts on New Zealand hydro catchment inflows and wind speeds	Jen Purdie, ClimateWorks Ltd	Feb 2022
NZ Battery project modelling draft report	John Culy Consulting & Concept Consulting	Apr 2022 (draft)
NZ Battery electricity market modelling study	EY	Jul 2022
Storage options for the NZ electricity sector – Operational and Organisational Issues	EGR Consulting	Jul 2022
NZ Battery – Review of development pipeline cost	Aurecon	Oct 2022 (draft Aug 2022)
NZ Battery - OptGen/SDDP Market Modelling Report	Jacobs	Dec 2022 (draft)

Appendix B NZ Battery Investment Logic Map



Ministry of Business, Innovation and Employment

Providing confidence in the reliability of a highly renewable electricity supply

INVESTMENT LOGIC MAP
Initiative

PROBLEM **BENEFIT** **RESPONSE** **SOLUTION**

CHANGES ASSETS

Failure to address dry year risk in an increasingly renewable electricity system will impose significant costs on NZ

Reduced risk of social harm
KPI 1: ↓ risk of outage or demand side interventions
KPI 2: ↓ risk of unaffordable price increases

Improved confidence in renewable energy sources
KPI 3 ↓ Price volatility
KPI 4: ↑ speed of renewable energy transition

Investor: Susan Hall, Director Energy Policy
Facilitator: Sue Powell
Accredited Facilitator: Yes

Version no: 0.8
Initial Workshop: 11/07/2022
Last modified by: Sue Powell 15/08/2022
Template version: 8.0

Appendix C Long-list assessment

The long-list of options reflects 28 different intervention options, in addition to the status quo, that could potentially be used to address dry-year risk. The options long-list was developed by the MBIE NZ Battery project and Energy Market's policy teams early in the project's inception. This appendix outlines each option and summarises the assessment undertaken, using the below feasibility criteria:

Table 1: Feasibility criterion

Feasibility criterion	Description
Mitigating dry year risk	Is the option able to be operated reliably and at the scale needed to provide security of supply through infrequent and prolonged dry conditions? Specifically, can the solution reasonably be expected to; 1. Have sufficient fuel and/or flexibility to vary its operations by ~ 3 TWh as a single solution, or 1 TWh as a partial solution? 2. Have the ability to dispatch ~1TWh of generation within three months in dry years?
Renewable	Does the option help meet New Zealand's renewable electricity generation targets? Specifically, does it support ambitions for 100% renewable electricity generation by 2030?[1]
Practical	Is this option broadly and reasonably considered to be practical to deliver? This criterion has four parts: 1. Is the technology that underpins the option viable or likely to be viable at scale by 2035? 2. Is there sufficient feedstock to operate at scale? 3. Is the option constructable by 2035? 4. Is the option likely to be acceptable from an environmental, regulatory, social, and cultural perspective?

Each option is described and then scored against the criteria in the sections that follow. The scoring of each option against the above criteria is based on information taken from desktop research into technologies and comparable case studies, engineering reports commissioned explicitly to understand feasibility of these technologies, and knowledge from within the NZ Battery Project Team (as well as wider MBIE Energy market teams and the Technical Reference Group).

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[1] Note: Renewable electricity generation means a source of electricity generation that is not depleted when used, including rain, wind, sunlight and geothermal. Renewable electricity generation does not necessarily mean zero emissions.

Long-list

Table 2: Options long list

Option type	Option	Description
Reduction in electricity demand	Improved energy efficiency	Energy efficiency is achieving the same output (e.g., heat or light) with less energy. Increased energy efficiency results in an enduring, long-term, reduction in load.
	Demand response	For the purposes of the long-list, demand response is a voluntary load reduction or load shifting by consumers in response to a price signal. 'Demand response' is a term that has been used more casually through-out the IBC to refer to any helpful response from consumers.
	Large scale load reduction (ad hoc)	Load reduction for both industrial and non-industrial users over a significant period. Large scale load reduction (ad hoc) is negotiated once there is electricity scarcity e.g., a dry year is occurring.
	Large scale load reduction (planned)	Planned large-scale load reduction is pre-contracting large scale industrial plant to reduce consumption when required to maintain security of supply in periods of electricity scarcity.
Increase existing hydro storage	Increased hydro storage at existing lakes	Increasing hydro storage by raising the level of existing hydro dams. This does not increase inflow but would increase storage and (all else equal) reduce spill.
	Relax hydro constraints at existing lakes	This is the relaxation of operating constraints imposed on hydro. Examples could include maximum and minimum lake heights, maximum and minimum outlet or river flows, and availability of contingent storage.
	Improve hydro management at existing lakes	Improved hydro management could be achieved through mandating higher lake levels in existing dams leading into winter (typically periods of increased energy scarcity / when dry years emerge).
Develop electrically charged storage	Lake Onslow pumped hydro scheme	This is a large-scale pumped hydro scheme built at Lake Onslow in the South Island. Pumped hydro works by pumping and storing water in an elevated reservoir when electricity is abundant / the price is low and releasing that water to generate electricity when electricity is scarce. A Lake Onslow pumped hydro scheme could take several different configurations.
	Other pumped hydro	This is the creation of a pumped hydro scheme similar to the Lake Onslow option above, but in another location. As with the Lake Onslow option, this option could take several different configurations.
	Other gravitational storage	Gravitational storage uses raised mass (other than water) to create and store gravitational potential energy which is released when the mass is lowered (when energy is needed).
	Renewable compressed air energy storage (CAES)	CAES uses electricity to pump air, compressing it in the process, into a suitable underground formation that acts as a storage tank. Releasing the pressurised air pushes a turbine, generating electricity when needed.

Option type	Option	Description
	Liquid air storage	This option cools air to -196°C, at which it becomes liquid, and stores it in insulated, low pressure vessels. When exposed to ambient temperatures, the air rapidly re-gasifies, causing a 700-fold expansion in volume that can be used to drive a turbine and create electricity.
	Flow battery energy storage	Flow batteries are a type of chemical battery where energy is stored by two chemical / electrolyte components. Energy is stored and released by pumping these components through the system on separate sides of an ion selective membrane creating electrical current.
	Lithium-ion and other standard battery storage	This option uses lithium-ion or comparable technology for inter-seasonal and inter-year storage, for example, a very large grid connected battery or batteries.
	Flywheel energy storage	Flywheel energy storage works by accelerating a rotor (flywheel) to a very high speed within a sealed vacuum chamber, and maintaining the energy in the system as rotational energy.
Build / modify current generation	Baseload or inflexible generation	The build out of additional baseload generation such that there is excess generation to fill the dry year gap. Both geothermal and nuclear generation have been explicitly considered.
	Intermittent renewable generation	This option is an overbuild of renewable generation to allow an excess of energy in normal years, which would be spilled (or monetised), but just enough energy in dry periods. Wind and solar generation have been explicitly considered, though the assessment could be extended to tidal/wave and other potential technologies.
	Fossil fuel generation without CCS	This option is a form of continuation of the status quo – using gas generation to cover dry year risk.
	Fossil fuel generation with CCS	This option uses gas generation to cover dry year risk but with carbon capture and storage processes to remove carbon from the resultant waste gases.
	Flexible geothermal generation	This option would use current or new geothermal generation plants and run them flexibly at inter-seasonal and inter-year timescales to provide dry year risk coverage. The assessment could similarly apply to deliberately holding solar or wind generation in reserve.
Green energy vector (Hydrogen)	H_2 production with subsurface storage	Hydrogen is produced using electrolysers powered by renewable energy. Once produced, hydrogen is then stored in a gaseous state in underground caverns. This option has also covered storing liquid hydrogen in above ground tanks.
	H_2 production with carrier storage	This option stores hydrogen produced from renewable energy in a chemical carrier form (e.g., ammonia or methane), decreasing its volume so that in can be more easily stored in tanks or wells.
	H_2 or carrier import with buffer storage	This option imports externally produced hydrogen or ammonia as required from an international hydrogen market.

Option type	Option	Description
Bioenergy	Biomass production and storage	This option is the storing of solid bio-material (e.g., wood chip or torrefied wood pellets) in bulk volumes, which is used to fuel generation plant.
	Biogas production and storage	This option uses biogas (e.g. methane produced from organic materials or waste), which could be stored in gaseous form in underground reservoirs (e.g. Ahuroa). The biogas is then used to power a gas turbine to generate electricity.
	Liquid biofuel production and storage	This option is the development of domestic ‘drop-in’ biofuels to power a liquid-fuel generation plant.
	Bioenergy import with buffer storage	This option is the use of imported biomass or biofuels to power generation plant.
Importation of energy	Connecting NZ’s and Australia’s grids	This option would connect NZ into the Australian power system to manage security of supply risks, as is done internationally.

Group 1: Reduction in electricity demand

The following four options explore approaches to reducing electricity demand without making changes to electricity supply.

Option 1: Improved energy efficiency

Description: Energy efficiency is achieving the same output (e.g., heat or light) with less energy. Increased energy efficiency results in an enduring, long-term, reduction in load.

Assessment:

Criteria	Description
Mitigating dry year risk	This does not meet the security of supply criterion as an improvement in general energy efficiency reduces total load all the time, rather than reducing it during selective periods of need (e.g., dry years). Energy efficiency could potentially reduce the seasonal variation in demand in a way that helps existing storage manage both seasonal and annual inflow variability. However, to meet the required scale, efficiency gains would need to be significant, disproportionately target winter loads, and be rolled out economy wide – while also noting the competing impact on winter demand of economy-wide electrification of heating. While it could make a contribution, it does not meet the need for scale.
Renewable	Efficiency is tied to the current state of the system – it will not impact upon the renewable share of the electricity system. However, in isolation it is consistent with renewable aspirations as it does not introduce more fossil fuels into the system.
Practical	**Viability:** While technologies exist that could help reduce winter peaks in some situations (e.g. insulation, replacing direct element heating with heat pumps etc) these technologies would not provide the reduction required to address dry year risk. At the scale required, commercial and industrial demand would also need to be targeted, which generally requires bespoke solutions. **Feedstock:** N/A. **Constructability:** It is unlikely that expansive energy efficiency could be rolled out by 2035 given construction and HVAC industry constraints. **Acceptability:** Energy efficiency is likely to have broad support from an environmental. regulatory, social and cultural perspective.
Outcome:	Energy efficiency has not been short-listed for a NZ Battery solution as it does not provide the targeted variable reduction in demand required to contribute to dry year security of supply. However, energy efficiency is highly beneficial for other reasons, so is considered as an important inclusion for the system in the counterfactual, and all options that are eventually tested through the multi-criteria analysis.

Option 2: Demand response

Description: Demand response is an unplanned reduction in load (use) by industry, commercial, and residential consumers in response to price signals (e.g., high market prices, where the responder is exposed to the price). Increased demand response results largely in short-term shifting of load, although behavioural changes can have longer-term load reduction effects.

Demand response could come from large industrial users who are exposed to wholesale electricity prices, but also commercial and residential consumers through specific retail tariffs (e.g. time of use tariffs). This could also be implemented through automation, similar to ripple control of hot water, where specific loads or appliances were turned down/off in response to these events.

Assessment:

Criteria	Description
Mitigating dry year risk	This option does not meet this criterion. Demand response is helpful in reducing load at peak times. However, demand response on its own is unlikely to yield a large reduction in load that can be sustained for long periods, sufficient to meet the TWh thresholds.
Renewable	Demand response is tied to the current state of the system – it will not impact upon the renewable share of the electricity system. However, in isolation it is consistent with renewable aspirations as it does not introduce more fossil fuels into the system.
Practical	**Viability:** Demand response is unlikely to be practical for consumers at the scale required to meet TWh thresholds as it would impose the economic costs that the NZ Battery project is trying to avoid. **Feedstock:** N/A. **Constructability:** N/A. **Acceptability:** It is unlikely that prolonged reliance on demand response at the scale needed to meet dry year risk mitigation will be acceptable to consumers or the New Zealand public.
Outcome:	This option has not been short-listed for a NZ Battery solution as demand response at the scale required to solve the dry year problem would impose the same economic costs identified as being part of the problem statement. However, some level of demand response is considered an important inclusion for the system in the counterfactual, and all options that are tested through the MCA. In particular, significant amounts of smart electric vehicle charging are assumed, as well as price-responsive industrial demand response.

Option 3: Large scale load reduction (ad hoc)

Description: Load reduction for both industrial and non-industrial users for a significant period. Large scale load reduction (ad hoc) is negotiated and occurs once a dry, calm, cloudy period is occurring. It is assumed some level of compensation is provided to consumers whose load is reduced, however this is not pre-planned and agreed upfront.

Assessment:

Criteria	Description
Mitigating dry year risk	New Zealand has very few large consumers that could meet the necessary scale of a dry year solution. The aluminium smelter at Tiwai, at 570MW, is our largest customer by a significant margin. The next largest is 100MW, and there are fewer than 10 consumers in total that are greater than 10MW. With the exception of hydrogen production (covered elsewhere), prospective consumers are not expected to exceed 150MW. The smelter could hypothetically provide 1TWh of load reduction over 3 months if it quickly ceased its full production. However, this would mean it could not fulfil contracted sales, and would face damage to plant and equipment and long start-up times. Its practical contribution that mitigates these costly impacts is likely closer to the 250GWh allowed for under its current contract with Meridian Energy. Practically speaking, achieving dry year security through demand-side measures would require disrupting multiple large customers for months at a time.
Renewable	Load reduction is tied to the current state of the system – it will not impact upon the renewable share of the electricity system. However, in isolation it is consistent with renewable aspirations as it does not introduce more fossil fuels into the system.
Practical	**Viability:** This option is technically viable by 2035. However, there are few consumers whose businesses could withstand a large disruption to their operations for months, with little forewarning. This would likely have implications for jobs, international and domestic competitive advantage (reducing a businesses' standing in the market in which it operates), and potentially industry emigration (re-locating elsewhere). Any negotiations around reducing load and compensation are likely to be fraught if held in the heat of the moment in a dry year, impacting the cost, reliability and efficiency of the solution, and risking protracted disputes after the fact. **Feedstock:** N/A **Constructability:** N/A. **Acceptability:** This option is unlikely to be acceptable to the New Zealand public. Unplanned disruption to consumer load at the scale required to manage dry year events would have detrimental impacts for multiple businesses – noting that while the immediate costs to businesses can be compensated for, there may be public costs from businesses' reduced activity that cannot be compensated.
Outcome:	This option has not been short listed as it is unlikely to be a practical solution at the scale necessary to mitigate dry year risk. Further, where this scale is achieved, it would impose the same economic costs identified as being part of the problem statement.

Option 4: Large-scale load reduction (planned)

Description: Planned large-scale load reduction involves pre-contracting a large scale highly flexible industrial plant (or plants) to reduce consumption when required. This option is suggested as a low-cost alternative to a battery – the logic being that it could be cheaper to pay a large industrial to do nothing than to build a 'battery'.

Assessment: This option scores the same as large-scale load reduction (ad hoc) as the principles underlying this approach are the same – the difference is whether the reduction is pre-planned or ad-hoc. All else being equal it is assumed that pre-contracted load reduction will be less expensive than unplanned load reduction.

Criteria	Description
Mitigating dry year risk	New Zealand has very few large consumers that could meet the necessary scale of a dry year solution. The aluminium smelter at Tiwai, at 570MW, is our largest customer by a significant margin. The next largest is 100MW, and there are fewer than 10 consumers in total that are greater than 10MW. With the exception of hydrogen production (covered elsewhere), prospective consumers are not expected to exceed 150MW. The smelter could hypothetically provide 1TWh of load reduction over 3 months if it quickly ceased its full production. However, this would mean it could not fulfil contracted sales, and would face damage to plant and equipment and long start-up times. Its practical contribution that minimises these impacts is likely closer to the 250 GWh allowed for under its current contract with Meridian Energy. Practically speaking, achieving dry year security through demand-side measures would require disrupting multiple large customers for months at a time.
Renewable	Demand response is tied to the current state of the system – it will not impact upon the renewable share of the electricity system. However, in isolation it is consistent with renewable aspirations as it does not introduce more fossil fuels into the system.
Practical	**Viability:** The viability of large-scale load reduction is contingent on the willingness of industry to provide this level of load reduction. There is precedent for industry agreement2. However, there are few consumers whose businesses could withstand a large disruption to their operations for months, with little forewarning. Avoiding the negative impacts on their business would likely mean the load offered would only represent a small portion of their total load – further reducing the ability of this option to meet the required scale, or requiring participation from a widening group of businesses, and hence broadening the impacts. There are likely to be many future opportunities for industry (new and existing) to provide a demand-side response for short periods to support peak demand. **Feedstock:** N/A. **Constructability:** N/A.

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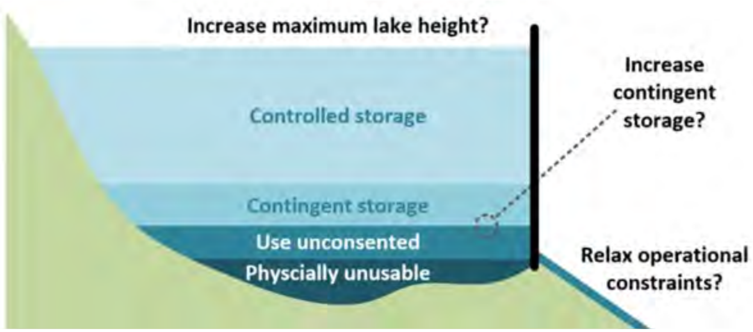
[2] In April 2021 in the face of rising wholesale prices - but still normal conditions regarding the System Operator's Electricity Risk Curves - Meridian Energy announced it had struck a swap deal with New Zealand Aluminium Smelters, to reduce the Tiwai Point aluminium smelter's consumption by up to 30.5 megawatts per hour until the end of May.

Criteria	Description
🟥	**Acceptability:** It is unlikely that prolonged reliance on load reduction at the scale needed to meet dry year risk mitigation will be acceptable to the New Zealand public given its economic costs – noting that while the immediate costs to businesses can be compensated for, there may be public costs from businesses' reduced activity that cannot be compensated.
Outcome:	This option has not been short-listed for a NZ Battery solution for the same reasons as Option 3. However, it is considered as a necessary inclusion for the system under all options. Further, some short-list options could include a level of planned demand response in dry years (e.g., green hydrogen electrolysis plants could provide a source of load reduction when scarcity metrics are met). Our consideration of demand response in this IBC is limited to that from hydrogen production, and from the Tiwai smelter under our sensitivity analysis within the EMM work completed.

Group 2: Increase existing hydro storage capacity

The following three options explore approaches to increasing the storage available or accessible in our current hydro system. These options range from increasing maximum lake height to relaxing operational constraints to enable larger storage capacity. This is visually represented in the diagram below:

Figure 1: Existing hydro expansion diagram



Option 5: Increase existing physical hydro storage

Description: Increasing hydro storage could be achieved by raising the level of existing dams, or further developing existing schemes. It could also potentially be achieved by dredging the bottom of existing hydro lakes. This would not increase hydro inflow but would increase storage and (all else equal) reduce hydro spill.

The NZ Battery Project identified several potential options for increasing existing hydro storage, including through discussions with generators. Lake Pukaki in the South Island (pictured right) was identified as the only potentially suitable location for extension that could meet the required scale.

Pre-Feasibility study: Pukaki was identified by MBIE and NIWA as a potential dry year solution. Stantec carried out a pre-feasibility study to determine what would be required to achieve this solution e.g., the constructability, cost, environmental, cultural, social effects that would need to be considered.

Assessment:

Figure 2: Lake Pukaki GIS mapping

Criteria	Description
Mitigating dry year risk	The Stantec study identified that Lake Pukaki could be increased to a level that meets the TWh thresholds to help mitigate dry year risk, but would largely rely on the existing Waitaki Hydro Scheme to deliver that, with only around 100 MW of new capacity likely to be added.
Renewable	Hydro is a renewable generation source.
Practical	**Viability:** Hydro is a well-established technology, so this option is considered technically viable. **Feedstock:** The Stantec study identified that enough feedstock (water) could be stored to provide multiple TWhs of storage capacity. However, the study identified that it would take ~13 years to fill the newly created storage capacity if no water was held back from downstream generation. This is too long to cover dry year risk in consecutive years. The refill time could be reduced to two years by holding back around a third of the Waitaki's scheme's current average generation. **Constructability:** The Stantec study indicates that the proposed storage increase is constructable by 2035, and it did not identify any geological fatal flaws from its desktop research. Stantec estimated indicative construction costs at $8.5b on a P50 basis (class 5, unescalated). Further work since that study indicates the risked contingency may be significantly underestimated. There would be significant disruptions to the use of Pukaki's hydro storage capacity during construction. **Acceptability:** Lake Pukaki has significant cultural values and is a popular tourist area. The Stantec study identified that the dam height increase required to meet storage requirements is approximately 30m. This would inundate ~1,500ha of glacial moraine (that includes nesting zone for threatened birdlife), areas of native vegetation, multiple properties and tourist viewing areas, and require re-routing of existing state highways. Given the height rise and the inundation of land in an area with significant visual amenity, expanding storage is unlikely to meet resource consent requirements. However, as with other proposed hydro options, there may be willingness to allow consent to meet climate objectives.
Outcome:	This option has not been short-listed. The combination of fill-time, impacts on existing generation, and small increase in capacity means that raising Lake Pukaki is relatively ineffective at solving the dry year problem when compared to other options, particularly when viewed relative to its indicative construction costs.

Option 6: Relax hydro environmental constraints

Description: This option is the relaxation of constraints imposed on hydro operations through consenting processes. This could include changes to maximum and minimum lake heights, maximum and minimum outlet or river flows, and availability of contingent storage (the last amount of hydro storage available before shortage). Relaxing these constraints could increase storage and/or provide additional flexibility to hydro scheme operation.

Assessment:

Criteria	Description
Mitigating dry year risk	Relaxation of hydro constraints could provide additional hydro storage. Drawing on contingent storage is the most likely approach to this. Contingent storage could make a moderate contribution in the extreme, with around 400 GWh available in winter at the alert storage level (rising to 618 in summer) with a further 214 GWh if an Official Conservation Campaign is called. Compare this with current daily national electricity generation of around 125 GWh. Contingent storage is also viewed as an insurance policy and the energy storage of last resort prior to large scale forced demand response. Using it for dry year security would prevent it from continuing that role.
Renewable	Hydro is a renewable generation source.
Practical	**Viability:** Relaxing hydro constraints is technically viable. **Feedstock:** N/A. **Constructability:** This option would not require construction, though there are issues around flow rates of the water in contingent storage that would need to be addressed. **Acceptability:** Resource consent conditions exist to protect river flow rates, lake levels and so the ecological health of waterways. For example, the National Policy Statement for Freshwater Management 2020 prioritises the health and well-being of water bodies and freshwater ecosystem health, over human health needs, and the ability for people and communities to provide for their own social, economic and cultural wellbeing. The trend has been for resource consent conditions to tighten, rather than loosen, over time reflecting growing public concern over water quality and quantity, and increasing competition for water use. This option is likely unacceptable as it increases the risk of river and lake levels breaching consent limits for marginal storage gains.
Outcome:	This option has not been short-listed as it is considered that it does not produce enough storage and is unlikely to be practical or acceptable. While in theory it is viable to have bigger variations in hydro lake levels and to also have much higher and lower river flows than consented, this is not expected to be acceptable – for cultural, recreational, ecological and safety reasons.

Option 7: Improve hydro management

Description: Improved hydro management could be achieved through requiring higher lake levels leading into winter to allow for increased availability of hydro energy to cover dry, calm, and cloudy periods. Another proposal has been to pay hydro generators to maintain minimum buffer hydro lake levels (to be used only as reserve energy).

Assessment:

Criteria	Description
Mitigating dry year risk	Holding lake levels higher going into winter may help mitigate the chance of a dry year event. However, the Project team considers that changes in hydro management to require higher lake levels heading into winter is unlikely to provide more than marginal additional storage in winter to meet security of supply requirements. The market already prices the option value of stored water and in theory optimises the value of releasing water now or storing it for later for the system benefit. Regardless, holding onto hydro flow for storage in winter may create energy shortfalls in shoulder months. These shortfalls would need to be met with other generation – where this is during a calm and cloudy period this may require increased generation from other new sources. This option would also increase the expected winter spill consequent on unforeseen heavy inflows.
Renewable	Hydro is a renewable generation source.
Practical	**Viability:** There are no technical impediments to improving hydro management. **Feedstock:** N/A. **Constructability:** This option would not require construction. **Acceptability:** This option is likely unacceptable as it increases the risk of lake levels breaching consent limits for marginal storage gains.
Outcome:	This option may reduce the risk of a dry year event in a given year but is not carried forward as it does not optimise the hydro storage resource (it would increase the risk of hydro spill in winter). It would likely also create the need for additional shoulder season generation.

Group 3: Develop electrically charged storage

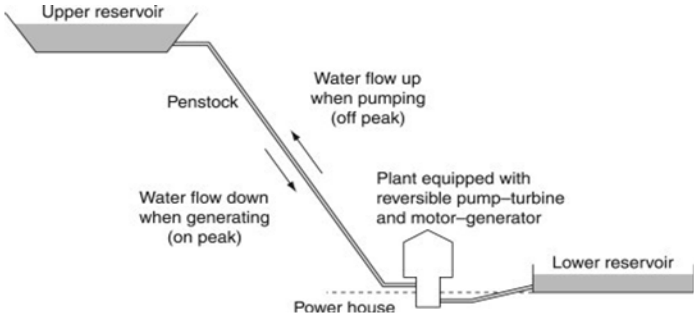
The following eight options explore approaches that use electricity and converts it to another form of energy that can be stored for months or years and then re-converts it into electricity.

Option 8: Lake Onslow pumped hydro scheme

Description: This option will use a pumped hydro energy storage scheme to pump water uphill using electrical power when power is cheap, then store it for use as hydro generation when power is scarce (i.e., during a dry year). As shown in Figure 3, pumped hydro requires an upper and lower reservoir with a height difference between them, connected by a tunnel with turbines that can both pump and generate.

Feasibility studies: Lake Onslow has been the subject of a number of geotechnical and design studies by Te Rōpu Matatau (an engineering alliance consisting of three engineering firms) to understand the energy storage capacity potential and geotechnical feasibility. These studies have not indicated any significant feasibility barriers to the construction and operation of a pumped hydro scheme at Lake Onslow.

Figure 3: Pumped hydro diagram



Assessment:

Criteria	Description
Mitigating dry year risk	Significant work has been undertaken that show that there exists the ability to store in excess of 5TWh of energy in water volume in the Lake Onslow basin[3].
Renewable	Pumped hydro would make use of renewable generation spill to pump and store water in the upper reservoir. This would then be released to generate energy in the same way a standard hydro dam would. This process does not require fossil fuel inputs.
Practical	**Viability:** Pumped hydro is a well-established technology, but construction may be subject to geotechnical risks. **Feedstock:** N/A **Constructability:** This option would be a significant undertaking and would likely require the importation of significant international expertise. Feasibility studies do not indicate any reason why this cannot be practically constructed and operated. Feasibility studies indicate it could be constructed between 2030 and 2037.

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[3] *Lake Onslow Phase 1A Options Overview,* Te Rōpū Matatau: Mott MacDonald, GHD, Boffa Miskell, 21/04/2022.

🟩	**Acceptability:** Lake Onslow pumped hydro has significant implications on the local environment and water resource. This is likely to lead to political / environmental risks and opposition that will need addressing. However, work to date has not indicated that any ‘fatal flaws’ exist.
Outcome:	This option has been short listed as work completed at the time of writing has indicated this option is technically feasible at a range of scales (each large enough to meet the dry year risk thresholds).

Option 9: Other pumped hydro storage

Description: Similar to the Lake Onslow pumped hydro scheme option, other pumped hydro storage schemes could (in theory) be established in other locations of New Zealand.

Feasibility studies: NIWA and the NZ Battery team undertook an initial GIS scan of New Zealand that identified 106 different basins with the geographical features necessary to materially contribute to solving the dry year risk problem[4]. Basic screening criteria was placed on these basins (e.g., not flooding major towns / critical infrastructure or national parks). This left just two potential sites.

Stantec was then commissioned to undertake a pre-feasibility study on the two possible sites identified by the GIS scan. This pre-feasibility study reduced the number of other pumped hydro options to one. This option entails a new lake in the Moawhango catchment in the North Island[5].

Assessment:

Criteria	Description
Mitigating dry year risk	Indicative desktop pre-feasibility studies have been undertaken that show that there likely exists the ability to store in excess of 1TWh of energy in a North Island pumped hydro scheme at Moawhango. This would meet the scale required to contribute to the dry year. However, there would be implications for the existing hydro scheme that this option would sit within. Further investigation would be necessary to determine its overall value for the electricity system and the dry year problem.
Renewable	Pumped hydro would make use of renewable generation spill to pump and store water in the upper reservoir. This would then be released to generate energy in the same way a standard hydro dam would. This process does not require fossil fuel inputs.
Practical	**Viability:** Pumped hydro is a well-established technology, but construction may be subject to geotechnical risks. **Feedstock:** N/A **Constructability:** This option would be a significant undertaking and would likely require the importation of significant international expertise. However, desktop pre-feasibility studies indicate the potential for this to be practically constructed and operated. Pre-Feasibility studies indicate it could be constructed between 2030 and 2035, with indicative construction costs on a P50 basis of $8b (class 5, unescalated). **Acceptability:** Pumped hydro has significant implications on the local environment and water resource. This is likely to lead to political / environmental risks and opposition that will need addressing. At the time of writing, it is not clear the extent of these impacts and how they affect the acceptability criteria.
Outcome:	Short-listing of this option is pending following a hui with local iwi to better understand the local impacts and appetite for further investigation of this option.

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[4] *Identifying Potential Sites For Large-Scale Pumped Hydroelectric Energy Storage (PHES) In New Zealand,* NIWA, September 2021.

[5] *Other Pumped Hydro and Other Hydro Options Initial Desktop Screening Study,* Stantec, March 2022.

Negotiations

[redacted]

Option 10: Other gravitational energy storage

Description: In principle, like water, any mass can be raised (to generate and store gravitational potential energy when prices are low) and lowered to release energy and generate electricity (when electricity is scarce and prices are high). Common examples of gravitational storage include the use of concrete filled containers raised on railway tracks or composite bricks raised by cranes.

Case study
Energy Vault[6] have developed to commercial demonstration stage, a grid scale gravity energy storage system – pictured right. This scheme consists of: • 35-ton composite bricks lifted by large cranes to create a tower • Bricks are then returned to the ground and the kinetic energy generated from the falling brick is turned back into electricity • 20 MWh to 80 MWh of storage capacity per system

Figure 4: Working energy vault gravitational storage system

Assessment:

Criteria	Description
Mitigating dry year risk	Theoretically, a vast number of gravitational storage options could be connected to meet 1 TWh of storage.
Renewable	Like pumped hydro, gravitational storage systems do not require the use of fossil fuel to storage and dispatch energy.
Practical	**Viability:** Gravitational storage technology has sufficient maturity. **Feedstock:** N/A **Constructability:** A simple calculation dividing 1 TWh by the storage capacity of existing commercial options suggest the scale required to achieve security of supply is unlikely to be feasible from a constructability perspective. Using Energy Vault as an example, 12,500 80-MWh systems would be required for 1 TWh of storage. However, it is worth noting that one unit may be cycled multiple times during a dry year period to reduce this figure. **Acceptability:** Given gravitational storage could be dispersed, the environmental, cultural and local impact may be able to be minimised to an acceptable level.
Outcome:	This option has not been short listed as the scale required to meet 1 TWh of storage is unlikely to be feasibly implemented. This option may have greater potential as a shorter-term peaking solution.

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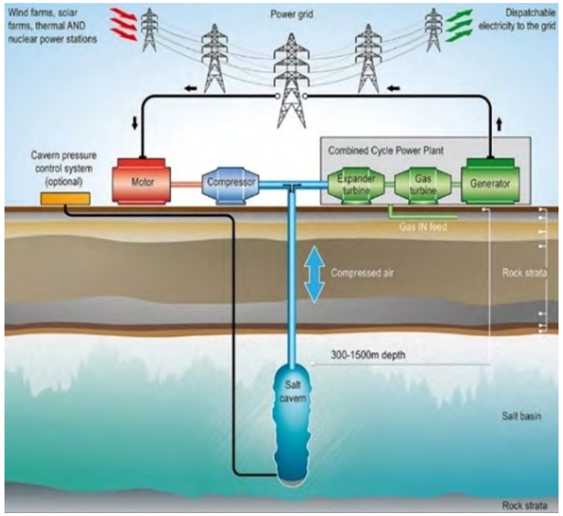
[6] Energy Vault is an example of a commercially available version of this technology – Energy Vault - Enabling a Renewable World™

Option 11: Renewable Compressed Air Energy Storage (CAES)

Description: Renewable CAES uses electricity to pump air, compressing it in the process, into a suitable underground formation that acts like a large storage tank. Releasing the pressurised air will allow the plant to re-generate electricity when needed. Overseas, this technology typically uses salt caverns as storage tanks, which are ideal because they are naturally airtight. An alternative to natural caverns is to build custom caves or containers, but at scale to be economic for long-term storage.

CAES was considered as part of a feasibility study conducted by WSP on non-hydro storage technologies.

Figure 5: CAES diagram



Case study

There are two suppliers that have developed operational CAES systems, these are:

1. **Hydrostor**[7] have developed to commercial demonstration stage a grid scale gravity energy storage system. In total, hydrostor has three projects in operation or under construction in Canada and Australia and a pipeline of 2 GW and 16 GWh of deployment potential.
2. **Storelectric**[8] have developed 20MW to multi-GWh CAES solutions that provide four hours to multi-day storage.

Assessment:

Criteria	Description
Mitigating dry year risk	The security of supply adequacy of a CAES system is directly related to the amount of energy that can be stored as retrievable compressed air (volume * pressure). CAES technology can theoretically scale to the level of the dry year problem. However, it is not suitable for long-term storage. This is because expanding air cools and must be heated before passing through the turbine to create electricity. Some existing CAES systems re-use the stored heat from compression (adiabatic), but this is not practical to do over months or years. Other systems use an external heat source (i.e., natural gas). However, this approach would require between 1.2 – 1.6 TWh of thermal energy to generate 1 TWh of electricity. If a renewable heat source of this scale were developed, it could more easily be used directly to generate electricity for dry year security.
Renewable	Renewable energy could be used to compress the air in a CAES system. While existing CAES systems use natural gas as an external heat source, this could theoretically be provided by biomass or hydrogen.

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[7] https://www.hydrostor.ca/projects/

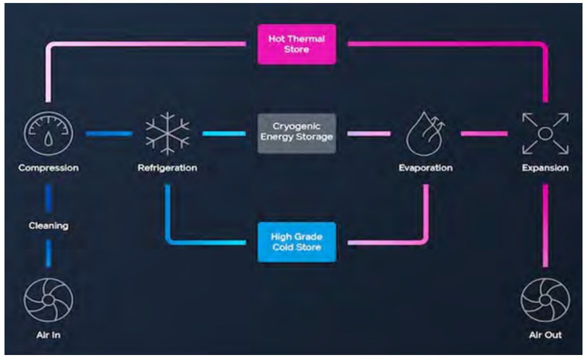
[8] Storelectric CAES Technologies - How Green CAES Works

Practical	**Viability:** Traditional CAES has not been developed at a scale close to 1 TWh. Additionally, an on-site renewable heat source able to produce enough heat to make a 1 TWh CAES plant viable would involve significant development and would likely be better used directly to generate renewable electricity. Furthermore, an inert cavern would be required to store the compressed air. Compressed air storage in depleted oil and gas facilities, such as Ahuroa, could create a potential explosion risk and environmental contamination risk . New Zealand does not have salt caverns as have been used in CAES systems elsewhere. It is not likely to be feasible to find an inert cavern (or caverns) with the structural competence and of the size required for a large-scale CAES system in New Zealand. **Feedstock:** N/A **Constructability**: A D-CAES system of the size required to store 1 TWh is significantly larger than anything built or known to be planned. Identifying and developing a suitable inert cavern is not feasible by 2035. Constructing a suitable man-made cavern is estimated to cost around $20b. **Acceptability:** Given CAES could theoretically be dispersed, the environmental, cultural and local impact may be able to be minimised to an acceptable level.
Outcome:	This option has not been short listed as it is not practical for large-scale, long-term energy storage, and it is unlikely that a viable cavern could be identified and developed in New Zealand in the timeframe.

Option 12: Liquid air storage

Description: This option stores air cooled to its liquid state in insulated, low pressure vessels. This requires cooling air to -196°C. When this liquid air is exposed to ambient temperatures it causes rapid re-gasification and a 700-fold expansion in volume. This is then used to drive a turbine and generate electricity. This is shown visually on the right. Liquid air storage was considered as part of a feasibility study conducted by WSP on non-hydro storage technologies.

Figure 6: Liquid air storage diagram



Case Study
Highview Power: Highview power have developed cryogenic energy storage, with operational plants up to 50 MW and 400 MWh. These plants can provide storage from 4 hours to 4 weeks.[9]

Assessment:

Criteria	Description
Mitigating dry year risk	Liquid air storage is not suited for large-scale, long-term storage. Liquid storage systems at this scale do not currently exist and are unlikely to be developed given the cost of energy storage at the scale required. Like adiabatic CAES systems (above), liquid air systems rely on the stored heat from the liquefaction process to be used to re-heat the stored air before passing through a turbine to generate electricity. This technology is hence suited to storing energy for periods of days or weeks, not months or years as required to provide dry year security. There would also be material losses from the cryogenic storage tanks over time, requiring ongoing top-up.
Renewable	Air can be cooled, compressed and re-gassified using renewable energy.
Practical	**Viability:** The current technology is promising for short-term storage (hours, days, weeks) but, due to the number of insulated low-pressure vessels required and the cost of keeping these chilled for extended periods, it is expected to be prohibitively expensive for long-term storage. **Feedstock:** N/A **Constructability:** A simple calculation dividing 1 TWhr by the storage capacity of existing commercial options suggest the scale required to achieve security of supply is unlikely to be feasible from a constructability perspective. **Acceptability:** Given storage could theoretically be dispersed, the environmental, cultural and local impact may be able to be minimised to an acceptable level.
Outcome:	This option has not been short listed as the technology is not suitable for large-scale, long-term storage as required to solve the dry year problem. There are also concerns around the viability of the tech from a constructability and cost perspective.

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[9] https://highviewpower.com/technology/

Option 13: Flow battery storage

Description: Flow battery energy storage is the storage of electrical energy using a type of chemical / electrolyte battery. Electrical current is stored and produced by pumping two chemical components (dissolved in liquids) through the system on separate sides of a specialised ion selecting membrane. Flow batteries can maintain their power / capacity for long periods. Flow battery storage was considered as part of a feasibility study conducted by WSP on non-hydro storage technologies.

Assessment:

Criteria	Description
Mitigating dry year risk	Flow batteries of the size to meet the 1 TWh threshold required for security of supply do not currently exist. Existing flow batteries are small in the context of the NZ Battery Project (e.g., well below <1 GWh). However, in theory they could be scaled in several different manners to meet the threshold. Flow batteries maintain charge for long periods, so could be used for long-term storage.
Renewable	The chemical reaction that allows for the creation of electrical current can be reversed using renewably generated electricity.
Practical	**Viability:** Flow batteries are only commercially viable at small scale at present. Vanadium redox flow batteries are the most advanced flow battery technology, though other technologies are progressing. However, costs remain high – estimated at over $12b for 1 TWh of storage capacity. **Feedstock:** N/A **Constructability:** The energy density of the storage in flow batteries necessitates significant scale to store the amount of electricity required to meet security of supply thresholds. Vanadium is a rare element, and sourcing enough to meet the NZ Battery Scale would be a significant barrier to development. **Acceptability:** Given storage could theoretically be dispersed, the environmental, cultural and local impact may be able to be minimised to an acceptable level.
Outcome:	This option has not been short listed. While it could potentially be scaled to a size that could support dry year security, there are concerns around the viability of the tech from a scale, and constructability perspective, and costs are high relative to other options.

Option 14: Electric battery storage

Description: This option uses lithium-ion or comparable technology for inter-seasonal and inter-year storage, for example, a very large grid connected battery / ies.

Case Study - Hornsdale power reserve: Australia led the world with the development of the 100MW / 129 MWh Hornsdale battery in 2017.[10] This was then expanded In September 2021 with an additional 50MW capacity – total construction cost AUD$172m. Since installation, the Hornsdale battery is estimated to have saved customers more than AUD$150m.

Figure 7: Hornsdale power reserve

Assessment:

Criteria	Description
Mitigating dry year risk	1 TWh of storage is theoretically possible – though this would require a battery several thousand times larger than the Hornsdale battery. Batteries are high-capacity low-energy storage systems suited to applications where they are cycled frequently, such as day/night load shifting. Further, lithium-ion batteries lose storage over time, so electricity would not be able to be stored for long enough intervals to meet inter-seasonal storage requirements / be operated in prolonged dry, calm and cloudy conditions.
Renewable	The chemical reaction that allows for the storage of energy can be reversed using renewably generated electricity.
Practical	**Viability:** Lithium-Ion battery technology at the size to meet dry year thresholds does not exist, but smaller batteries could in theory be scaled to meet these thresholds. However, lithium-ion battery storage is expensive even when significant cost reductions in batteries are assumed[11]. It is estimated that the Hornstone battery cost AUD$170m to construct. At a size several thousand times the Hornstone battery, a battery solution to meet dry year requirements would cost hundreds of billions of dollars. **Feedstock:** N/A **Constructability:** A simple calculation dividing 1 TWh by the storage capacity of the largest existing commercial battery suggests the scale required to achieve security of supply is unlikely to be feasible from a constructability perspective. Further, there are concerns with capacity degradation over time. **Acceptability:** Given storage could theoretically be dispersed, the environmental, cultural and local impact may be able to be minimised to an acceptable level.
Outcome:	This option has not been short listed as there are concerns around the viability of the tech from a scale, storage time, and cost perspective. However, lithium-ion batteries are expected to form a key element of New Zealand's electricity sector to help to firm small and community

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[10] https://hornsdalepowerreserve.com.au/

[11] *Accelerated Electrification Report,* Interim Climate Change Commission, 2019.

	scale renewable projects. As a result, lithium-ion batteries form an important inclusion for the system in the counterfactual, and all battery options tested in the MCA.

Option 15: Flywheel storage

Description: Flywheels can store kinetic energy as rotating mass. They are very short-duration systems, with even shorter planned discharge times than lithium-ion batteries, measured in minutes rather than hours.

These systems work by rotating a mass within a sealed vacuum chamber at up to 16,000 rpm. A flywheel diagram of a vacuum chamber is included on the right.

Figure 8: Flywheel vacuum chamber

Case Study – Beacon power: Beacon power have developed an operational plant in Pennsylvania and has another plant planned for New York. Both plants have a storage capacity of ~20MW[12].

Assessment:

Criteria	Description
Mitigating dry year risk	1 TWh of storage is theoretically possible. However, flywheels are high-capacity low-energy storage systems suited to applications where they are cycled frequently, such as system frequency regulation. They cannot store electricity at scale for long enough intervals to meet inter-seasonal storage requirements or be operated in dry, calm and cloudy conditions.
Renewable	Flywheels can be rotated with renewable energy.
Practical	**Viability:** The technology has not been proven for this kind of application or at the scale required. **Feedstock:** N/A **Constructability:** A simple calculation dividing 1 TWh by the storage capacity of the largest existing commercial site suggests the scale required to achieve security of supply is unlikely to be feasible from a constructability perspective. **Acceptability:** Given storage could theoretically be dispersed, the environmental, cultural and local impact may be able to be minimised to an acceptable level.
Outcome:	This option has not been short listed as the technology is not able to be operated in a manner that stores electricity for a long enough time to be able to meet security of supply thresholds, and is unlikely to be constructable.

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[12] https://beaconpower.com/carbon-fiber-flywheels/

Group 4: Build or modify electricity generation

The following five options explore approaches that increase or modify existing electricity generation technology.

Option 16: Baseload or inflexible generation

Description: This option describes the build out of additional baseload generation such that there is excess generation to fill the dry year gap. The consideration here covers both geothermal generation and nuclear energy.

Assessment:

Criteria	Description
Mitigating dry year risk	Building out baseload generation could mitigate dry year risk. However, New Zealand's geothermal resource is limited. There are insufficient traditional geothermal generation development options to maintain an overbuild in the long-term - wind and solar generation would be required to maintain overbuild, which is considered under option 17. There are other geothermal technologies that do not require an aquifer, which may expand the potential, but these are in the very early stages of technology development. Nuclear generation could potentially be built such that there is sufficient generation to meet demand in dry years. Overbuilding baseload generation would result in substantial spill in normal and wet years.
Renewable	Geothermal is a renewable resource if it is properly designed, though traditional geothermal does have associated carbon emissions. Nuclear fuels are not strictly renewable, as the uranium isotopes used are finite resources, and there are significant waste-disposal issues. However, power stations use a small amount of fuel,
Practical	**Viability:** Geothermal and nuclear energy are baseload generation technologies that are mature. Geothermal already exists at scale in New Zealand and we have considerable experience with this technology. Developments in nuclear generation are improving its safety and reducing its efficient scale and cost, making them more attractive in countries that are already familiar with nuclear power generation. However, New Zealand does not have any experience or capabilities in nuclear generation, nor in disposal of high-level radioactive waste. International treaties prohibit export of the waste overseas. Developing arrangements for domestic disposal is likely to be a significant barrier to its use here. Similar considerations in the UK have been protracted, and are expected to cost tens of billions of dollars.[13] **Feedstock:** There is insufficient geothermal resource for this option. New Zealand does not have any existing feedstock of nuclear fuel, though this could be imported. **Constructability:** There is not enough information to determine whether this is constructable within the timeframes.

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[13] https://www.theguardian.com/environment/2022/sep/23/uk-nuclear-waste-cleanup-decommissioning-power-stations

🟥	**Acceptability:** As significant geothermal generation already exists it is assumed further build out would be acceptable. Nuclear power is prohibited by legislation and is unlikely to be considered acceptable by large portions of the New Zealand public. Disposing of nuclear waste would be a significant social and environmental issue to navigate.
Outcome:	This option has not been shortlisted. The further development of New Zealand’s limited geothermal resource is anticipated under any scenario. Holding it in reserve is considered under option 20. The NZ Battery project has treated the development of other nuclear generation to mitigate dry year risk, and the associated waste disposal facilities, to be socially, and environmentally prohibitive.

Option 17: Intermittent renewable generation

Description: This describes the build out of renewables (predominately solar and wind) to produce sufficient capacity to dry year risk such that no inter-year storage is required. This will likely include both large-scale projects by commercial providers but also small individual and community scale projects (distributed energy resources). Practically this will mean the production of excess energy in normal years, which would be designed to be spilled (or monetised).

Assessment:

Criteria	Description
Mitigating dry year risk	There is, in principle, no physical limit to the amount of new renewable generation that the market could deliver over time. Roaring 40s[14] identified three possible offshore wind farm sites off the west coast of the North Island, near Auckland, Waikato and south Taranaki. These three offshore wind farms total 8,000 MW. This would be more than sufficient to meet dry year risk requirements, assuming an overbuild is maintained.
Renewable	This option is focussed on the development of renewable generation.
Practical	**Viability:** Renewable generation technology is mature. However, this option will likely require a level of uneconomic build out that the market would not provide without incentive. Given, renewable overbuild would lead to significant amounts of spilled generation, and hence long periods of cheap electricity, it is likely that users would step into the market to capture this excess energy. This would erode the ability to use it for security of supply. As a result, this option is unlikely to end up providing the prolonged dry, calm, cloudy period security of supply sought, unless the new demand to use up the spilled energy is: • Pre-contracted to reduce in prolonged dry, calm, cloudy periods, or • Highly flexible and responsive to – and exposed to – electricity spot prices. **Feedstock:** N/A **Constructability**: The scale of renewable overbuild required to meet security of supply requirements may out-strip current construction and vendor capacity – however development could be phased over time. **Acceptability:** This option is likely to be acceptable, given existing consenting frameworks. However, consenting and reduced social license could present barriers to uptake in the extreme.

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[14] www.mbie.govt.nz/assets/wind-generation-stack-update.pdf Distributed Energy Resources - Understanding the potential - main report - final_0.pdf (transpower.co.nz)

Outcome:	This option has been short-listed for a NZ Battery solution, however it forms a key part of the counterfactual for this IBC and is considered as a necessary background for all other options. This option is generally considered to be the likely course of action should 2030 renewable electricity generation targets be imposed but no NZ Battery intervention made.

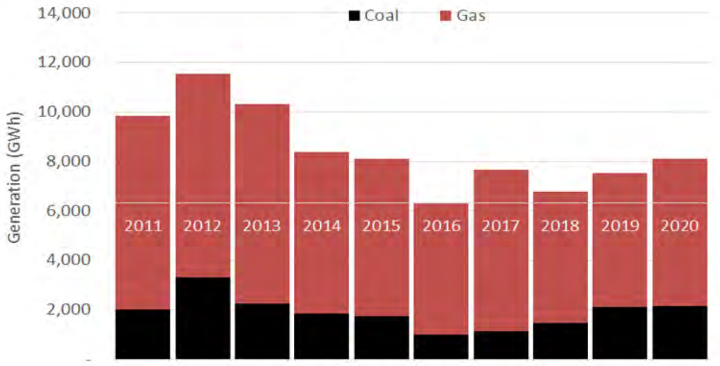
Option 18: Fossil fuel generation without Carbon Capture and Storage (CCS)

Description: Oil, gas and coal are used flexibly in New Zealand to meet baseload, backup and peaking electricity generation requirements – this includes the management of dry year risk.

Generation from fossil fuels makes up around a quarter of New Zealand's electricity generation[15]. Over the previous decade, thermal generation has provided New Zealand with between 6 and 12 TWh of generation.

This option represents the use of gas or coal to meet back-up and peaking generation requirements in dry years. It is expected that fossil fuel generation could be met with flexible contracts (either domestically and internationally) as well as stockpiles.

Figure 9: Thermal generation figures (NZ 2011 - 2020)



Assessment:

Criteria	Description
Mitigating dry year risk	Gas and coal generation is used successfully to cover dry year risk. All else being equal, a continuation of the status quo would manage dry year risk adequately, assuming supply can be maintained.
Renewable	Gas and coal are not renewable sources of generation – both gas and coal have limited total availability.
Practical	**Viability:** The technology required to meet dry year risk currently exists at scale in New Zealand and globally already. **Feedstock:** Gas or coal for electricity generation could be expected to be provided for by global or local markets. **Constructability**: New Zealand's thermal generation fleet is aging. Where this option is used to manage dry year risk in future, some additional investment is expected to be needed to replace old fleet (Huntly). However, given the maturity and abundance of the technology, there are no concerns over the ability to procure and construct this. **Acceptability:** The continued use of fossil fuels for electricity generation may become unacceptable in future years. Additionally, where international sources of gas and coal are relied upon, this may also be unacceptable from an energy security perspective.
Outcome:	This option has not been shortlisted as it is a not a source of renewable electricity generation, and hence does not meet the objectives of NZ Battery Project.

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[15] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

Option 19: Fossil fuel generation with CCS

Description: This option uses the carbon capture and storage process which removes carbon dioxide from waste gases produced in large-scale industrial processes, transporting it (via pipelines) to a reservoir (deep underground) where it is injected into porous rock. This could, in theory, be applied to gas and coal generation here.

The Productivity Commission has concluded that CCS is a rapidly evolving and potentially significant mitigation technology, which could be well-suited to large-scale, single-source emitters, but when and whether CCS will be viable in New Zealand remains unclear. There are also significant regulatory hurdles that will need to be solved to allow the use of CCS on a scale large enough to capture and sequester the carbon emitted from fossil fuel powered electricity generation[16].

Assessment:

Criteria	Description
Mitigating dry year risk	Gas and coal generation is used successfully to cover dry year risk. All else being equal, a continuation of the status quo would manage dry year risk adequately, assuming supply can be maintained.
Renewable	Burning fossil fuels for electricity generation is not renewable as it is finite both in fuel (gas or coal) and in capture volumes (reservoirs). CCS can reportedly be around 95% effective at capturing CO2–e produced, which could push CCS emissions rates down to the level of our lower-emission geothermal plant.
Practical	**Viability:** The technology for effective CCS exists and is in use overseas. Carbon capture technology has been used in NZ to recover and inject CO2 to enhance fossil fuel recovery. There has not yet been a detailed analysis of the viability of CCS use in NZ or been any significant investment in CCS technology for capture and storage. **Feedstock:** Gas for electricity generation could be expected to be provided for by either global or local markets. **Constructability:** New Zealand's thermal generation fleet is aging. Where this option is used to manage dry year risk in future, some additional investment is expected to be needed to replace old fleet (Huntly). However, given the maturity and abundance of the technology, there are no concerns over the ability to procure and construct this. **Acceptability:** The continued use of fossil fuels for electricity generation may become unacceptable in future years. Additionally, where international sources of gas are relied upon, this may also be unacceptable from an energy security perspective.
Outcome:	This option has not been shortlisted as it is a not a source of renewable electricity generation, and hence does not meet the objectives of NZ Battery Project..

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[16] University-of-Waikato-CCS-Report-2013-web.pdf

Option 20: Flexible geothermal generation

Description: Geothermal generation describes the use of super-heated water from underground aquifers to generate electricity. Geothermal is currently used in New Zealand to provide around 7.8TWh of baseload generation each year (there is currently over 1,000 MW of plants across ~20 sites)[17].

This option would require the build out of 400MW of additional geothermal generation to be operated in a flexible manner. These plants would be similar to standard geothermal plants but would be run in a reduced capacity mode in normal years (to maintain the operability of the steam-field) and at an increased output mode in dry years to meet dry year electricity demand.

Desktop feasibility studies: WSP was contracted to investigate the feasibility of this option. Its May 2022 report identified it as prospective and worth further investigation, which was undertaken and described in its subsequent October 2022 report.[18]

Assessment:

Criteria	Description
Mitigating dry year risk	Feasibility studies performed by WSP have indicated that this option is feasible. WSP's October report determined that flexible geothermal could generate enough electricity to provide 0.6TWh of flexible supply over three months. While this is strictly below the threshold for this criterion, it is able to provide reliable energy over a more extended period – up to 2.4TWh over a year.
Renewable	Using geothermal heat to produce electricity is renewable.
Practical	**Viability:** Existing geothermal technology could be used in a flexible manner with incorporation of additional design and operating procedures. **Feedstock:** The 0.6TWh of flexible supply over three months was determined with consideration of the geothermal resources that may be available. **Constructability:** As existing geothermal technology can be used with incorporation of additional design and operating procedures – it is assumed that this option is constructable. The 0.6 TWh of flexible supply over three months was determined with consideration of what is likely constructible within the timeframe. **Acceptability:** Flexible geothermal plants are unlikely to be significantly different in appearance or scale to current geothermal plants in New Zealand. It is assumed that consenting and acceptability criteria are able to be met. Further, there is a strong history of partnership with mana whenua for geothermal projects. However, there may be a degree of opposition for some fields or where the number of plants required is significant.
Outcome:	This option has been shortlisted as a partial solution.

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[17] NZ Battery *Project Other Technologies Feasibility Study Options Analysis Report,* WSP, 23 May 2022.

[18] NZ Battery Project, Other Technologies Feasibility Study, WSP, 30 September 2022.

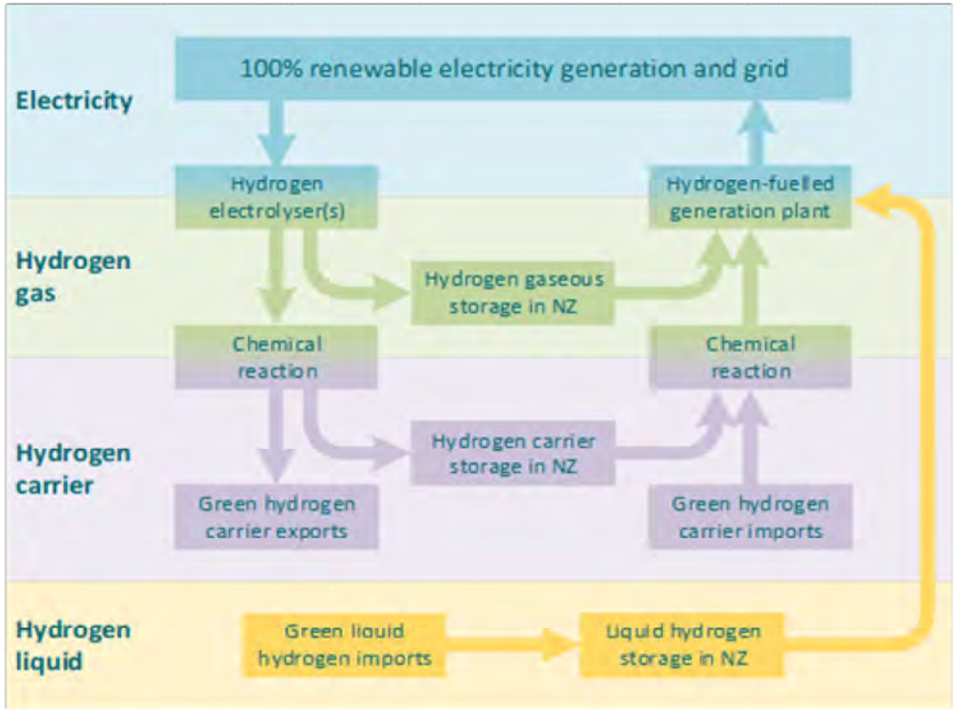
Group 5: Green energy vector (e.g., hydrogen)

Description: Hydrogen in the NZ battery context describes the use of hydrogen or a hydrogen carrier (ammonia) in a combustion turbine to produce electricity. A hydrogen solution has significant inbuilt flexibility as it can be produced domestically or imported, stored, used to generate electricity, used elsewhere in the economy, or exported. Depending on the commercial structure, where hydrogen is produced domestically it may also be interruptible, this would allow a hydrogen solution to also act as a source of load reduction in periods of high electricity demand.

This section covers three different approaches to the use of hydrogen to power electricity generation in prolonged dry, calm, cloudy periods. These are:

1. **Option 21: H_2 production with gaseous storage.** This option is the domestic production and storage of hydrogen in gaseous form at ambient temperatures in underground reservoirs or tanks (e.g. Ahuroa – by converting the Ahuroa gas storage facility to store hydrogen). This option would work similarly to other battery options by producing and storing hydrogen from electricity when electricity is abundant and prices are low, and turning off and / or using the stored hydrogen to generate electricity when electricity is scarce.
2. **Option 22: H_2 production with carrier storage.** This option is the same as option 1 above. However, hydrogen produced would be stored as green ammonia in large storage tanks, or another chemical carrier. This could include synthetic methane, which could be stored underground.
3. **Option 23: H_2 import with buffer storage.** This option describes an option where hydrogen is imported from an international hydrogen market for use in domestic energy production.

Figure 10: Hydrogen operation diagram



Desktop feasibility studies: WSP was contracted to investigate the feasibility of the three separate hydrogen options. Its May 2022 report identified hydrogen with ammonia carrier storage as prospective and worth further investigation, which was undertaken and described in its subsequent October 2022 report.[19]

Assessment:

Criteria	Description
Mitigating dry year risk	It is expected that a hydrogen solution that both produces hydrogen as a fuel for a combustion turbine and turns off electrolysers in dry years could produce around 0.8 TWh over three months[20]. While this is strictly below the threshold for this criterion, it could provide reliable energy over a more extended period, and there may be ways to refine the concept further. There is a nascent international market for green ammonia , but it is not yet clear that it will exist on a scale to support dry year risk management.
Renewable	It is expected that hydrogen/ammonia will be able to be produced by utilising excess renewable generation, or that an international market for green hydrogen could develop.
Practical	**Viability:** Electrolysis of hydrogen is mature and scalable, and the subject of considerable investment interest globally. Conventional natural gas fed ammonia synthesis technology (non-carbon free) and ammonia storage, handling and transport infrastructure is very mature, having been at commercial scale for several decades[21]. Small-scale deployments of green ammonia synthesis integrated with renewable energy fed electrolysis exist presently, with synthesis technology vendors focused on offering large-scale solutions[22]. While the technology for ammonia cracking does not currently have high maturity or scale, it is expected to have reached required maturity levels by 2030, especially given the focus amongst the global supply chain on ammonia as an energy vector. As international markets for green ammonia are still to develop at scale, the ability to export it and interrupt production for prolonged periods in a dry year are key uncertainties of this option – noting practical limits to the quantity of ammonia that can likely be stored, and that it will not be known whether hydrogen can be stored in underground reservoirs in New Zealand until 2040 or beyond. Development of a domestic market for green hydrogen/ammonia, and the ability to interrupt supply to it in dry years is similarly uncertain. **Feedstock:** It is anticipated that enough renewable electricity could be developed to support hydrogen production at sufficient scale for a hydrogen solution. **Constructability:** Constructability of the preferred hydrogen option is assumed to pass as the feasibility report did not highlight any fatal flaws. However, there may be constraints in accessing equipment, as demand is likely to exceed supply in the near term. **Acceptability:** The ability to stockpile large scale ammonia storage is likely to face significant consenting challenges due to the health and safety implications. A more distributed storage solution could help to manage these challenges, though an import/export model preferences a single port site.
Outcome:	**Outcome:** An option utilising domestic hydrogen production with carrier storage has been shortlisted as a partial NZ Battery solution, though uncertainties remain as to its viability on this scale while the relevant markets are still developing.

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[20] NZ Battery Project, Other Technologies Feasibility Study, WSP, 30 September 2022.

[21] Ibid.

[22] https://www.ir.plugpower.com/press-releases/news-details/2022/Plug-Selected-by-New-Fortress-Energy-for-120-MW-Green-Hydrogen-Plant-on-Gulf-Coast/default.aspx

Group 6: Bioenergy

Description: Four approaches are considered here for biofuel systems that can support flexible bio-fuelled generation for prolonged dry, calm, cloudy period security of supply. These are:

1. **Option 24: Biomass production and storage.** This option is the production, store, and use of wood chips or torrefied wood pellets in a combustion turbine. The biomass production process requires up-front processing of wood chip to make the wood lighter and more energy intensive.
2. **Option 25: Biogas production and storage**. This option uses biogas e.g., methane produced from organic materials, which could be stored in gaseous form in underground reservoirs (e.g., Ahuroa). The methane is then used to power a combustion turbine to generate electricity.
3. **Option 26: Liquid biofuel production & storage.** This option would involve development of domestic ‘drop-in’ biofuels for use in power systems. Such a fuel could be used in a liquid-fuel generation plant, an example of which is the existing Whirinaki 155MW diesel plant.
4. **Option 27: Biofuels import with buffer storage.** This option is the importation and storage of biomass, biogas or liquid biofuels for use in a combustion turbine.

Desktop feasibility studies: WSP was contracted to investigate the feasibility of the four bioenergy options[23]. Its May 2022 report suggested that biomass production and storage is the most feasible option (however, it was suggested that the feasibility of biofuel production should be considered further). Biogas and the production and importation of biofuels have been discounted on the following basis:

- **Biogas – Insufficient scale:** Based on available NZ Bioenergy Association information, the biogas from landfills is considered the largest source of biogas. However, total energy generation available from landfill gas is insufficient to meet the scale of the NZ Battery project.
- **Biofuel production – technology maturity:** The technology to produce ethanol from biomass has the lowest technological maturity of the bioenergy pathways, resulting in high technical risk. It is unclear that the conversion process could meet the required technology maturity levels within project timeframes.
- **Biofuel importation – fuel security:** As a standalone option the importation of bioenergy is not recommended, largely due to the security of supply risk from the international markets, especially when faced with an unpredictable demand profile[24].

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[23] NZ *Battery Project Other Technologies Feasibility Study Options Analysis Report,* WSP, 23 May 2022.

[24] Ibid.

Case study
Drax power station is the conversion of a large coal plant to run on renewable biomass imported from the US. Drax is the UK's largest renewable power station generating 4 GW and 14 TWh pa (biomass capacity 2.6 GW) [25]. Short-term biomass for operation is stored on-site in large domes.

Assessment:

Criteria	Description
Mitigating dry year risk	Feasibility studies undertaken by WSP have indicated that Biomass in the form of NZ's sustainably managed exotic forests could provide 1 TWh of storage and generation over three months. Potentially up to 4 TWh could be considered if sufficient certainty of supply could be secured through commercially suitable arrangements[26].
Renewable	Although not emissions free, biomass is a renewable feedstock and if complemented by a planned planting operation is carbon neutral over time. The supply chain required to bring biomass to source will likely pose renewable energy challenges (given the reliance of fossil fuel powered log trucks). It is estimated (using a 100km collection radius to a biomass generation plant) that 45 log truck movements a day would be required to maintain a 1 TWh biomass stockpile.
Practical	**Viability:** Mature technology options exist to burn biomass and generate the dry year energy needs and is proven across several reference projects (e.g., Drax power plant). Mature technology is also available to achieve both harvest and processing of fuel and good practices for minimisation of forest residues. The use of solid biomass from pine logs as a combustion fuel within a Rankine cycle power generation technology therefore offers a high level of technological maturity across the full technology pathway. However, the length of time that wood can be stored for has some uncertainty that would need to be resolved or managed. **Feedstock:** Using sustainably-managed pine forests in New Zealand, WSP estimate that cover against dry year risk would require repurposing 4% of New Zealand's total annual export log volumes. However, this resource would require negotiation, and may compete against more economic uses for biomass, which may mean that there is not adequate supply in practice. **Constructability:** Constructability of the biomass option is assumed to pass as the feasibility report did not highlight any fatal flaws. **Acceptability:** Where biomass makes use of an existing wood source it is expected to meet acceptability requirements. Further, the expected increased use of biomass may have significant employment benefits. However, there has been some concern internationally over the sustainability of using logs for energy purposes.
Outcome:	A biomass option has been shortlisted as a partial NZ Battery solution.

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[25] https://www.drax.com/?asset=drax-power-station

[26] NZ Battery Project, Other Technologies Feasibility Study, WSP, 30 September 2022.

Group 7: Import renewably sourced electricity

Option 28: Connecting to Australia's electricity grid

Description: This option would connect NZ into Australia's power system to manage dry year risk. This is common intra-state and internationally[27]. In theory, there could be an HVDC connection across the Tasman Sea with the Australian national electricity market. Electrically, HVDC links are controllable so this approach would not require common system operation but would require the HVDC link to (in effect) be part of the Australian system as a purchaser of power (and could be a seller too).

Assessment:

Criteria	Description
Mitigating dry year risk	This could theoretically provide enough energy to meet dry year requirements. However, energy adequacy would rely on there being many TWh of excess energy in the Australian system during prolonged dry, calm, cloudy periods in New Zealand.
Renewable	Australian electricity generation relies heavily on coal. While there are significant new renewable generation projects under consideration in Australia, and huge solar potential, it is not expected that Australia will have a 100% renewable electricity generation in the timescales considered. Developing specific renewable generation in Australia would appear to have little advantage over developing that same generation domestically.
Practical	**Viability:** HVDC technology is mature. **Feedstock:** Although theoretically possible, we note that Australia is currently struggling with its own security of supply challenges due to expedited coal generation retirement.[28] **Constructable:** A DC link between New Zealand and Australia is unlikely to be constructable and maintainable. There is no DC link of such a scale in the world and currently no vessel capable of physically laying and supporting such a cable connection - embarking enough cable for a single run across the 2,400 km stretch, or having the capability to effect or make a repair joint in waters of the depth seen in the Tasman Sea, which reaches 5 km in parts. At such depths, the effect of hydrostatic pressure on the cable and the ability to raise it again if repairs are required is uncertain. The deepest DC cable in the world currently is between Sardinia and mainland Italy, at a maximum depth of 1.6 km. A DC link between UK and Morocco is being considered, which would span 3,800 km (5 x the longest existing DC link internationally), but only reach a maximum depth of 700 m – with most of the route being below 250 m. A specialty cable production

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[27] An example of this is Basslink, an HVDC connection between Tasmania and the state of Victoria Australia. www.basslink.com.au. Internationally, there are several examples in use https://en.wikipedia.org/wiki/List_of_HVDC_projects.

[28] https://www.abc.net.au/news/2022-08-31/power-supplies-in-australias-biggest-grid-to-run-short-by-2025/101389018

🟥	factory and cable-laying ship would be developed to support the project.[29] It is estimated that the cabling for that project will cost around $15 billion.[30] **Acceptability:** This option may not be acceptable from an energy security and sovereignty perspective – New Zealand's electricity system would be subject to Australian energy policy, resilience of the HVDC cable, and the demand of Australian consumers.
Outcome:	This option has not been shortlisted on the basis that this would not meet the renewable or practicality criteria.

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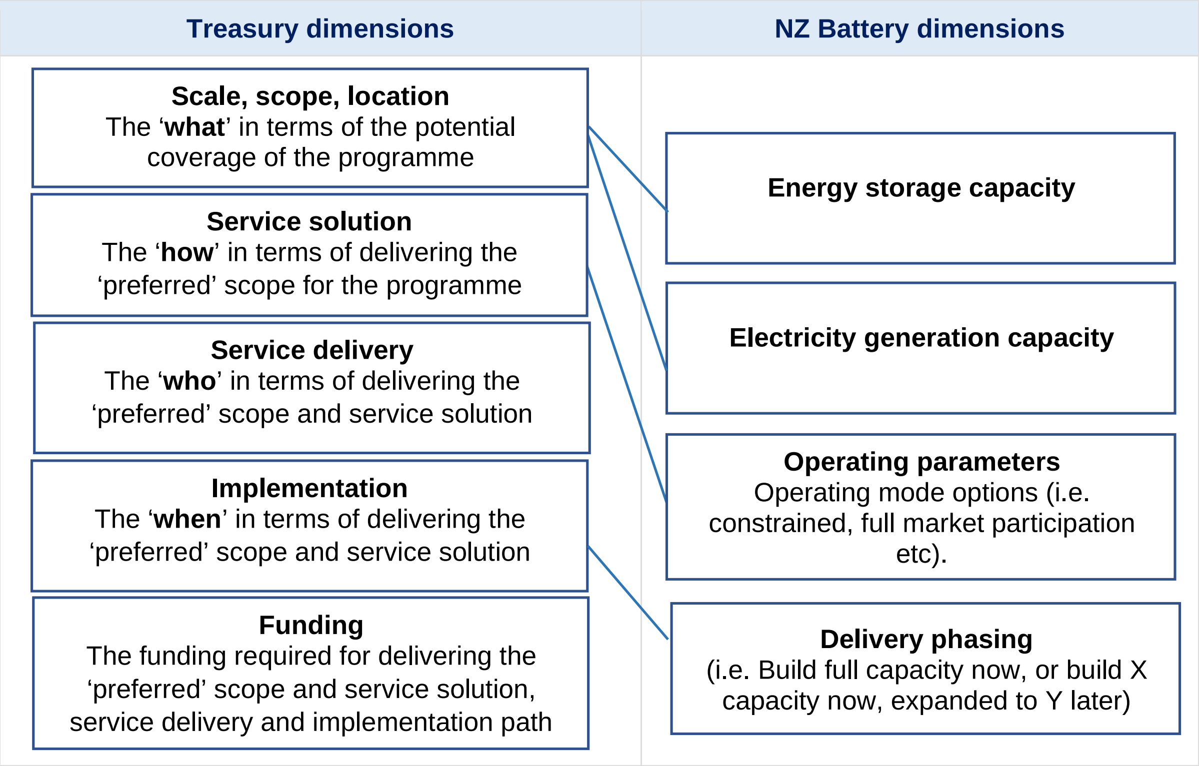
[29] https://www.power-technology.com/projects/morocco-uk-power-project-morocco/

[30] https://www.greentechmedia.com/articles/read/xlinks-revives-desertecs-dream-with-a-few-twists

Appendix D Initial Shortlist Refinement



Scale, scope, location
The '**what**' in terms of the potential coverage of the programme

Service solution
The '**how**' in terms of delivering the 'preferred' scope for the programme

Service delivery
The '**who**' in terms of delivering the 'preferred' scope and service solution

Implementation
The '**when**' in terms of delivering the 'preferred' scope and service solution

Funding
The funding required for delivering the 'preferred' scope and service solution, service delivery and implementation path

Energy storage capacity

Electricity generation capacity

Operating parameters
Operating mode options (i.e. constrained, full market participation etc).

Delivery phasing
(i.e. Build full capacity now, or build X capacity now, expanded to Y later)

Table 3: Treasury dimensions of choice as they map to NZ Battery dimensions

Scoring methodology

Functionally, each dimension of choice is assessed according to how it meets or achieves Investment Objectives. Table 4: Dimensions of choice assessment criteria provides a scale for this assessment.

Only those elements that score 'Fully meets', are used as the building blocks to create the refined shortlist options. Those elements that score 'partially meets' may be assessed as a sensitivity in further EMM undertaken, or for the benefit of the CBA.

Table 4: Dimensions of choice assessment criteria

Assessment	Description
Does not meet	A dimension that is reasonable or feasible but does not meet the stated Investment Objectives. Dimensions that do not meet Investment Objectives will **not be** carried forward for sensitivity testing.
Partially meets	An option dimension that is reasonable or feasible but only somewhat meets the stated Investment Objectives. For example, a proposed option dimension might partially meet one Investment Objective. This dimension **is not used as the base assumption** but **may be used in sensitivity testing**.
Fully meets	An option dimension that is reasonable or feasible and fully meets all three stated Investment Objectives. Dimensions that fully meet criteria will be **assumed as the base** estimate.

Scoring of the dimensions of choice for each shortlist are based off information taken from feasibility studies and EMM studies commissioned by MBIE[31].

Lake Onslow Pumped Hydro

Description

Lake Onslow, located in Central Otago in the South Island of New Zealand, was first identified as a potential site for a pumped hydro scheme in 2005, and as a potential solution to the dry year problem in 2019[32].

Energy generation and storage capacity

Te Rōpū Matatau (TRM) was commissioned to undertake a feasibility study to better understand the Lake Onslow option and its potential size and scale[33]. Among a range of other design configurations, the TRM report identified several possible energy storage and generation capacity configurations. These different available configurations form the dimensions of choice for energy generation and storage. The range of possible choices for each are outlined in Table 5 below and explored and optimised in Table 6 and Table 7 below.[34]

Table 5: Lake Onslow generation and storage dimensions of choice

Dimensions of choice	
Energy storage capacity	**Electricity generation capacity**
3 TWhrs	500 MW
5 TWhrs	750MW
7 TWhrs	**1,000 MW**
8.5 TWhrs	1,250MW
8.5 TWhrs	1,500MW

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[31] *Other Pumped Hydro and Other Hydro Options Initial Desktop Screening Study,* Stantec, March 2022

Identifying Potential Sites For Large-Scale Pumped Hydroelectric Energy Storage In New Zealand, NIWA, September 2021.

NZ Battery Project Other Technologies Feasibility Study Options Analysis Report, WSP, 23 May 2022

Concept Consulting Market Modelling outputs, Culy 2022.

NZ Battery Electricity Market Modelling Study, EY, July 2022.

[32] *Note on the pumped storage potential of the Onslow-Manorburn depression, New Zealand*. Journal of Hydrology (NZ) 44 (2): 131-135. Bardsley, W.E. (2005).

Accelerated electrification, Interim Climate Change Commission, 2019.

[33] *Feasibility Study Report NZ Battery Project Lake Onslow Pumped Storage Scheme,* Te Rōpū Matatau, 2022

[34] There are a range of other design dimensions that are not included in this dimension of choice assessment that may impact storage and generation, these include the size and design of the lower reservoir, tunnel, and tailrace configurations etc. These elements will be considered in the DBC.

Table 6: Scoring: Energy Capacity

Investment Objectives	3 TWhr	5 TWhrs	7.5 TWhrs	8.5 TWhrs
Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system	~3TWh is considered to be a minimum viable size required to cover the majority of dry year risk. All energy capacity values above ~3 TWh can be sensitivity tested.			
Put downward pressure on the total cost of electricity supply in a 100% renewable electricity system	Initial market modelling suggests that a 3TWh storage capacity provides smaller benefits than a 5TWh system. This will be confirmed via additional sensitivity testing.	Initial market modelling indicates the benefit to the electricity system is greater with a 5TWh storage capacity than a 3 TWh storage capacity. A higher benefit (all other costs equal) should place greater downward pressure on the total costs of the electricity system.	Initial market modelling suggests that there are only marginal benefits associated with storage volumes above 5TWh. Initial market modelling indicates there is only a minimal $12-$18m/yr increase in gross value from increasing storage from 5TWh to 7.5TWh and increasing capacity from 1GW to 1.25 GW.	
Accelerate emissions reduction through increased renewable share of energy	A greater energy storage capacity will provide greater certainty the dry year risk can be meet. Further, it increases the amount of load spill that the option can soak up (potentially improving wind and solar renewable generation economics – through higher GWAP) and the degree to which the operator can offer into the derivatives market (greater ability to play in the derivative market should reduce the price to hedge exposure and improve renewable generation penetration as a lower cost of hedging should improve the economics for generators to provide PPAs). However, it is not clear where size becomes less efficient from a cost to benefit perspective - this is to be determined by future sensitivity testing.			
Feasibility criteria				
Mitigating dry year risk	~3TWh is considered to be a minimum viable size required to cover the majority of dry year risk. All energy capacity values above ~3 TWh can be sensitivity tested.			
Renewable	Pumped hydro would make use of renewable generation spill to pump and store water in the upper reservoir. This would then be released to generate energy in the same way a standard hydro dam would. This process does not require fossil fuel inputs.			
Practical	It is unclear the practicality differences as a unit of energy storage size. However, all else being equal it is assumed less storage is more practical to deliver. This will need to be weighed against the benefits of greater storage.			

Table 7: Scoring: Energy Generation

Investment Objectives	500MW	750MW	1000MW	1250MW	1500 MW
Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system	500 MWs of generation is sufficient to meet dry year security of supply requirements. Early market modelling indicates that 500MWs of generation capacity significantly reduces the value of Lake Onslow.	750 MWs of generation is sufficient to meet dry year security of supply requirements. Early market modelling indicates that HVDC constraints start to impact upon the value of additional generation capacity above 750MWs. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs.	1,000 MWs of generation is sufficient to meet dry year security of supply requirements. Early market modelling has indicated that (due to HVDC constraints) the value of additional electricity generation above 750MW is modest. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs.	1,250 MWs of generation is sufficient to meet dry year security of supply requirements and is technically feasible. Early market modelling has indicated that (due to HVDC constraints) the value of additional electricity generation above 750MW is modest. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs.	1,500 MWs of generation is sufficient to meet dry year security of supply requirements and is technically feasible. Early market modelling has indicated that (due to HVDC constraints) the value of additional electricity generation above 750MW is modest. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs.
Put downward pressure on the total cost of electricity supply in a 100% renewable electricity system	Early market modelling indicates that 500MWs of generation capacity significantly reduces the value of Lake Onslow. This will Lead to a Lake Onslow configuration with lower total benefit and therefore a higher total cost to the electricity system.	Early market modelling indicates that HVDC constraints start to impact upon the value of additional generation capacity above 750MWs. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs..	Early market modelling indicates that HVDC constraints start to impact upon the value of additional generation capacity above 750MWs. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs. It is anticipated from early modelling that 1,000 MWs of generation is optimal.	Early market modelling indicates that HVDC constraints start to impact upon the value of additional generation capacity above 750MWs. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs.	Early market modelling indicates that HVDC constraints start to impact upon the value of additional generation capacity above 750MWs. Additional sensitivity testing is required to determine the value of generation capacity above 750MWs.
Accelerate emissions reduction through increased renewable share of energy	It is unclear whether there are impacts from variations in generation capacity. Greater electricity supply at one time will reduce price volatility to a point. Additional sensitivity testing is required to determine the optimal setting.				

Investment Objectives	**500MW**	**750MW**	**1000MW**	**1250MW**	**1500 MW**
Feasibility criteria					
Mitigating dry year risk	500 MWs of generation is sufficient to meet dry year security of supply requirements.	750 MWs of generation is sufficient to meet dry year security of supply requirements.	1,000 MWs of generation is sufficient to meet dry year security of supply requirements.	1,250 MWs of generation is sufficient to meet dry year security of supply requirements.	1,500 MWs of generation is sufficient to meet dry year security of supply requirements.
Renewable	Pumped hydro would make use of renewable generation spill to pump and store water in the upper reservoir. This would then be released to generate energy in the same way a standard hydro dam would. This process does not require fossil fuel inputs.				
Practical	It is unclear whether there are any practicality impacts from variations in generation capacity. All else being equal it is assumed it is less practical to build additional generation capacity.				

Delivery phasing

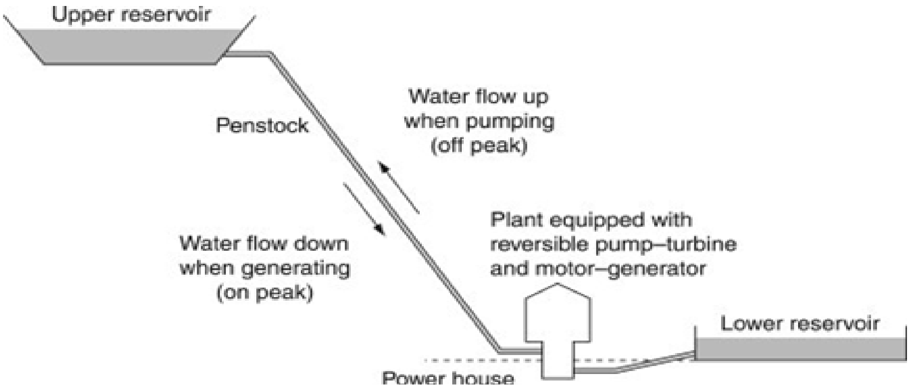
The Lake Onslow option does not have the ability to be phased.

Operating parameters

Pumped hydro solutions work in two stages. First, when electricity is abundant, electricity is drawn from the grid to pump water from a lower reservoir to an upper reservoir. Then when electricity is scarce, water is released back down to the lower reservoir through turbines to generate electricity.

In using electricity and storing it as water in the upper reservoir for future use, pumped hydro systems transfer electricity across time periods and maximise its total economic utility[35]. In conjunction with maximising the economic utility of electricity, this transfer also generates gross profit for the pumped hydro operator as electricity is purchased and stored at low prices and released and sold at high prices[36]. See Figure 11 for a high-level visualisation of how a pumped hydro system operates.

Figure 11: Pumped hydro visualisation



Unlike many energy storage options currently available, pumped hydro can store and dispatch electricity across both short and long-term horizons. For example, pumped hydro can be utilised both intra-day / intra week to capture spill and firm renewable generation as well as inter-seasonally.

As well as physically transferring electricity across time horizons, as pumped hydro systems both buy and sell in the same market, they are uniquely placed to buy and sell a range of derivative instruments. These could include the buying and selling of generalised wholesale electricity call and put options[37]. This would provide the holder the ability to sell or buy electricity to or from a pumped hydro scheme at predefined strike prices. The sale and purchase of these options would both help derive additional revenue through premiums but also would allow the pumped hydro operator to minimise risk.

As a minimum, to solve the dry year problem, it is expected that a Lake Onslow pumped hydro solution will operate in the market to firm the electricity / hydro system in dry years. However, there is a dimension of choice as to the degree to which it also operates to firm renewable generation in the short-term and trade derivative energy instruments to capture as much value as possible.

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[35] The ability to transfer electricity across time is subject to roundtrip efficiencies and storage loss (evaporation) etc.

[36] Gross profit is defined as operating revenues less operating expenses

[37] *Storage Options for the New Zealand Electricity Sector - Operational and Organisational Issues,* E Grant Read, 2022

A key consideration when assessing this dimension of choice is the market impact that a Lake Onslow pumped hydro solution would have on the wholesale electricity market, derivatives market, and investment market. Any single large-scale development will have a significant impact on both prices and physical / volume outcomes in the electricity market[38].

This is in part by design, a pumped hydro solution is intended to provide power in times of energy scarcity and in doing so will reduce wholesale prices during these periods. In addition, when pumping, Lake Onslow will also provide load that will help support a price floor in times of electricity abundance by soaking up otherwise spilled generation. In effect, where Lake Onslow can pump and generate in the market whenever economically efficient to do so, it will create a cap and collar effect on the wholesale electricity market supressing overall electricity price volatility.

Providing a cap and collar and suppressing price volatility is generally considered positive for both the electricity system and consumers for three reasons:

- It will increase the Generation Weighted Average Price (GWAP) that intermittent renewable generators (wind and solar) receive in the market (potentially incentivising the build out of additional renewable generation),
- Cap the price consumers pay in times of scarcity, and
- Ignoring capital costs of a pumped hydro system, a reduction in volatility should reduce the cost of forward price agreements for electricity and bring down the total cost of electricity for consumers to a price closer to the short run marginal cost of generation.

However, given the size and impact of a Lake Onslow solution, there will be a range of second order impacts that will need to be considered to ensure that the intended beneficial impacts outline above are not undermined. Such effects could arise where a commercial entity was allowed to control the facility in a way that advanced its own commercial interests at the expense of national interests. E.g., selling derivative instruments into the market prior to buying or selling into the market to maximise premiums or to minimise pay-outs. Where second order effects are not contained, Lake Onslow may drive market participants from the market or unduly supress investment signals.

To better understand how to structure an operating model in a way that allows Lake Onslow to operate in the market without distorting it in a way that undermines the benefits of doing so, a report on market dynamics of pumped hydro was commissioned[39]. This report identified several ways to minimise negative market impacts of Lake Onslow. Broadly these are:

1. **Virtual slicing offer model:** This describes virtually slicing storage, generation and pumping capacity of the Lake Onslow facility and auctioning them to different market participants. This effectively splits Lake Onslow into several mini pumped hydro assets to create competitive tension, distribute market power between a range of smaller ‘operators’, and introduce different incentives into the operating decisions of the asset (as each slice owner may have different considerations and uses for pumping, storing or generation depending on the portfolio of investments they hold). This operating model would allow for Lake Onslow to participate fully in the market and capture firming, hedging and dry year benefits in a way that minimises monopolised market power and potential second order effects.

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[38] Ibid.

[39] Above n 15.

2. **National benefits optimisation model**: This describes the operation of the asset by one party. However, operation would be controlled and set by a formal reservoir management model. This would be run regularly to maximise a net national benefit “objective function”, assuming the current / forecast status of the facility, and other key components of the national electricity system, forecast weather / load conditions, host system flows etc. The expected water value determined by the optimisation function would be published and held constant for some period, such as a week or month, or perhaps adjusted in some pre-announced fashion, as a function of a hydrology index. Buy / sell offers in spot / hedge markets would then be based on the announced water value. This operating model would allow for full market participation and capture of firming, hedging and dry year benefits but would be constrained to operate in the best interests of the national market.

3. **Hybrid model:** This is a combination of the above two operating models. For example, the facility could be split into separate slices, of which a portion is provided to a single operator that is using a national benefits optimisation model and the remainder is auctioned. Alternatively, a single operator could manage the pumping and storage capacity of the facility and the generation capacity could be auctioned.

4. **Rules based operation:** This is the operation of the asset according to pre-determined rules – this could include policy considerations. This option would naturally restrict the degree and frequency of Lake Onslow’s market interaction to pre-defined parameters.

Broadly, the above four options can be distilled into two separate dimensions of choice for operational parameters. These are:

- **Dimension 1: Market participation:** This is the use of Lake Onslow to operate whenever deemed economic to do so – subject to minimum security of supply operational thresholds. This will include both to solve for dry year and to solve for intermittent firming intra-day and intra-week. This also includes offering hedging options to market participants. This dimension includes the market slicing, national benefits model and hybrid operating models.

- **Dimension 2: Security of supply mode:** Under this operating mode, Lake Onslow would not necessarily operate in the market whenever economically efficient to do so. For this option we are assuming that Onslow would be restricted to its core purpose – dry year coverage. As a result, under this operating model Lake Onslow would not work to firm renewable generation in the short-term and would lay mostly idle until needed for dry year generation or in periods of high risk of supply insecurity. However, it is expected that Lake Onslow would still capture energy that might otherwise be spilled in order to fill itself.

The commercial arrangements required to facilitate the operation of each dimension is outlined briefly in the Commercial Case at section 3.2.7. The scoring of this dimension of choice is explored in Table 8 below.

Table 8: Scoring: Operating parameters (Lake Onslow)

Investment Objectives	**Full market participation**	**Security of supply mode**
Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system	This operating model will not impact upon the option's ability to provide security of supply cover in a dry year. It is a commonly held misconception that operating in a way that uses storage to meet dry year and firming requirements (as they arise) reduces the ability to meet dry year coverage. However, as a pumped hydro option can pump water whenever required, it can take advantage of periods of excess energy (within dry years) to replenish its storage. Further, where operations are based off a water value algorithm - the value of pumping water will increase with scarcity ensuring that pumping is always valued where water is scarce.	This operating mode could be calibrated using hydro risk curves that would facilitate dispatch of electricity where required during dry years.
Put downward pressure on the total cost of electricity supply in a 100% renewable electricity system	Full optimisation using a slice of system or hybrid model is expected to reduce the expected negative second order effects of full market optimisation / operation as there would be sufficient competitive tension and diversification of incentives to control market power. (preventing one commercial entity using its significant market power in a way that advanced its own commercial interests, at the expense of the national interest).The best economic use of resources, if investing in a flexible facility, will generally be to use that facility to capture all the benefits which can be captured by playing diverse market roles, over multiple time scales (Read 2022).	Initial market modelling suggests that running a Lake Onslow option under a security of supply mode will significantly reduce the value of the Lake Onslow option. It also implies that Lake Onslow will not be used to mitigate ‘calm, cloudy’ periods which further reduces security of supply in a broader sense. Such “clarity of purpose” may seem attractive, however, the best economic use of resources, if investing in a flexible facility, will generally be to use that facility to capture all the benefits which can be captured by playing diverse market roles, over multiple time scales.
Accelerate emissions reduction through increased renewable share of energy	A pumped hydro system will incentivise the build out of renewable generation in two ways: 1. The purchase of electricity within the wholesale electricity market to store / pump water where the price of electricity (and therefore the cost of pumping) is below the Expected Marginal Value of Stored Energy will have the effect of creating (in some instances) an effective price floor (and higher GWAP). 2. A large storage facility will be able to offer renewable generators with hedging instruments that allow them to provide continuous supply to buyers (allowing them to generate a higher average GWAP).	Reducing the opportunity for a pumped hydro scheme to operate in the market will both reduce the level of pumping required and the ability to offer hedging contracts to renewable generators (this will reduce the ability of the option to accelerate emissions reduction through reduced incentive to generators).
Feasibility criteria		

Investment Objectives	Full market participation	Security of supply mode
Mitigating dry year risk	Both options mitigate dry year risk.	
Renewable	Pumped hydro would make use of renewable generation spill to pump and store water in the upper reservoir. This would then be released to generate energy in the same way a standard hydro dam would. This process does not require fossil fuel inputs.	
Practical	Both options meet this requirement and are complex. A slicing , hybrid or constrained operating model would require significant regulation and oversight.	

Other Hydro: Lake Moawhango Pumped Hydro

Description

To identify alternative pumped hydro sites, NIWA was commissioned to develop a Geographic Information System (GIS) screen to identify surface water catchments in New Zealand with physical characteristics able to house a pumped hydro scheme[40]. It only considered physical criteria, ignoring all broader issues such as land use or ownership. The physical screening criteria included:

- **Size of basin:** Identified locations must be big enough to allow for a volume of water to allow for storage of at least 1 TWhr
- **Head size:** The head should be greater than 300m between upper and lower water sources
- **Distance:** Upper and lower water sources should be within 30km of each other
- **Dam length:** Maximum dam length should be less than 3km
- **Dam height:** Height is restricted to 120m.

The first scan identified 95 potential sites. Most of these sites would involve flooding protected areas (e.g., national parks), towns, or significant infrastructure (e.g., major roads and transmission). The NZ Battery team further refined the criteria and undertook deeper geographic investigation of the specific sites to avoid such obviously undesirable effects, reducing the number of potential locations to two:

1. The Upper Moawhango river in the central North Island, and
2. The Taruarau river in the central North Island.

Stantec was then commissioned to undertake a feasibility on the two possible sites identified by the GIS scan[41]. This study identified the Moawhango river site as the most feasible[42].

Unlike Lake Onslow, Moawhango is a multi-dam system. Energy storage is held in one reservoir, however generation is produced across multiple power stations within the Tongariro and Waikato power schemes.

Energy generation and storage capacity

A range of possible energy storage and generation capacity choices for Moawhango were identified. These options were largely dependent on the dam configuration and location of the intake / outlet. To determine a feasible structure, storage size, and generation capacity, Stantec followed the below process:

1. First, the dam configuration was optimised as a function of storage per unit of dam. More efficient dam sites, in terms of fill required to build the dam, will provide better storage vs dam fill volume ratios and therefore, a lower cost per volume of water stored.

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[40] Above n 7.

[41] Above n 7.

[42] Ibid.

2. The intake / outlet location was then optimised based on two factors:
    a. The size of the head between storage and generation, and
    b. The environmental impacts of releasing water at various locations.
3. Finally, as total storage and generation capacity for all options is below 3 TWh, the option that provided the largest storage and generation capacity was chosen.

The size of energy storage and electricity generation capacity considered by Stantec is 2.7TWhrs of storage and 570MW of electricity generation capacity. See visualisation of the selected configuration below.

Commercial Information

Given storage and generation capacity has been ‘maximised’, there are no dimensions of choice for this option. However, where this option is revisited in greater detail at the DBC stage, the optimal storage and generation capacity should also be revisited.

Operating parameters

Despite the inherent size differences between Lake Onslow and the Moawhango pumped hydro options, the dimensions of choice for operations are the same – as such, a scoring breakdown has not been provided.

Delivery phasing

While some components of the scheme could theoretically be phased, this has not been assessed in enough detail at this stage to determine the feasibility or impacts of phasing. Accordingly, the Moawhango option has not been assumed to be able to be phased. However, where this option is revisited in greater detail at the DBC stage, it is expected that construction phasing would be assessed and this dimension of choice should be revisited.

Portfolio option

Description

The portfolio option describes a combination of biomass, flexible geothermal, and hydrogen technologies to form an additive portfolio. Each is described in greater detail below:

- **Biomass:** This option describes the production, storage, chipping and use of woody biomass used in a combustion turbine to generate electricity.
  - **Energy storage capacity:** Feasibility studies indicate that biomass derived from domestic exotic forests can provide ~1 TWh of storage[43]. To meet this threshold a log stockpile of 1.1m tonnes is required. This stored wood degrades over time and is assumed to be replenished at a rate of 33% per year, or up to 50% following a dry year event to maintain sufficient energy storage capacity. This recharge rate is equivalent to ~4% of total annual biomass export volumes or ~1.6% of the total annual biomass harvest each year.
  - **Generation capacity:** The biomass option includes a ~500MW turbine able to dispatch in excess of 1TWh within three months.
- **Flexible geothermal:** This option describes the build out of 400MW of geothermal generation to be operated in a flexible manner[44]. A flexible geothermal plant would be similar to a standard geothermal plant but would be run in a reduced capacity mode in normal years (maintaining some operation is necessary for technical reasons) and at an increased output mode in dry years to meet electricity demand.
  - **Generation capacity:** In a reduced capacity a flexible geothermal plant is expected to produce 100MW of electricity generation and up to 400MW when fully operational. Where operating constantly at full capacity a flexible geothermal solution could provide ~0.6TWh over three months and up to 2.4TWhrs per annum if required[45].
- **Hydrogen:** The option describes the domestic production of green ammonia, with storage of sufficient ammonia to provide hydrogen to fuel a gas turbine generator and the surplus going to other domestic uses or export. Supplementation with overseas import of ammonia if required[46].
  - **Energy storage capacity:** This option recommends production and storage of green ammonia. With stored green ammonia being sufficient to produce ~ 0.3TWh of electricity.
  - **Generation capacity:** When using ammonia / hydrogen in a combustion turbine, this option could feasibly produce 150MW of electricity generation, producing up to 0.3TWh within 3 months.
  - **Load reduction:** Where hydrogen electrolysers are turned off, they are expected to provide ~229MW of load reduction (available within minutes of a request). Interrupting the hydrogen electrolysers would provide a net load benefit of 0.5TWh over three months.

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[43] Above n 7.

[44] Ibid.

[45] Ibid.

[46] Ibid.

The generation and interruption components together provide up to 0.8TWh over a three-month period. Should a longer period of dry year support be required the electrolyser interruption could be extended.

Note that large-scale load reduction is considered in the portfolio option through the hydrogen component. Given the small number of NZ consumers that can materially contribute to dry year security, it has otherwise only been considered as a sensitivity within our economic modelling.

Energy generation and storage capacity

The portfolio option includes all three technologies, using the concept designs identified through the WSP report. This combination would allow around 2.4 TWh of energy to be delivered over the course of three months, with a smaller ongoing response able to be provided where electricity deficits last longer. For example, given flexible geothermal does not rely on a finite feedstock, it could continue to be operated in a ‘ramped up’ mode for an indefinite period. In addition, a hydrogen electrolyser could remain switched off, and the biomass component could try to identify, purchase and use additional feedstock to generate electricity.

The build-up of the technologies within the portfolio option has not been optimised. There are a range of ways the three technology concept designs could be configured, scaled, or replicated. It may be that a different combination or suite of technologies presents the most net-beneficial approach to solving the dry year problem. However, the portfolio option put forward represents a base case that allows for meaningful assessment. Further work would need to be undertaken to identify an optimal approach. It is also possible that, in practice, a portfolio option would be progressed in a technology agnostic way. Further work would also need to be undertaken to confirm feasible delivery models.

Operating parameters

There are no dimensions of choice associated with operating parameters for the portfolio option. Unlike for the pumped hydro options, each component within the portfolio is assumed to be optimised to maximise its ability to generate revenue given constraints around minimum supply expectations[47].

This assumption has been made for the portfolio option because:

- The portfolio option will likely be geographically distributed
- Each option will likely operate over different timescales
- Each option will have different energy storage, use and generation profiles, and
- Each technology option could more feasibly be operated by different parties (commercial or government).

It is assumed that the above points will mean the operations of the different technology options is diversified in a way that mitigates issues of market power and investment distortion.

The optimal operation of each technology is outlined below:

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[47] For the flexible geothermal option, flexibility of generation is key to its ability to solve for dry year risk. As a result, minimum supply thresholds are expected to include restrictions on how / when the option can operate in ramped up mode.

- **Hydrogen:** The hydrogen option has significant inbuilt flexibility in the way it operates. There are two components of hydrogen that can be sequenced to potentially optimise operations:
    - Ammonia production uses hydrogen which is produced through an electricity-intensive electrolysis process. Similar to the pumped hydro options, a set of hydrogen electrolyser plants would act as a load sink within the electricity system soaking up and using electricity to produce hydrogen / ammonia where it is economically beneficial to do so. This has two sub-benefits.
        - First, the electrolysers would act to provide support for the price of wholesale electricity in times of excess production (reducing overall price volatility).
        - Second, where interruptible, electrolysers could act as a load reduction battery that could be shut off to reduce demand in the market in times of high load and energy scarcity. If operating at maximum capacity, load reduction could provide 369MWs of electricity back to the grid within minutes of a request[48].
    - Hydrogen and ammonia have been the subject of significant work internationally to electrify and decarbonise heavy industry and transport. As a result, it is expected that there will be significant international and domestic markets for hydrogen and ammonia in future. Where this eventuates, hydrogen electrolysers may be able to sell excess hydrogen or ammonia into these markets.

      The hydrogen component of the portfolio option is expected to operate in a way that best maximises the economic value to the operator. However, there may be a minimum ammonia / hydrogen storage threshold that must be maintained to ensure dry year risk is adequately covered. This may act as a physical restriction on potential use. This has relied on assumptions around the future international price of green ammonia, the willingness to pay for electricity to produce it, and the opportunity cost of using it to generate electricity.
- **Biomass:** Biomass, like current thermal generation, could be used to cover short-term peaking demands as well as provide a partial solution to solve for long-term dry year risk. It is expected that a biomass option would operate whenever economically efficient. However, given the constraints of its assumed fuel supply, and its slow start-up rate, there may be a minimum storage threshold that must be maintained to ensure dry year risk is adequately covered. This will act as a physical restriction on potential use.
- **Flexible geothermal:** Flexible geothermal is expected to operate in a turned down / baseload manner for much of its useful life and operate in a ramped-up mode in times of energy scarcity (which we have assumed to be based on water values). However, unlike the other options, flexible geothermal is anticipated to be slow to ramp up and turn on and would take around two weeks to be made fully available. As a result, flexible geothermal would only operate during longer periods of energy scarcity.

Delivery phasing

Each technology component of the portfolio solution has been designed to be procured and developed in standalone building blocks. The operability of each building block is not dependent on another. This allows the procurement and delivery of the portfolio option to be staged and phased over time. As with the make-up of the portfolio option, there are

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[48] Above n 7.

numerous ways a portfolio option could be phased to maximise the benefits of the options. These are assessed in Table 9 below:

Table 9: Scoring: Portfolio option delivery phasing

Investment Objectives	Full delivery	Phased delivery approach
Provide security of supply during a dry year that is no worse than today in a 100% renewable electricity system	Full delivery will provide the fastest delivery of benefits to the electricity system that are expected to provide dry year security of supply. Further, full delivery is helpful for comparability purposes with other options. However, both options will be expected to meet security of supply requirements over time.	Both options will be expected to meet security of supply requirements over time. Earlier deliver of this benefit is seen as beneficial.
Put downward pressure on the total cost of electricity supply in a 100% renewable electricity system	Full delivery will provide the fastest delivery of benefits to the electricity system that are expected to reduce total electricity system costs. However, delivery of all portfolio options concurrently may outstrip the ability of local and international suppliers of key elements of the portfolio. As well as the capacity of the local market to instal and build the portfolio. This may lead to price increases due to scarcity of labour etc. further, where immature technology is being used there may be first mover costs associated with delivery.	Although phased delivery will slow the realisation of electricity system benefits (expected to lead to lower total electricity system costs. Phased delivery may actually reduce the total cost of the portfolio option (thus increasing the net benefit to the electricity system. Phased delivery could reduce total portfolio construction costs in two ways: 1. it may be easy for the market to deliver from a capacity perspective. 2. it would allow greater time for some technologies to mature and reduce in cost.
Accelerate emissions reduction through increased renewable share of energy	Full delivery will provide the fastest delivery of benefits to the electricity system that are expected to improve accelerated emissions reduction through increased renewable share of renewables.	Both options will be expected to accelerate emissions reduction through increased renewable share of electricity over time. Earlier delivery of this benefit is seen as beneficial.
Feasibility criteria		
Mitigating dry year risk	Both options will meet this criteria but over different time scales.	Both options will meet this criteria but over different time scales.
Renewable	Both options meet this criteria.	Both options meet this criteria.
Practical	Delivery phasing will be dependent on the market's ability and willingness to provide the portfolio solution. Optimal phasing will require market testing and further analysis in the DBC. Despite market deliverability concerns, full delivery has been chosen as optimal in this analysis largely for comparability purposes.	
	Delivery of all portfolio options concurrently may outstrip the ability of local and international suppliers of key elements of the portfolio.	A phased delivery approach is likely more feasible as it will allow for greater time to develop the maturity of the hydrogen element of the portfolio option. In addition, it will likely be more easily delivered by the market.

Appendix E Economic Modelling assumptions

1. Scope

This ‘Assumptions book’ presents the key assumptions used in the NZ Battery project’s economic modelling, as at the cover date. It covers four areas:

- An **overview of NZ battery economic modelling**, which provides the context for and purpose of our assumptions, in section 2
- Our **inflow assumptions** for hydro, wind and solar, are critical as these drive the dry year problem, in section 3
- Our baseline **economic modelling assumptions**, covering everything other than inflows and the NZ Battery Options themselves, in four parts:
    - Common modelling assumptions in section 4
    - Demand-side assumptions in section 5
    - Supply-side generation assumption in section 6 (with accompanying long tables of generation stacks in section 14 at the end of this document)
    - Transmission assumptions in section 7
- Our **NZ Battery options** in sections 8 to 133.

This Assumptions Book focuses on what the assumptions are, rather than the rationale for them. That is for brevity and because in many cases the rationale for the assumptions have been well versed within the NZ Battery Project. In some cases however, where assumptions have been introduced or detailed recently, rationales are included.

The tables distinguish with colour between ‘raw’ assumptions and derived assumptions, e.g.

Table 10: Sample table: Base electricity demand assumptions

		2021	2035	2050	2065
Growth in Base ex NZAS	% p.a.		0.5%	0.8%	0.6%
Base excluding NZAS	TWh	37.3	40.0	45.1	49.3
		White – Raw assumptions		*Blue – Derived assumptions*	

2. Economic modelling approach

The fundamental purpose of the economic modelling is to:

- Explore whether a particular NZ Battery option could work operationally within the electricity system over timeframes of hours to years (with operation at shorter timeframes being considered, where necessary, separately through detailed power systems analysis)
- The economic benefit that an NZ Battery option could provide, relative to a counterfactual without NZ Battery. To do this, we use exactly the same assumptions for the NZ Battery run as for the counterfactual, apart of course from assuming the NZ Battery option itself in the former.
- Understand how an NZ Battery would integrate with the market and supporting work on resilience and power system integration.

To achieve these aims we engaged two mutually supporting and methodologically independent modelling efforts:

- John Culy's energy model
- Stochastic Dual Dimension Programming (SDDP) modelling

2.1 Culy modelling

The Culy model determines the most economic mix of generation in a particular study year, with an optimisation based on plant gross margins. The plant gross margin is the spot market revenue less the SRMC. The revenue is derived from the full simulation model by week and time zone averaged over inflow years. The plant gross margin is calculated for actual new plant and for a notional very small new plant where none is built yet, to determine the capacity of each plant type built. A manual iterative approach is used. This involves adding new capacity of each type (geothermal, wind, solar, batteries and green peakers) until each new plant just covers its fixed operating costs and achieves a normal return on the capital invested. This also adjusts the mix of wind/solar between regions to take advantage of supply diversity and regional marginal loss differentials. A new entry equilibrium is achieved when each type of available new technology in each region is revenue adequate.

2.2 SDDP modelling

The SDDP model is considered by many in the industry (in New Zealand and overseas) as the 'gold standard' approach to economic-based grid modelling of electricity systems with a significant hydro component.

SDDP is the name of the algorithm, but also the name of a specific model developed, maintained, supported and licenced by PSR[49], that uses that algorithm. We are using the PSR SDDP model. PSR partner the SDDP model with a generation expansion model named OptGen. For brevity, we use the term SDDP in this document to cover both the OptGen and SDDP models being used together. Transpower has developed the New Zealand version of the model over decades with PSR (and Tom Halliburton) and achieved widespread industry and Commerce Commission regulatory acceptance of its application for grid investment decisions.

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[49] www.psr-inc.com

We have engaged Brian Moore through Jacobs (initially through EY) to conduct the SDDP runs, supported by Tom Halliburton on expert review, and initially supported by Andrew Sykes of Transpower, who kindly provided a starter-set of SDDP databases, including a full transmission grid model.

The SDDP model simulates system operating costs for a given plant mix, with the objective of finding the least cost generation dispatch. Therefore SDDP takes into account only variable costs, including fuel, carbon charges, variable operation and maintenance costs, the cost of deficits and some penalty costs for the violation of operating constraints. An optimal plant mix is determined by the companion model OptGen. The objective of OptGen is to find the lowest total cost of system operation, including both variable costs and fixed costs, including capital charges and fixed operating and maintenance costs. OptGen uses an iterative search process testing various combinations of new plant to determine the optimal development program of new plant over the planning period. OptGen calculates the total fixed costs incurred for each development program, and solves the corresponding SDDP case to determine the total variable cost of that program.

2.3 Synergistic modelling approaches

Our twin modelling approaches have been deliberately chosen as mutually supporting and methodologically independent modelling efforts, each with their own advantages, and capable of providing assurance of each other’s results.

Culy’s model is much faster to run than SDDP, and so can be used to explore multiple options, for example the benefits of different combinations of storage (TWh) and capacity (MW) sizes of pumped hydro systems.

The SDDP model is much more granular and hence slower to run, so we have to target its use carefully for key scenarios, but it provides greater granularity. Importantly, as water values will be critical to how a future 100% renewable New Zealand electricity system runs, and the SDDP model calculates them using a best-practice and forward looking algorithm, we can use the SDDP model to support the water value assumptions used in Culy’s model. This is critical, as the value of stored energy to the future system with mass intermittent generation could be materially different to the value of stored energy today. The SDDP model can also determine transmission constraints and hence where, what and when transmission upgrades may be appropriate (and is used to support Transpower’s NZ Battery project power system analysis as well as the economic modelling). The SDDP model represents the operation of hydro plant in a river chain system in detail including the effect of each plant’s head pond and water travel times down the river system.

Table 11: Comparison of Culy and SDDP models as used

	Culy	SDDP
Focus	Electricity sector economic model	
Spatial resolution	Islands with regions for wind and solar, and HVDC link	To regional and substation level
Temporal resolution	Weekly with intra-week duration curves, modelled as typical days with hours resolution	Can be varied, down to hourly
Grid model	HVDC only, with losses	Full transmission network including limited security-constrained dispatch. Losses modelled on HVDC but not explicitly on HVAC
Hydro / pumped hydro dispatch	Based on assumed water values	Based on dynamically calculated water values
Prices	Cost-based assuming perfect competition	

2.4 Modelling strengths and limitations

Economic models are powerful tools in gaining insight into complex interactions and inter-relationships, especially those open to quantification and that are beyond past experience. This is very much the case here, given the possibilities of:

- Unprecedented amounts of intermittent generation
- Significant reduction in controllable thermal generation
- Large storage schemes
- Different optimal operating regimes for our hydro resource.

But in considering the outputs of such models, we need to bear in mind some limitations.

Both models assume, in effect:

- Perfect competition
- Perfect foresight by investors on everything except inflows, for which they have perfect foresight on probability distributions
- Risk neutrality by investors.

They assume also that, in the representative year considered, wind, solar and green peaker cost are constant, i.e. that the 1000’th MW costs the same as the first MW. This is a deliberate modelling simplification of a reality where an upwards-sloping cost curve is likely, as wind and solar generation shifts to less favourable sites, or as different technologies or increasingly expensive fuel sources are needed for increasing quantities of green peakers. The results need to be considered in this light.

Both models are cost-based so:

- Output prices are likely to be an underestimate market prices
- Output price forecasts from them are less certain
- Output price volatility forecasts are even less certain.

Both models predict possible futures, but are silent on how we might get there from a regulatory or market design perspective.

As with all models, comparative results are more robust that absolute results. Our economic modelling programme is focused on comparative results, especially the gross incremental economic value of adding an NZ Battery to the system, all other assumptions equal.

3. Inflow assumptions

We use the term ‘inflow’ for hydro inflows, converted to energy production (GWh) terms assuming the modern hydro fleet, as is conventional. We use the term ‘inflow’ also to cover wind and solar ‘inflows’ of wind energy or irradiance, converted to energy production terms, per MW of plant installed.

Using historical inflows at high resolution (daily for hydro, hourly for wind and solar) ensures that we have the best available view of the complexity of hydro, wind and solar interactions.

3.1 Hydro

We used the Hydrological Modelling Dataset from the Electricity Authority, including the 2021 update. This provides generation-adjusted inflows by catchment by day back to 1932.

While the climate probably has changed since the 1930s, and will change further going forward, we used the full range of inflow sequences back to 1932, as there is invaluable time-sequence information in them. For example, there were sequential dry years in the 1970s and we need to ensure that our dry year solution is robust to a repeat of such events.

3.2 Wind

We used wind inflow simulated actuals sourced from the Renewables Ninja website which is based on historical satellite imagery. Forty years of hour data were downloaded for eight regions, back to 1980. Regions used are:

- Northland
- Kaimai
- Hawkes Bay
- Waikato
- Auckland
- Wairarapa
- Canterbury
- Southland

It was found that Renewable Ninja average wind based synthetic data, including its assumed power curves, matches pattern and volatility of actuals[50] quite closely. The Renewable Ninja data were scaled to actuals where possible.

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[50] Comparisons were made with available data from Tararua, Te Uku, White Hill, Te Apiti, West Wind, Mahineragi, Te Rere Hau and Waverly (the last estimated to align with observed capacity factors)

3.3 Solar

We used solar inflow simulated actuals sourced from ANSA[51] and based on meteorological records. Forty[52] years of hour data were provided for the following regions, back to 1980. The technology assumptions are described section 6. The regions used are:

Utility solar:

- Far North
- Auckland
- Waikato
- Bay of Plenty
- Hawkes Bay
- Wellington
- Nelson-Tasman
- Christchurch
- Central Otago

Rooftop solar:

- Auckland
- Wellington
- Christchurch

3.4 Aligning hydro, wind and solar sequences

With 40 years of wind and solar inflow data, and 89 years of hydro inflow data, we needed a way of 'back-casting' the wind and solar inflow data to the years 1932 to 1979. We kept wind and solar inflow data aligned together to preserve wind/solar inflow relationships.

We could do that randomly, by for example repeating the same 40-year block, but it would be better to correlate them as much as possible. We tried and tested multiple ways of achieving this, including:

- Annual, quarterly and four-weekly time frames
- Different weightings North Island versus South Island

We measured these approaches against the resultant wind/hydro correlation and, for annual timeframes, the annual inflow deviation. We found that annual matching performed best: it has few discontinuities, avoids seasonality issues and preserves intra year wind/solar correlations.

We therefore mapped each hydro year before 1980 with the closest hydro year 1980 to 2020, and hence with the corresponding wind/solar year.

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[51] www.ansa.nz

[52] We actually had 50 years of data, but only used the latest 40 to preserve wind/solar inflow relationships.

3.5 Climate change impacts on inflows

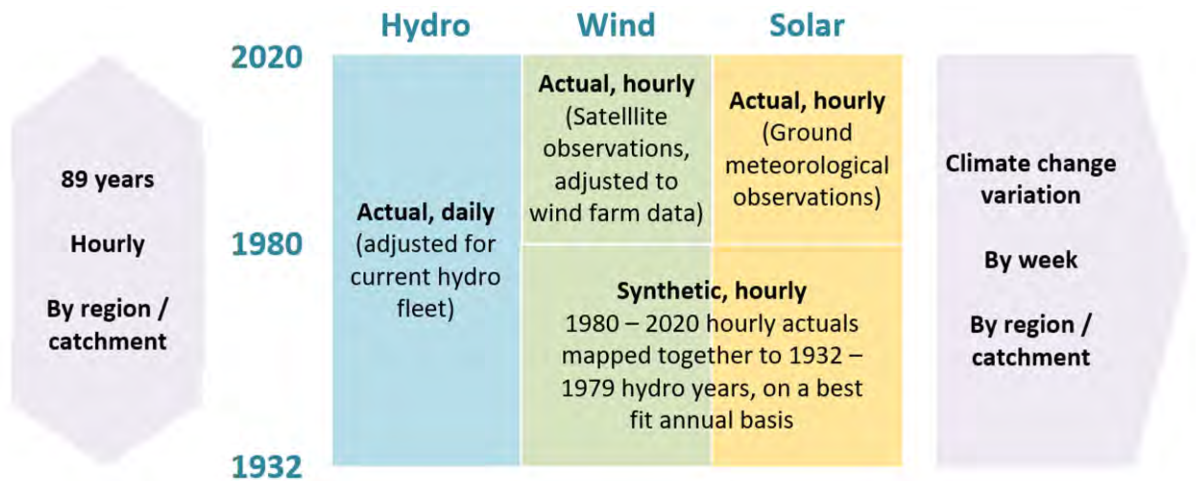
We engaged Dr Jen Purdie of ClimateWorks to estimate the climate change impacts on New Zealand hydro catchment inflows and wind speeds at 2050. She provided estimates by week of year, by catchment for hydro and by region for wind, of expected inflow percentage changes for 2050, noting that:

- There was greater confidence in the direction of the change than its timing
- This confidence of direction is especially strong for South Island hydro, with winter and spring precipitation falling more as rain than as snow, and hence hydro inflows arriving sooner
- There was no evidence of systemic expected changes to irradiance, so we did not adjust solar inflows for climate change effects.

For our baseline modelling, we applied these estimated climate change impacts 50% at 2035, 100% at 2050, and 100% at 2065 (our three modelling horizons: see section 4.1).

3.6 Inflow data summary

Figure 13: Summary of inflow data used



4. Common modelling assumptions

4.1 Reference years

We have focused our effort on studying three representative periods:

Table 12: Economic modelling horizons

Demand and generation	NZ Battery (when modelled)	Reference year
100% renewables achieved Electrification of demand underway	NZ Battery built and in early operation	2035
Electrification about half complete	NZ Battery in ‘steady state’ operation	2050
Full electrification		2065

As explained below, demand is assumed to grow significantly over time with the electrification of process heat and transport, and is the main driver of the growing need for continuing generation investment over time (given our 100% renewable assumption means that renewable investment to replace existing fossil-fuel generation has already occurred). As there is uncertainty in the rate of uptake of electrification and in the future path of industrial load, and large generation investments have a binary nature, results for these reference years should be considered as 'around then' rather than as precise dates.

4.2 Gross benefits

The model runs with an NZ Battery option do not include the NZ Battery capital or other fixed costs. This is so that the implications of different capital cost structures can be examined ex-post. Comparison of and NZ Battery option to a no-NZ Battery counterfactual thus provides gross benefits rather than net benefits of an NZ Battery.

4.3 Financial assumptions

We use the following financial assumptions for consistency with the NZ Battery indicative business case:

Table 13: Common financial assumptions

Base costing year	*$NZ 2021*	Calendar 2021
Costs	*$NZ 2021*	P50 including contingency
Discount rate	*% p.a.*	6% pre-tax real = 7 % nominal post-tax return on capital

Note that the discount rate used in the models is to reflect the commercial discount rate of market generation investors, and so does not need to be the same as the rate used for the NZ Battery indicative business case. How we use the discount rate to derive marginal, annualise generation costs is described in section 6.2: the post-tax nominal 7% rate gives a capital recovery factor which is very close to that resulting from a using real pre-tax 6% rate in the New Zealand context if the long run inflation is 2% p.a.

In SDDP, a separate discount rate can be used for hydro storage, including of major pumped hydro storage options. Variations to this hydro storage discount rates are considered as a sensitivity.

4.4 Carbon charge assumptions

We have adopted the Climate Change Commission's carbon charge assumptions:

Table 14: Carbon charge assumptions

		2020	2035	2050	2065
Carbon charge	*$ / tCO2e*	$30	$160	$250	$390

Most of our modelling is of a 100% renewables world. Our use of carbon charges is therefore restricted to:

- Geothermal new investments (we assume that existing geothermal plant continue to run baseload, and are replaced with lime plant at end of life, so their emissions net out in our comparative model runs)

- Fossil fuel peakers in our less than 100% renewables sensitivities[53]
- NZ Battery options with any greenhouse gas emissions.

In late 2022, the ETS price exceeded $80 /tCO2e, falling to around $70 in early 2023. We do not use the $30 figure in the table in our modelling, which starts at 2035, and expect to review our future carbon charge assumptions for any future NZ Battery economic modelling work.

5. Demand assumptions

The following sections discuss the context and components of assumed demand.

5.1 NZAS

It is assumed that Tiwai Point aluminium smelter ('NZAS') will be retired before 2035. Its retirement and its timing, and whether it will be replaced on retirement by another large load, is uncertain. Alternative futures are modelled as a sensitivity.

5.2 Base demand

In recent years, average generation has been around 43 TWh per annum (pa) and consumption 40 TWh pa, both including NZAS at about 5 TWh p.a. Generation exceeds consumer load because of transmission and distribution losses. Both the Culy and SDDP models include HVDC losses but assume lossless HVAC grids. We therefore define demand as demand for generation, including HVAC transmission and distribution losses, excluding HVDC losses, and excluding NZAS.

We assume 2021 base demand and annual rates of gross demand growth as follows:

Table 15: Base electricity demand assumptions

		2021	2035	2050	2065
Growth in Base ex NZAS	% p.a.		0.5%	0.8%	0.6%
Base excluding NZAS	TWh	37.3	40.0	45.1	49.3

5.3 Energy efficiency

Demand is assumed net of general efficiency improvements over time, and thus implicitly include the Climate Change Commission's assumptions on energy efficiency improvement. The Climate Change Commission's demonstration pathway includes in its base demand:

- Residential and commercial efficiency improvements of 1% per annum per person. From a 2020 base, this equates to 14% increase by 2035, 26% by 2050 and (in our extended timeframe) 36% by 2045.
- Commercial and public building's heat demand reducing by 2035 by 30% for new builds and 25% for existing.

Efficiency improvements in transport are accounted for explicitly as described in section 5.5 below.

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[53] Some NZ Battery technical reports refer to fossil fuel peakers as "black peakers" as a counterpoint to "green" – or renewable energy – peakers.

5.4 Embedded generation

Our demand is gross demand so exclusive of any embedded generation that we explicitly model, including:

- Residential and commercial rooftop solar, covered in section 6.4.2
- Utility wind and solar farms, covered in sections 6.3 and 6.4 (which include embedded and grid-connected plant)
- Small hydro schemes (such as Highbank, Cobb and Waipori) which are accounted separately in our inflow data.

5.5 Transport

Significant transport electrification through the progressive introduction of electric vehicles (EVs) is assumed as:

Table 16: Transport electrification assumptions

			2021	2035	2050	2065
Efficiency	**Light**	*MWh / vKm*	0.19	0.18	0.16	0.16
	Heavy	*MWh / vKm*	4.24	10.0	12.8	12.8
Usage (EV & ICE)	**Light**	*billion vKm*	41.7	51.2	53.0	56.2
	Heavy	*billion vKm*	3.16	3.5	3.6	3.9
Proportion of EVs by usage	**Light**	*% vkm*	1%	45%	95%	99%
	Heavy	*% vkm*	0%	2%	6%	6%
	Off road	*% On Road*	-	5%	15%	20%
Total transport demand	**Light**	*TWh pa*	0.0	4.1	8.2	8.8
	Heavy	*TWh pa*	0.0	0.8	2.6	3.0
	Off road	*TWh pa*	-	0.3	1.6	2.36
	EV Total	***TWh pa***	**0.1**	**5.2**	**12.4**	**14.2**

Transport demand includes electricity use for travel plus round trip battery charging losses plus average distribution and HVAC transmission losses.

5.6 Process heat

Significant process heat electrification through the progressive electrification of fossil-fuelled industrial processes is assumed as follows, allowing that some industrial decarbonisation will be through biomass or equivalent rather than electrical means:

Table 17: Process heat additional demand assumptions

		2035	2050	2065
Low and mid temperature	*TWh*	2.4	5.2	6.2
High temperature (dairy)	*TWh*	1.8	2.8	2.4
Process heat total	*TWh*	**4.2**	**8.0**	**8.6**

5.7 Summary of gross demand

We thus assume gross base demand as follows, built up from the components described above:

Table 18: Summary of gross electricity demand assumptions

		2021	2035	2050	2065
Base excluding NZAS	TWh pa	37.3	40.0	45.1	49.3
Transport	TWh pa	0.0	5.2	12.4	14.2
Process heat	TWh pa	-	4.2	8.0	8.6
Total gross demand excl. NZAS	TWh pa	**37.3**	**49.4**	**65.5**	**72.0**

5.8 Demand response

Demand response includes the shifting or reduction in load in response to price, as well as shortage, which could for example be manifested, as a last resort, as rolling black-outs. The term ‘demand response’ tends to mean different things to different people, so we use it as the generic but refer preferentially to three specific forms of response:

- **Load shifting**. This is where ‘demand response’ is in the form of delayed or shifted consumption of electricity. This includes ‘classic’ short-term demand response from space or water heating or cooling[54]. It includes also emerging forms of load shifting through the use of batteries, including residential/commercial batteries (possibly as part of a solar system), utility-scale batteries, and smart EV-charging
- **Load curtailment**. This is where load, such as industry, voluntarily reduces consumption in response to high prices. If the prices are efficient at reflecting the marginal costs of supply, this is an efficient and economically desirable outcome. If the prices eliciting the load curtailment are inefficiently high, then such curtailment is inefficient
- **Shortage**. This is where load is forced off because (despite high prices likely to be prevailing), there is not enough voluntary load curtailment to balance limited supply with demand, and demand needs to be physically reduced through for example rolling black-outs. While shortages are undesirable, a power system – especially one like ours subject to the vagaries of weather – ‘gold plated’ enough that shortage would never occur would not be economic: accepting some small but non-zero risk of shortage can provide an optimum outcome.

Economic models place a dollar value on electricity supply to consumers, which is used to find the economic optimum between increased supply-side investment and reliability and security of supply. It is usually expressed in energy terms, e.g. $/MWh.

Most discussion in the industry on this has been focused on the value of lost load (VoLL), a value enshrined in the Code to guide Transpower’s assessment of connection and interconnection investments. Such discussion has been focused on short-term loss of supply measured in minutes or hours. As Castalia have noted, “VoLL would be a relevant concept for setting a security of supply mechanism for capacity-related shortages. It is not a relevant concept when dealing with energy related shortages, since energy related shortages can be

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[54] But does not include load shifting from ripple control, which in included in the base demand shapes used.

addressed through conservation campaigns and planned rota-cuts, which impose lower costs per kWh saved."[55,56]

Distribution and average HVAC transmission losses are included, so demand response is measured relative to demand for generation.

Other than these demand responses, demand is assumed inelastic. Thus, if an NZ Battery option reduces average prices, any resultant demand increase and accelerated uptake of electrification is not modelled.

5.8.1 Load shifting

Gross demand implicitly assumes existing levels of load shifting from ripple control, as base demand shapes used are after load control.

EV smart-chargers and embedded batteries are not included in gross demand but are explicitly modelled, based on Transpower's assumptions in Whakamana i Te Mauri Hiko.

5.8.2 Load curtailment

We assume three tranches of increasing load curtailment:

Table 19: Load curtailment assumptions

			2021	**2035**	**2050**	**2065**
Tranche	**Curtail at prices above**	**Percentage**	0.50 GW	0.60 GW	0.80 GW	1.00 GW
1	**$700 /MWh**	40%	0.20 GW	0.24 GW	0.32 GW	0.40 GW
2	**$1,000 /MWh**	30%	0.15 GW	0.18 GW	0.24 GW	0.30 GW
3	**$1,500 /MWh**	30%	0.15 GW	0.18 GW	0.24 GW	0.30 GW

5.8.3 Shortage

We assume three tranches of shortage corresponding to increasingly deep and prolonged shortages.

While we expect our economy and community to become increasingly reliant on electricity as technology and electrification advances, we assume that the economic and social cost per unit for the first responses to shortage – the 'low hanging fruit' – will remain constant over time.

Table 20: Shortage assumptions

Shortage tranche	**Covers, for example:**	**Curtail at prices above**	**Demand applied to**
1	**Conservation campaign**	$800 /MWh	*First 5% GWh use in a shortage*[57]
2	**Shallow rolling outages**	$3,000 /MWh	*5% of demand*
3	**Deep rolling outages**	$10,000 /MWh	*Remainder of demand*

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[55] Castalia 2007 Electricity security of supply policy review

[56] EC 2007 Security of Supply Reserve Energy Review Modelling Presentation (web)

[57] This is modelled in Culy but not SDDP modelling, but is rarely used

6. Generation generic assumptions

This section covers our assumptions on new generation and new battery investments, and how our economic models use the assumptions.

6.1 Existing generation

Table 21: Existing generation assumptions

Hydro including contingent storage	Maintained at current levels, with no expansion other than as an NZ Battery option
Wind and solar	Maintained at current levels, until end of life when they are replaced with equivalent or expanded projects.
Geothermal	All existing geothermal plant retained, and Tauhara (currently under construction) assumed commissioned. Variable operating costs subject to the carbon charge. All existing (and new) geothermals are assumed to be "must run", so their operation is unaffected by carbon charges.
Fossil fuel including cogen	All existing fossil fuel generation is retired by 2035 Glenbrook, Kapuni, Kinleith, Mangahewa cogeneration plants remain in service (Te Rapa retired as currently planned)

6.1.1 Contingent storage

Contingent storage is hydro storage that is, by the conditions of its resource consent, only available for electricity generation under certain conditions. Contingent storage is the water at the bottom of the lake, below its normal operating range for electricity generation, so it can only physically be used when the lake is at or below the bottom of its normal operating range.

In most of our modelling runs, we assume that dry years will be managed without resource to contingent storage. For contingent storage scenarios, we assume that the current contingent storage arrangements continue unchanged through our study time horizon.

Table 22: Contingent storage assumptions

Level of risk	Nominal risk	Available contingent storage[58]	Cumulative total	
			Summer	Winter
Normal	<1%	None	0	
Watch	1%+	None	0	
Alert	4%+	67 GWh from Lake Hawea 331 GWh from Lake Pukaki 220 GWh from Lake Tekapo (summer only)	618 GWh	398 GWh
Emergency	10%+	214 GWh from Lake Pukaki	214 GWh	
TOTAL			**832 GWh**	**612 GWh**

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[58] Contingent Storage additional information.pdf (transpower.co.nz)

6.2 Marginal new generation investment costs

Because we are focused on modelling specific years, and we are focused on comparison of futures with and without NZ Battery, we use marginal, annualised generation capital and operating costs. While new generation is expected to be built in large 'chunks' such as a 200 MW wind farm, we model it as built over time by the MW. This avoids large binary decisions, such as whether that farm was built just before or just after the start of a reference year, from causing artificial swings in cost or benefit when we compare two scenarios for a specific year.

For these reasons, we distil new generation investment costs down to marginal levelised costs of energy (LCOE) in $/MWh and fixed annualised costs in $/kW/year as key parameters. The costs are assumed to continue 'in perpetuity' thus covering mid-life upgrades and replacements at end of life.

To develop them we use a real capital recovery factor, calculated for each generation type, which achieves a post tax nominal return of 7%. This gives the real capital recovery required on the assumption of a constant real revenue per annum over an economic life, accounting for timing of cashflows, depreciation, degradation, tax and ongoing or other periodic capital costs such as mid-life upgrades.

6.3 Wind generation investment

6.3.1 Onshore wind

We base our wind generation building-block costs on generic systems:

Table 23: Onshore wind costs by farm size

			Size of farm				
			20MW	**50MW**	**100MW**	**150MW**	**200MW**
	Capacity available	*MW*	Unrestricted				
CAPEX	**Turbines**	*$ / kWac*	1240	1230	1240	1250	1220
	EPC other	*$ / kWac*	1800	860	570	480	420
	CAPEX other	*$ / kWac*	210	190	180	180	170
	Contingency	*$ / kWac*	5%	5%	5%	5%	5%
	Total (less transmission)	*$ / kWac*	3400	2400	2100	2000	1900
OPEX	**Total**	*$/kW/year*	51	50	48	46	44
Proportion in generation stack		*%*	1%	2%	26%	28%	43%

We then assume learning curves for some components, reducing real costs over time. Other components are assumed constant cost in real terms.

Table 24: Onshore wind CAPEX learning curves

	Cost multiplier				% p.a.		
	2021	2035	2050	2065	2035	2050	2065
Turbines and EPC other	100%	87%	78%	76%	-1.0%	-0.7%	-0.2%

We then combine from the previous tables:

- Total CAPEX less transmission, 2022, by farm size
- Weighted by the proportion in generation stack, by farm size, and
- Adjusted by the learning curve per CAPEX component.

To give us the marginal $/kWac and LCOE as below. VOM for wind is low, so we can model it explicitly or include it in FOM, so both options are tabulated:

Table 25: Onshore wind marginal costs

Capital cost excluding transmission		2021	2035	2050	2065
FOM (VOM not modelled)	*$/kW/yr*	46	46	46	46
FOM (VOM modelled)	*$/kW/yr*	42	42	42	42
VOM (if modelled)	*$/MWh*	1.2	1.2	1.2	1.2
Base $/kWac	*$/kWac*	1820	1580	1420	1380
Fixed annualised costs	*$/kW/yr*	190	170	160	150
New entry costs = LCOE	*$/MWh*	54	48	45	44

To this we add transmission costs by region, constant in real terms, calculated as the average costs per kW per region from the wind generation stack (see section 14.2):

Table 26: Onshore wind transmission costs

Region	**Cost**
	$/kWac
Northland	410
Auckland	410
Waikato	340
Bay Of Plenty	100
Central North Island	290
Taranaki	210
Hawke's Bay	580
Wellington	270
Nelson-Marlborough	330
Canterbury	390
South Canterbury	320
Otago-Southland	280
Weighted average	**320**

Combining the fixed annualised costs and new entry costs without transmission, with these regional transmission costs gives the wind fixed annualised costs and new entry costs by region by reference year.

Note that the following table of fixed annualised costs is presented for the case of VOM not modelled. See the accompanying spreadsheet for the case of VOM modelled, and (as with many tables in this Assumption Book) for more decimal places if required.

Table 27: Onshore wind fixed annualised costs (VOM not modelled)

Region	**Onshore wind fixed annualised costs** *$/kW/yr*			
	2021	**2035**	**2050**	**2065**
Northland	230	210	190	190
Auckland	230	210	190	190
Waikato	220	200	190	190
Bay Of Plenty	200	180	170	170
Central North Island	220	200	180	180
Taranaki	210	190	180	180
Hawke's Bay	240	220	210	210
Wellington	220	200	180	180
Nelson-Marlborough	220	200	190	180
Canterbury	220	210	190	190
South Canterbury	220	200	190	180
Otago-Southland	220	200	180	180
Weighted average	**220**	**200**	**190**	**180**

Table 28: Onshore new entry costs

Region	**Onshore wind new entry costs = LCOE** *$/MWh*			
	2021	**2035**	**2050**	**2065**
Northland	63	58	54	53
Auckland	63	58	54	53
Waikato	61	56	52	52
Bay Of Plenty	56	51	47	46
Central North Island	60	55	51	50
Taranaki	59	53	50	49
Hawke's Bay	67	62	58	57
Wellington	60	54	51	50
Nelson-Marlborough	61	56	52	51
Canterbury	63	57	54	53
South Canterbury	61	56	52	51
Otago-Southland	60	55	51	50
Weighted average	**61**	**56**	**52**	**51**

6.3.2 Offshore wind

Investment in offshore wind in New Zealand is possible within the horizon considered. Roaring 40s identify three most likely areas, off the:

- West coast of Auckland, with some 4 GW of potential
- Waikato west coast, with some 2 GW of potential
- South Taranaki coast, with some 2 GW of potential (and the highest wind speed).

As Roaring 40s describe it:

> *The South Taranaki coast option is a large area with an extremely good wind resource (average wind speed 9.6 m/s) and a water depth of less than 50 m. The Auckland and Waikato coast options aren't as attractive from a wind resource perspective (average wind speed 8.3m/s) and are in deeper water (60 m to 150 m deep) but have the advantage of being closer to the large load centre of the Auckland Region.*

Offshore wind is currently significantly more expensive than onshore wind, but its costs are declining more rapidly. Here are the Climate Change Commission's assumptions:

Table 29: CCC wind cost assumptions

	Capacity factor	**Capital**	**FOM**	**VOM**	**Cost reduction rate**	**Capital**	
						2035 average	*2050 average*
	%	$ / kW	$ / kW / yr	$ / MWh	% p.a.	$ / kW	$ / kW
Onshore wind	40 %	$ 2100	$ 24	$10	0.53 to 0.80	**1,900**	**1,720**
Offshore wind	44 %	$ 5200	$ 140	$ 0	2.33 to 3.50	**3,349**	**2,175**

There is uncertainty in when and how much offshore wind investment there will be in New Zealand. However, as Roaring 40s conclude, and given that some potential investors are expressing interest[59] we cannot rule out offshore wind by 2035 either. Work is underway within MBIE to develop a regulatory regime for licensing offshore renewables to be in place by the end of 2024.

Our modelling, of onshore wind only, indicates that significant onshore wind investment is likely in the Auckland, Waikato and Taranaki regions (along with wind elsewhere across New Zealand). The modelling takes into account the regional wind resource, the advantages of diversity between regions,proximity to transmission, and losses and capacity of the HVDC link. Wind tends to be stronger offshore than onshore, but with similar shapes to their distributions over time.

Thus, the results of our modelling of onshore wind can be interpreted, through post-processing of modelling results, as including onshore and offshore possibilities in those three regions.

Further, the critical generation investments for the comparative economic analyses are those that depend on the NZ Battery scenario – no NZ Battery, and different NZ Batteries. We try to capture the nuances of the NZ electricity market's response to the supply/demand/storage

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[59] For example, the NZ Super Fund and Copenhagen Infrastructure Partners are considering investment in a large scale offshore wind to South Taranaki (web).

balances under each of these scenarios, and assume that onshore wind developments will be more reflective of these differences than would major, binary offshore wind developments.

6.4 Solar generation investment

6.4.1 Utility scale solar generic

To obtain an expected cost per kW we base our building-block costs on generic systems:

- Single-axis tracking, also referred to as azimuth tracking
- Inverter loading ratio 1.3 (i.e. 30% overbuild relative to inverter capacity, with clipping)
- Photovoltaic performance degradation of 0.6% p.a. (on the dc side of the inverter)
- Capacity factor of 22% (as a lifetime average, equivalent to 24% in year one)
- 25 year life.

Table 30: Utility solar costs by farm size, less transmission

			Size of farm				
			20MW	**50MW**	**100MW**	**150MW**	**200MW**
	Capacity available	*MW*	Unrestricted				
CAPEX	**EPC Modules**	*$ / kWac*	750	670	620	590	570
	EPC Inverters and trackers	*$ / kWac*	450	430	410	400	400
	EPC Labour	*$ / kWac*	500	435	390	365	350
	EPC Materials	*$ / kWac*	500	435	390	365	350
	Other	*$ / kWac*	50	40	40	40	30
	Contingency	*$ / kWac*	9.7%	8.9%	7.6%	6.3%	5.0%
	Total (less transmission)	*$ / kWac*	2,468	2,189	1,991	1,871	1,785
OPEX	**FOM**	*$/kW/year*	36	33	31	30	29
Proportion in generation stack			-	2%	20%	10%	69%

We then assume learning curves for modules, inverters, trackers and labour components as below.

Table 31: Utility solar learning curves

	Cost multiplier				**% p.a.**		
	2021	**2035**	**2050**	**2065**	**2035**	**2050**	**2065**
Modules	100%	**52%**	**26%**	**18%**	-4.6%	-4.6%	-2.3%

We then combine from the previous tables:

- Total CAPEX less transmission by farm size
- Weighted by the proportion in generation stack, by farm size, and
- Adjusted by the learning curve per CAPEX component.

To give us the marginal costs as follows:

Table 32: Utility solar marginal costs

Capital costs exclude transmission		**2021**	**2035**	**2050**	**2065**
FOM	*$/kW/yr*	0	0	0	0
VOM	*$/kW/yr*	29	29	29	29
Base $/kWac	*$/kWac*	1800	1200	780	670
Fixed annualised costs	*$/kW/yr*	190	130	96	87
New entry costs = LCOE	*$/MWh*	88	61	45	41

To this we add transmission costs by region, constant in real terms, calculated as the average costs per kW per region from the solar generation stack (see section 14.3):

Table 33: Utility solar transmission costs

Region	**Cost**
	$/kWac
Northland	250
Auckland	220
Waikato	250
Bay Of Plenty	190
Central North Island	270
Taranaki	380
Hawke's Bay	190
Wellington	290
Nelson-Marlborough	270
Canterbury	350
South Canterbury	190
Otago-Southland	280
Weighted average	**260**

Combining the fixed annualised costs and new entry costs without transmission, with these regional transmission costs gives:

Table 34: Utility solar fixed annualised costs

Region	Utility solar fixed annualised costs *$/kW/yr*			
	2021	2035	2050	2065
Northland	207	149	117	108
Auckland	204	146	114	105
Waikato	207	148	117	107
Bay Of Plenty	202	144	112	103
Central North Island	209	150	119	110
Taranaki	218	160	128	119
Hawke's Bay	202	143	112	102
Wellington	210	152	120	111
Nelson-Marlborough	209	150	119	110
Canterbury	215	157	125	116
South Canterbury	202	144	112	103
Otago-Southland	209	151	119	110
Weighted average	**208**	**149**	**118**	**108**

Table 35: Utility solar LCOE

Region	Utility new entry costs = LCOE *$/MWh*			
	2021	2035	2050	2065
Northland	99	71	56	51
Auckland	97	69	54	50
Waikato	98	71	55	51
Bay Of Plenty	96	68	53	49
Central North Island	99	72	56	52
Taranaki	104	76	61	56
Hawke's Bay	96	68	53	49
Wellington	100	72	57	53
Nelson-Marlborough	99	72	56	52
Canterbury	102	75	60	55
South Canterbury	96	68	53	49
Otago-Southland	100	72	57	52
Weighted average	**99**	**71**	**56**	**52**

6.4.2 Rooftop solar

Rooftop solar is modelled at a fixed build rate, so investment in rooftop solar is not a variable optimised alongside wind, utility solar and other generation. This is to reflect that rooftop solar investment drivers are multi-faceted, not just based on wholesale price. Rooftop solar:

- Is accounted for after demand, so it is treated as another form of generation to meet gross demand for generation
- Is implicitly grossed-up to include the quantity of distribution and HVAC transmission losses saved
- Implicitly also accounts for the average level of module efficiency degradation.

Table 36: Rooftop solar assumptions

		2021	2035	2050	2065
Residential	*%*	2%	8%	14%	20%
Commercial		-	5%	7%	10%
Residential installations	*Number of installations (millions)*	0.04	0.16	0.31	0.47
Commercial Installations		-	0.02	0.03	0.04
Residential	*kW per installation*	3.8	4	4	4
Commercial		7	7	7	7
Residential	*TWh*	0.2	0.8	1.5	2.3
Commercial		-	0.1	0.2	0.3
Rooftop		**0.2**	**0.9**	**1.7**	**2.6**

This is similar to the Climate Change Commission’s assumption of 10% of household have 3.5 kW solar rooftop installations by 2040.

Rooftop solar is assumed to be in one of the three load centres Auckland. Wellington and Christchurch for which we have full solar inflow sequences (see section 3.3).

We model rooftop solar uptake as exogenous, i.e. not in response to market prices. Hence, the model results can be interpreted for higher or lower rooftop solar uptake – as a first approximation – by considering lower or higher demand, i.e. modelled results for 2050 could be interrupted as say for late 2040s or early 2050s.

6.5 Geothermal generation investment

It is assumed that Tauhara, currently under construction, is commissioned at 250 MW.

We assume new market geothermal investment options in three tranches (after Lawless 2020):

- Low-emissions, with 230 MW available and 60 Kg C / MWh gross emissions
- Medium-emissions, with 450 MW available and 115 Kg C / MWh gross emissions
- High-emissions, with 100 MW available and 150 Kg C / MWh gross emissions.

A significant uncertainty in future geothermal investment is the rate of geothermal carbon re-injection, as:

- Most carbon is already captured, but currently vented to the atmosphere. These gases could instead be re reinjected into the subsurface field. There is some geothermal carbon reinjection in Iceland, the USA and Turkey, and trials are underway here in New Zealand.
- To truly sequester the reinjected carbon, it needs to mineralise, which can happen in basaltic rock such as exists in Iceland. However, the rock type in our geothermal zone is not well suited to mineralisation because it does not contain all the desired minerals found in basalt.
- Absent mineralisation, there is a significant risk that reinjected carbon migrates through the reservoir and leads to an increasing concentration of carbon coming up through production wells, as has been observed in Turkey. It may take years before this effect is observed (or demonstrated not to occur) in our trials.
- Alternatively, it may be that continual reinjection keeps the carbon sub-surface indefinitely, even if it does not mineralise.
- However, the re-injection of carbon can dissolve rock, increasing the permeability of the reservoir around the injection well and beyond, with the possibility of over time creating a CO_2 fountain with local as well as atmospheric impact.
- It is thus an unknown how successful geothermal carbon reinjection will be in New Zealand over our long-term outlook horizon, and successes are likely to be field-specific
- We therefore will run sensitivities around an assumed success rate of 50% for low, medium and high emissions fields.

For modelling purposes, we include the successful 100% injection, zero emission fields with low emissions fields, as they all get built in all scenarios, and different emissions rates can then be post-processed to reflect different assumptions.

This leads to the following capacities of market geothermal availability:

Table 37: Geothermal resource assumptions

		Emissions	**Geothermal resource**
		Kg C / MWh	*MW*
Emissions tranche	**Zero net**	0	400
	Low	60	120
	Medium	115	230
	High	150	50
TOTAL			**800**

Another significant uncertainty is geothermal capacity factor. Geothermal plant are typically run continually as baseload plant. In recent years our geothermal fleet has been running in the high 80s percentage capacity factors[60]. Lawless (2020), looking forward, suggests

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[60] New Zealand Geothermal Association 2020 Annual NZGA Geothermal Review (web), confirmed by MBIE analysis.

capacity factors in the range of 90% to 95% will be achievable. We have assumed a figure in the low 90s of 91%.

Table 38: Geothermal generic generation assumptions

				2020	**2035**	**2050**	**2065**
		CAPEX	*$ / kW*	$5500 / kW			
		FOM	*$ / kW pa*	$ 189 / kW pa			
		VOM excluding carbon charge	*$ / MWh*	$ 0 / MWh			
		Capacity factor	*%*	91%			
Emissions tranche	**Low**	**Emissions**	*Kg C / MWh*	Up to 60			
		VOM	*$ / MWh*	$ 2	$ 10	$ 15	$ 23
		LCOE	*$ / MWh*	$ 81	$ 88	$ 94	$ 102
	Medium	**Emissions**	*Kg C / MWh*	115			
		VOM	*$ / MWh*	$ 3	$ 18	$ 29	$ 45
		LCOE	*$ / MWh*	$ 82	$ 97	$ 108	$ 124
	High	**Emissions**	*Kg C / MWh*	150			
		VOM	*$ / MWh*	$ 5	$ 24	$ 38	$ 59
		LCOE	*$ / MWh*	$ 83	$ 103	$ 116	$ 137

6.6 Peakers

Peakers are fast-start turbines that can run for an hour or two, or days or weeks or longer. Peakers are modelled in all scenarios, as our modelling of a future world without peakers does not produce a credible solution.

Peakers are assumed to be ‘green’ peakers in our 100% renewable scenarios, which are the focus of our analysis.

We also model fossil fuel peakers as a sensitivity.

Some modelled peaker operation for multi-day events could represent also other technologies operating at similar price levels, such as load curtailment (additional to that covered in section 4.8.2) or storage devices capable of multi-day generation such as flow batteries.

6.6.1 Green peakers

A green peaker is a low capital cost, high operating cost generation plant, running on a zero-carbon fuel. With their high operating costs, green peakers would be expected to operate at low capacity factors only to cover periods of low intermittent renewables and/or very dry periods.

CAPEX costs are expected to be similar to fossil-fuel powered peakers:

Table 39: Green peaker CAPEX assumptions

CAPEX	*$ / kW*	**$1,000**

Lifetime	*Years*	25
Capital recovery factor	*%*	7.8%
Capex recovery	*$ / kW pa*	$78
Fuel holding costs	*$ / kW pa*	$14
FOM	*$ / kW pa*	$10
Fixed costs annualised	*$ / kW pa*	$100

Operating costs are primarily driven by the cost of fuel, which is problematic to estimate across our extended time horizon, and given the variety of possible fuel types, including ethanol, biodiesel, biogas, green hydrogen and green ammonia. We assume $45 / GJ but consider this to be at the cheaper end of a range of possible but unknown prices (and so will perform sensitivity analyses around higher prices):

Table 40: Green peaker OPEX assumptions

Cost of bio fuel	*$ / GJ*	$ 45
Generation efficiency	*%*	34%
Fuel cost of generation	*$ / MWh*	$ 480
O & M	*$ / MWh*	$ 8
VOM	*$ / MWh*	$ 480

Modelled green peaker operation could represent also other technologies operating at similar price levels, such as load curtailment or storage devices capable of multi-day generation such as flow batteries.

We expect to review our green peaker operating costs assumptions to support any further and future economic modelling work.

6.6.2 Fossil fuel peakers

In most scenarios we do not consider fossil fuel peakers in 2035 and beyond. However, in any scenarios that we run with fossil fuel peakers, the following are the assumptions we use.

We assume that coal use for electricity generation ceases before 2035, and that oil use is minimal by comparison with natural gas. This is a conservative assumption, as it is not guaranteed that the market would – with no incentives other than carbon prices – close off coal as an option. So, assuming a gas-only rather than gas and coal future is a strong assumption.

However, given this strong assumption, our issue is the availability and cost of natural gas for electricity generation in New Zealand. The main driver for continued investment in our gas supply chain and infrastructure is likely to be the petrochemical industry and other demand, rather than electricity generation. Our assumption on this is that existing gas peakers and gas storage at Ahuroa are retained, but only used as a last resort backup, and that additional capacity of gas peakers are allowed as required to maintain a secure system (in economic terms) as demand increases.

Because our models use marginal generation costs, we need to distil our assumptions into an annualised fixed cost and a VOM, as below:

Table 41: Fossil fuel peaker CAPEX assumptions

CAPEX	*$ / kW*	$ 1000
Lifetime	*Years*	25
Capital recovery factor	*%*	7.8%
CAPEX recovery	*$ / kW pa*	$ 78
FOM	*$ / kW pa*	$ 10
Fixed costs annualised	*$ / kW pa*	$ 88

For gas costs we assume that gas storage at Ahuroa is maintained at around 11-17 PJ with additional investment to enable greater daily extraction rates (flex) as required, with fixed costs comprising:

- Working capital costs for Ahuroa gas storage as $ 7 million per annum
- Upgrading Ahuroa extraction rate ($ 0.4 billion CAPEX), annualised as $ 41 million per annum
- Option fees to provide gas supply flexibility not met from Ahuroa of $ 15 million per annum.

This suggests the availability of gas for peaking at some $ 13.5 / GJ inclusive of flex.

It is possible that the upstream gas industry ceases to be able to maintain the required upstream investment, in which case imported liquid natural gas (LNG) would set a backstop price. A Gas Industry Company paper[61] provides some insight on future LNG prices, as being not much different than the $ 13.5 / GJ assumed for domestic gas above.

Table 42: Fossil fuel peaker OPEX assumptions excluding carbon

Cost of gas	*$ / GJ*	$ 13.5
Generation efficiency	*%*	34%
Fuel cost of generation	*$ / MWh*	$ 140
O & M	*$ / MWh*	$ 8
VOM excluding carbon	*$ / MWh*	$ 150

Table 43: Fossil fuel peaker OPEX assumptions including carbon

		2021	**2035**	**2050**	**2065**
Carbon content of gas	*kg CO_2 / GJ*	54			
Carbon content	*t CO_2 / MWh*	0.53			
Carbon prices	*$ / t CO_2*	$ 30	$ 160	$ 250	$ 390
Carbon cost	*$ / MWh*	$ 17	$ 92	$ 140	$ 220
VOM	*$ / MWh*	$ 170	$ 240	$ 290	$ 370

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[61] Gas Industry Company 2021 Gas Market Settings Investigation Consultation Paper (web), section 5.9.

6.7 Grid-scale batteries

We assume that grid-scale batteries (Li-ion or equivalent) will be available in 5-hour and 12-hour sizes:

Table 44: Grid-scale batteries generic opportunities assumptions

			2021	**2035**	**2050**	**2065**
CAPEX	**5-hour battery**	*$ / kWac*	$2000	$1084	$864	$689
	12-hour battery	*$ / kWac*	$3900	$2114	$1685	$1343
	Decline rate	*% p.a.*		-4.0% p.a.	-1.5% p.a.	-1.5% p.a.
Round trip efficiency		*%*	85%			
Cell replacement rate		*% pa*	1% of total capex			
FOM		*$ / kW pa*	$10 / kW pa			
VOM		*$ / MWh*	Nil			

Transmission costs of grid-scale battery connection are assumed low, as grid-scale batteries are likely to be connected at strong points of the grid, and included in CAPEX.

6.8 Instantaneous reserves

Instantaneous reserves are held such that generation can be ramped up, or load ramped down, within seconds to maintain system frequency should a generation or transmission asset fail. Generation kept as reserve cannot be used for dispatch. Batteries have reserve capability (as do some NZ battery options, including pumped hydro).

Instantaneous reserves are an important feature of the New Zealand market. In particular, HVDC transfer can be limited by instantaneous reserve requirements to cover for HVDC failure.

Our assumption for our horizon of 2035+ is that instantaneous reserve requirements will not cause cost differences between with and without NZ Battery scenarios, because:

- Our modelling predicts very significant amounts of Li-ion batteries with a high capability to provide instantaneous reserves
- North Island reserve requirements for the HVDC contingent event will be significantly less once the 1400MW upgrade is completed
- For southwards flow, Lake Onslow in pumping can in effect provide its own reserve cover through setting its turbines to trip.

7. Transmission generic assumptions

This section covers generic transmission assumptions. In addition there are specific transmission assumptions for NZ Battery options, detailed in their section.

We assume that the grid upgrades proposed by Transpower in their January 2022 Net Zero Grid Pathways (NZGP) go ahead, and are commissioned prior to 2035.

Table 45: Transmission generic generation assumptions

HVDC	HVDC 4th Cable	1400 MW north, 950 MW south
Central North Island upgrades	Brownhill-Whakamaru	We assume 45% series compensation on both Brownhill Whakamaru circuits, 2025
	Brownhill-Pakuranga	Brownhill to Pakuranga cable is operated unconstrained from 2025 (once series compensation in place)
	Tokaanu-Whakamaru 1&2	Duplexed with Goat at 120°C, 2027
	Bunnythorpe-Tokaanu 1&2	Duplexed with Goat at 120°C, 2027
	Huntly-Stratford-1	Circuit protection upgrade to increase effective capacity, giving this circuit the same capacity as the Stratford-Taumarunui-Te Kowhai-Huntly circuit which is strung on the same double circuit towers, from 2029
	Special protection scheme	Tokaanu intertrip scheme disabled (modelled in SDDP by removing TKU bus split)
	Tactical thermal uprate	Ongarue circuit breaker #92 split
Wairakei Ring	Te Mihi-Wairakei-1	Thermal upgrade to 100°C, 2027
	Te Mihi-Whakamaru-1	Thermal upgrade to 100°C, 2027
	Whakamaru-Wairakei-1	Thermal upgrade to 100°C, 2027
	Ohakuri-Wairakei-1	Duplexed Goat at 120°C, 2027
	Atiamuri-Ohakuri-1	Duplexed Goat at 120°C, 2030
	Atiamuri-Whakamaru-1	Duplexed Goat at 120°C, 2027
	Edgecumbe interconnector	62.5 MVA (winter/summer/shoulder)
	Special protection scheme	Edgecumbe-Kawerau-3 and Kawerau-Ohakuri-1 overload protection scheme
Bombay to Otahuhu	Committed projects	New 220 kV bus at Bombay between Huntly and Drury connected into Drury-HLT-1 and Huntly-TAT-2 Remove Arapuni-Bombay and Bombay-Hamilton 110 kV circuits
Additional system splits	Splits on 110 kV system to resolve overloads	Ongarue-Rangitoto-1 Mangamaire-Masterton-1 Edgecumbe-Kawerau 1 and 2 Glenavy-Studholme-2

8. NZ Battery Lake Onslow pumped hydro option

The Lake Onslow pumped hydro scheme is under active investigation: the following assumptions reflect the current state of Lake Onslow design work (MOL = maximum operating level).

Table 46: Lake Onslow main options

	Upper storage	Installed capacity	Upper reservoir	Lower reservoir			
			MOL	**Storage**	**Location**	**MOL**	**Pumped?**
	TWh	*MW*	*masl*	*Mm^3*		*masl*	
Small	3	500	743	0	Negotiations	62	No
Medium	5	1000	765	5		87	Yes
Large	7.5	1250	785	10		86.6	Yes

The assumptions below are based on the ‘Medium’ option.

Negotiations

[redacted]

8.2 Upper reservoir

Table 47: Lake Onslow (medium option) upper reservoir dimensions

Elevation	**Reservoir Storage**	**Active storage**	**Area**
masl	*Mm*^{3}	*Mm*^{3}	*Km*^{2}
695	246	-	24
705	529	283	32
715	882	637	39
725	1,307	1,062	46
735	1,804	1,558	53
745	2,365	2,120	59
755	2,986	2,740	65
765	3,664	3,418	71

Table 48: Lake Onslow (medium option) upper reservoir evaporation

	Evaporation
	mm/month
January	120
February	96
March	67
April	39
May	20
June	8
July	8
August	21
September	41
October	71
November	96
December	113

There is assumed to be no significant seepage loss, and no net inflows as current flows on the Teviot River will need to be maintained.

Groundwater seepage from the Lake Onslow basin for lake levels from 685m to 765m are expected to vary from <0.1m3/s to 0.75m3/s respectively.

8.3 Pumping and generating performance

The medium option for Lake Onslow has four 250 MW turbines. Turbines are assumed to:

- Be reversible with fully variable loading such that there is a full range of available dispatches between zero and maximum generation and maximum pump.
- Have a very fast ramp rate relative to the highest hourly resolution used in our economic modelling. Their potential contribution to ancillary services is not modelled (other than as discussed in section 6.8).

The following Lake Onslow pumping and generation assumptions are for when all four 250 MW turbines are in operation, in two modes:

- **Sustained operation**, when the lower reservoir is and its lower pumps are in active use as required to maintain pumping volumes over times, so the production coefficients include the main turbines and lower pumps.
- **Arbitrage operation**, in which the lower reservoir is operating in closed loop i.e. no interaction with the river or use of the lower pumps, so the production coefficients include the main turbines only. This is a mode of operation that could be used for daily cycling.

So, the **production coefficients** for the turbines in the tables below capture lower pump efficiency when used in sustained operation. The production coefficients include headlosses in both directions due to long waterways. The ratio of pumping and generating production coefficients give the round-trip efficiency, excluding evaporation effects.

Table 49: Lake Onslow (medium option) turbine performance in sustained operation

Elevation		*masl*	**695**	**705**	**715**	**725**	**735**	**745**	**755**	**765**
Pumping	**Power consumption**	*MW*	1124	1115	1105	1095	1084	1075	1066	1056
	Total pumping flow	*cumecs*	156	153	150	147	144	141	138	135
	Production coeff.	*MW/ cumec*	7.20	7.29	7.37	7.45	7.53	7.62	7.72	7.82
Generating	**Maximum output**	*MW*	1000	1000	1000	1000	1000	1000	1000	1000
	Total turbine flow	*cumecs*	206	201	196	191	186	183	179	176
	Production coeff.	*MW/ cumec*	4.85	4.98	5.10	5.24	5.38	5.46	5.59	5.68
Round-trip efficiency		*%*	**67.4%**	**68.3%**	**69.3%**	**70.3%**	**71.4%**	**71.7%**	**72.3%**	**72.6%**

Table 50: Lake Onslow (medium option) turbine performance in arbitrage operation

Elevation		*masl*	**695**	**705**	**715**	**725**	**735**	**745**	**755**	**765**
Pumping	**Power consumption**	*MW*	1092	1084	1074	1065	1055	1047	1038	1029
	Total pumping flow	*cumecs*	156	153	150	147	144	141	138	135
	Production coeff.	*MW/cumec*	6.99	7.08	7.16	7.24	7.33	7.43	7.52	7.62
Generating	**Maximum output**	*MW*	1000	1000	1000	1000	1000	1000	1000	1000
	Total turbine flow	*cumecs*	206	201	196	191	186	183	179	176
	Production coeff.	*MW/cumec*	4.85	4.98	5.10	5.24	5.38	5.46	5.59	5.68
Round-trip efficiency		*%*	**69.4%**	**70.2%**	**71.3%**	**72.3%**	**73.4%**	**73.6%**	**74.3%**	**74.5%**

The following turbine parameters are for an elevation of 695 masl and 608m of gross head:

Table 51: Lake Onslow (medium option) turbine parameters

Capacity	***MW***	**250**
Generation rated discharge rate per unit	*cumec*	51.4
Pumping maximum discharge per unit	*cumec*	39.0

In the following table is for sustained mode, and pumping efficiency includes 'lower' pumping up from the Clutha River to the lower reservoir (for the medium Lake Onslow option which has the lower reservoir Negotiations[62].

Table 52: Lake Onslow (medium option) pumphouse parameters

Turbines		***Units***	**2**	**3**	**4**
Maximum generate (turbined) flow		*cumec*	104	156	208
Maximum pump flow		*cumec*	78	117	156
Generation efficiency		*%*	84.2%	84.2%	84.2%
Pump efficiency		*%*	86.4%	86.4%	86.4%
Round trip efficiency	Average	*%*	71.0%	71.0%	71.0%
	When full	*%*	74.5%	74.5%	74.5%

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[62] Values are based on Negotiation 1000MW, 10 Mm^3 lower reservoir volume option, so these numbers are slightly conservative for our medium 5 Mm^3 option, which has a maximum operating level 0.4m lower, but the difference is negligible.

8.4 Lower reservoir

The medium option for Lake Onslow is for a lower reservoir Negotiations The lower reservoir will be raised slightly above the level of the Clutha River, with ‘lower’ pumps used to fill it. During generating operation, the lower reservoir can be drawn down to river level.

Table 53: Lake Onslow (medium option) lower reservoir parameters

Lower reservoir size	*Mm3*	Commercial Information
Maximum operating level	*masl*	87
Max flow in (max harvest rate)	*cumec*	250
Lower pumps?		Yes

8.5 Transmission

Transmission assumptions for Lake Onslow are in addition to the generic transmission assumptions presented in section 7.

8.5.1 Grid connection

Transpower has developed, for early modelling purposes, a conceptual Lake Onslow grid connection comprising:

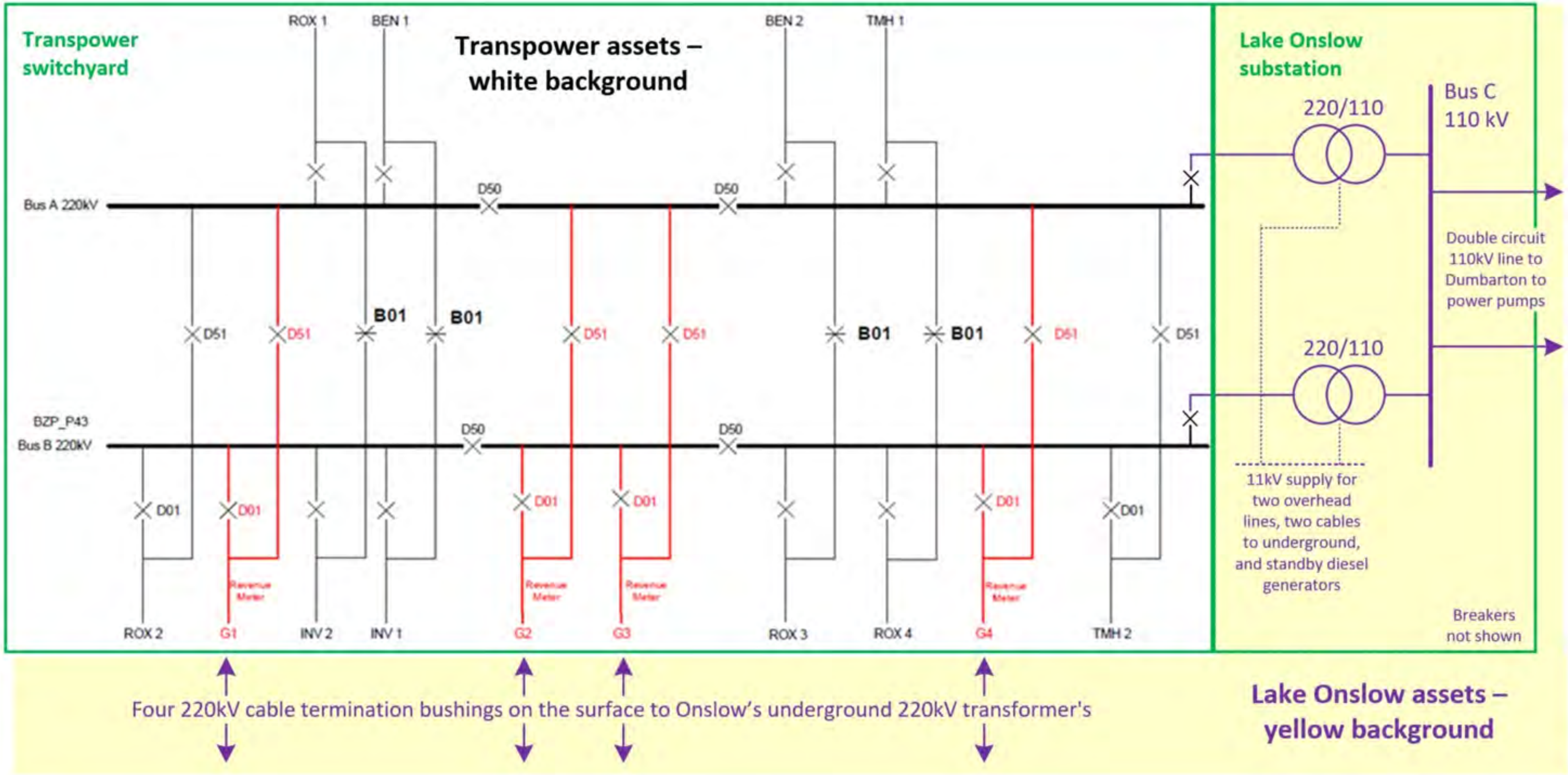
- A new Onslow substation on the surface above the powerhouse (which is deep underground), assumed some 40 Km south-east of Roxburgh substation
- Loop in, loop out connection of Onslow substation to all of the:
    - Invercargill – Roxburgh 1 and 2 circuits
    - Roxburgh – Three Mile Hill 1 and 2 circuits
- Dismantling the sections of those lines between the diversion points
- New Benmore – Onslow double circuit 220 kV line.

Commercial Information

[redacted]

8.6 Scheme overview

Figure 16: Lake Onslow substation conceptual design bus configuration



We assume this conceptual grid connection design, with the following parameters. The relevant codes used here are:

BEN	Benmore
INV	Invercargill
LO	Lake Onslow
ROX	Roxburgh
TMH	Three Mile Hill (west of Dunedin)

- Circuits use suffixes 1, 2…
- Lines (one line of towers can carry one or two circuits) use suffixes A, B…
- Some names use here are not to industry standard and are placeholders to be refined as necessary in future.

Table 54: Lake Onslow local line and circuit changes

Line name		Type	Circuit(s) carried	Comments	Length
Existing	**Proposed**				
INV-ROX B	**INV-LO B**	Single circuit	INV-LO-ROX 2	Diversion in	6 km
INV-ROX B	**INV-LO B**	Double circuit	INV-LO-ROX 1 & 2	Diversion in	22 km
INV-ROX A	**LO-ROX A**	Double circuit	INV-LO-ROX 1 & 2	Diversion out	19 km
INV-ROX A	**LO-ROX A**	Single circuit	INV-LO-ROX 1	Diversion out	3 km
ROX-TMH A	**LO-TMH A**	Double circuit	ROX-LO-TMH 1 & 2	Diversion in	24 km
ROX-TMH A	**LO-ROX B**	Double circuit	ROX-LO-TMH 1 & 2	Diversion out	22 km
-	**BEN -LO A**	Double circuit	BEN-LO 1 & 2	New Build	220 km
INV-ROX B	**-**	Single circuit	INV-ROX 2	Removal of diverted sections	12 km
INV-ROX A	**-**	Single circuit	INV-ROX 1		11 km
ROX-TMH A	**-**	Double circuit	ROX-TMH 1 & 2		17 km

Table 55: Lake Onslow connection circuit parameters

	Summer	Winter	Shoulder	Voltage	R	X
	MVA	*MVA*	*MVA*	*kV*	*ohms*	*ohms*
INV-LO 1	347.1	382.2	365.0	220	7.61	48.52
INV-LO 2	347.1	382.2	365.0	220	7.43	48.54
LO-ROX 1	347.1	382.2	365.0	220	1.98	14.09
LO-ROX 2	347.1	382.2	365.0	220	2.05	14.93
LO-ROX 3	385.2	469.8	429.8	220	1.29	11.58
LO-ROX 4	385.2	469.8	429.8	220	1.29	11.58
LO-TMH 1	385.2	469.8	429.8	220	2.97	26.74
LO-TMH 2	385.2	469.8	429.8	220	2.97	26.74
BEN-LO 1	709.4	781.0	746.2	220	7.60	67.68
BEN-LO 2	709.4	781.0	746.2	220	7.60	67.68

8.6.1 HVAC North Island

We assume some additional transmission investments will be made, beyond those in the generic transmission assumptions presented in section 7, where the SDDP modelling and/or Transpower's power system analysis has indicated that they are likely to be economic. We assume these upgrades will be made by 2035, and by duplexing:

- Bunnythorpe-Haywards A and B (BPE-PRT-HAY 1 & 2), primarily to enable southward flow
- Bunnythorpe-Wairakei A (BPE-TNG-RPO-WRK), primarily to enable southward flow.

8.6.2 HVDC

We assume that the HVDC link capacity will not be upgraded beyond 1400MW, as to do so would require upgrade of the whole line including the lengthy overhead portions, and would create too great an extended contingent event (ECE) and potentially resilience risk.

We assume that, given that Lake Onslow pump will reduce spill from North Island wind and solar, the HVDC southwards flow will be maximised:

- Southwards flow will increase from 950MW (68% of 1400MW) to 1050MW (75%) with the Bunnythorpe-Haywards duplexing identified above
- Additional increase towards the 1400 MW technical maximum southwards, to 1300MW (93%) south, will be achieved with lower North Island voltage management, e.g. installation of dynamic reactive plant such as StatComs.

Transpower has cautioned that this assumed ability to increase of the HVDC link southwards capacity has not been studied and could, for example, raise issues for the Benmore-Twizel and/or Aviemore-Waitaki-Livingstone lines. Nevertheless we need an NZ Battery working assumption so – accepting that this will need detailed study if we are to proceed – we assume the above HVDC southwards expansion for modelling purposes.

8.6.3 HVAC South Island

Onslow when generating requires transmission capacity to be upgraded between the Roxburgh region and the Waitaki Valley. There are a number of options for this, and a detailed analysis will need to be undertaken of which option is most economic: we assume for modelling purposes that this will be achieved by:

- A new double-circuit 220 kV line from the Lake Onslow substation directly to Benmore
- Duplexing of the Aviemore-Benmore line, primarily to enable pumping.

Onslow when pumping may require grid support. To date, power system analysis of Onslow pumping has been limited to fixed speed synchronous turbines, but the Onslow design is based on variable speed turbines[63]. The Transpower analysis for synchronous turbines indicates that pumping under certain grid configurations, generation and load patterns, and pumping load combinations could breach system transient stability limits, and to maintain grid stability could require dynamic reactive plant of some 500 MVars (at a South Island site other than Onslow), possibly as synchronous condensers.

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[63] To conduct such power system analysis, Transpower needs a DigSILENT model of the turbines, which TRM has provided for synchronous turbines but we do not yet have a model for variable speed turbines.

Variable speed turbines offer a transient response advantage compared to fixed speed synchronous turbines due to significantly faster dynamic response, and can offer enhanced system stability support. Therefore, it is expected that the additional reactive support required by the grid would be reduced where variable speed machines are used. Further, the cases of grid configurations, generation and load patterns, and pumping load combinations that place stability limits at risk are expected to be rare. Use of variable speed machines would allow the pumps to be unloaded to a safe pumping load without requiring the pumps to be shutdown. Such unloading may be facilitated by Special Protection Schemes or similar, so we have assumed:

- Special protection schemes (NZ Battery estimate).

This is an NZ Battery working assumption pending the full power system analysis by Transpower.

8.6.4 Summary of transmission assumptions

These are in addition to the generic transmission assumptions tabulated in section 7:

Table 56: Lake Onslow specific transmission assumptions

	Transmission investment specific to Lake Onslow	
Connection	Substation	Lake Onslow substation
	Circuits diverted into Onslow	Invercargill – Roxburgh A & B, Roxburgh – Three Mile Hill A
HVAC South Island	Increase transfer Roxburgh region to the Waitaki Valley	New Onslow to Benmore double-circuit 220 kV line
	Ensure grid stability when Onslow is pumping	Special protection schemes
HVDC	Increase southwards flow	1300 MW southwards
HVAC North Island	Bunnythorpe-Haywards 1 and 2	Duplexed
	Bunnythorpe-Wairaki 1	Duplexed
	Brownhill-Whakamaru 1 and 2	45% series compensation

8.7 Host system interaction

The Lake Onslow scheme would interact physically and possibly commercially with Contact Energy which owns and operates the Clutha River power system including the Lake Hawea control structure, Clyde Dam and Roxburgh Dam.

The SDDP model maximises national benefit, i.e. it finds a least cost dispatch, so implicitly assumes that Contact Energy and NZ Battery would be operating together for the national good.

9. NZ Battery Upper Moawhango pumped hydro option

The primary reference for this scheme is Stantec’s Other Pumped Hydro and Other Hydro Options Initial Desktop Screening Study, prepared for MBIE, March 2022 (revision 3 of 23 May 2022), referred to as ‘Site 1’.

9.1 Scheme overview

The scheme includes:

- Upper Moawhango reservoir with new dam to contain it
- Horizontal tunnel to a head-pond
- Tunnel from the headpond to an undergrpound pump/power station Commercial Information

Commercial Information

Table 57: Upper Moawhango summary of key parameters

Upper reservoir total storage	*Mm^3*	1714
Upper reservoir live storage	*Mm^3*	1199
Storage provided	*TWh*	2.75

The storage provided in the table above includes the energy provided from all downstream generation, owned by Genesis and Mercury.

Commercial Information

[redacted]

Commercial Information

[redacted]

Commercial Information

[redacted]

Commercial Information

[redacted]

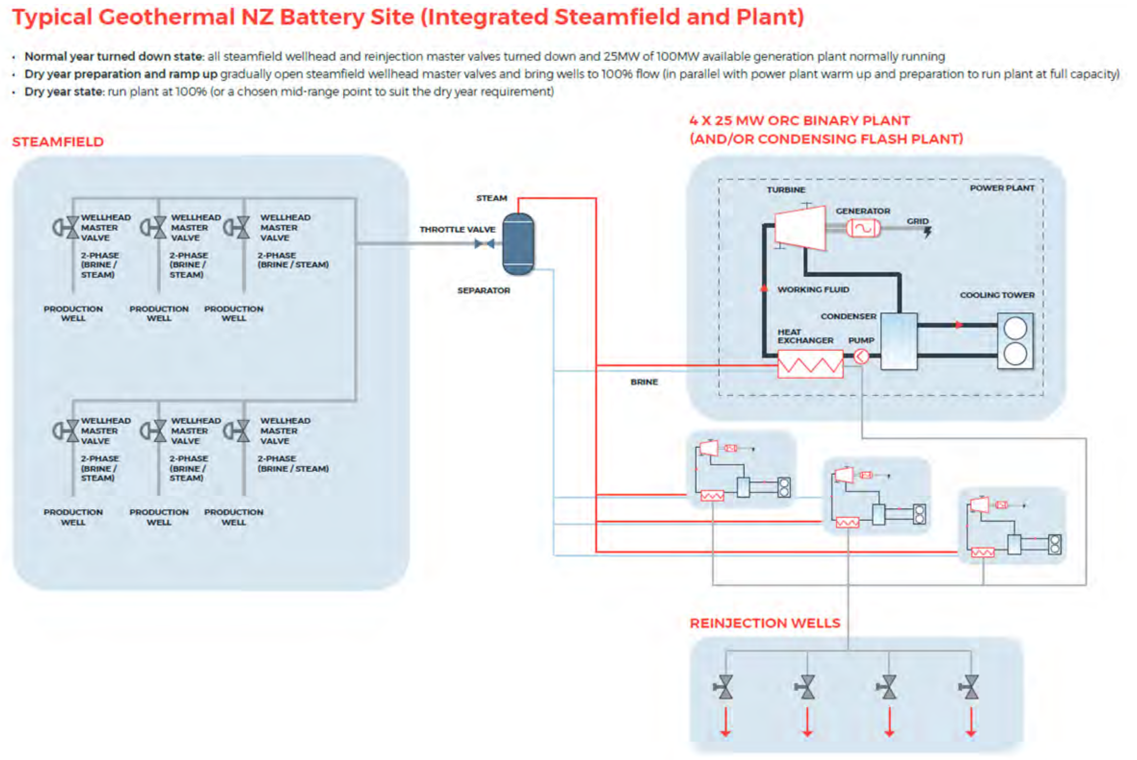
10. NZ Battery geothermal reserve option

10.1 Overview

Key features of the geothermal reserve option are based on those recommended by WSP and include:

- A total of 400 MW of new geothermal plant are developed, specifically designed to enable ramping flexibility
- Each plant will be 100 MW comprising four 25 MW units. One unit will always be operating in baseload. In an emerging dry year, wells are slowly de-throttled and the other generation units brought progressively online.
- It takes two weeks to ramp up to full capacity across all units, and the same time to ramp back down
- The plant are spread across several greenfield geothermal sites in the Taupo volcanic zone (the zone includes the south-eastern Waikato and central Bay of Plenty).

Figure 21: Geothermal reserve scheme overview (from WSP)



Typical Geothermal NZ Battery Site (Integrated Steamfield and Plant)

- **Normal year turned down state:** all steamfield wellhead and reinjection master valves turned down and 25MW of 100MW available generation plant normally running
- **Dry year preparation and ramp up** gradually open steamfield wellhead master valves and bring wells to 100% flow (in parallel with power plant warm up and preparation to run plant at full capacity)
- **Dry year state:** run plant at 100% (or a chosen mid-range point to suit the dry year requirement)

10.2 Modelling assumptions

Table 58: NZ Battery geothermal reserve modelling parameters

Capacity	**Baseload**	*MW*	100 MW
	Flexible	*MW*	300 MW
	Total	*MW*	400 MW
Ramp rate	**Up**	*MW / time*	150 MW / week
	Down	*MW / time*	150 MW / week
Location			Taupo volcanic zone
Operating mode			SOS Mode

For SOS Mode the hydro risk trigger used is the $80 MWh Waitaki water offer curve, reflecting the state of the major storage in the South Island.

The NZ Battery geothermal reserve, when modelled, requires geothermal resource which removes its availability to the market. It is assumed that the 400MW of geothermal reserve targets higher gross emissions fields first, to allow full baseload market geothermal plant preferential use of the lower emissions resources.

Given our 50% carbon reinjection success rate assumption, this means that the full 400 MW of low, medium and high emissions resource that does not have successful re-injection is used for geothermal reserve, and the fields with successful reinjection are used for market baseload geothermal, also totalling 400 MW. The geothermal reserve can then, for modelling convenience, be considered as a single emissions tranche with a weighted average emissions rate:

Table 59: NZ Battery geothermal reserve option emissions tranches

Emissions tranche		**Geothermal reserve capacity**	**Remaining market capacity**
Tranche	*Kg C / MWh*	*MW*	*MW*
Re-injection	0	-	400 MW
No re-injection average	100	400 MW	-

Geothermal is assumed to have zero base VOM, but will have a VOM reflecting the emissions and carbon charge:

Table 60: NZ Battery geothermal reserve VOM

		2021	**2035**	**2050**	**2065**
VOM excluding carbon charge	*$ / MWh*	0			
Emissions	*Kg C / MWh*	100			
VOM	*$ / MWh*	3	17	26	40

While there will be some start-up costs, we assume that start-ups occur sufficiently frequently that this in included as part of the FOM.

10.3 Transmission implications

Transmission export is required for four new 100MW geothermal generation stations, spread across several greenfield geothermal sites in the Taupo volcanic zone.

We assume each will require a connection substation, with an average of 10 to 20 Km of diversions of the nearest 220 kV line. Some of the geothermal generation stations could be close enough to a line to require no diversion, some required diversions could be longer.

Transpower has identified two upgrades that may be required in addition to those in its current NZGP, depending on geothermal reserve generation locations, the location of biomass option in a portfolio solution, and other market generation investments:

- Reconductoring the 115 Km Ohakuri-Edgecumbe-A line (as may be required for the biomass option)
- Reconductoring the 220 Km Bunnythorpe-Wairakei-A line.

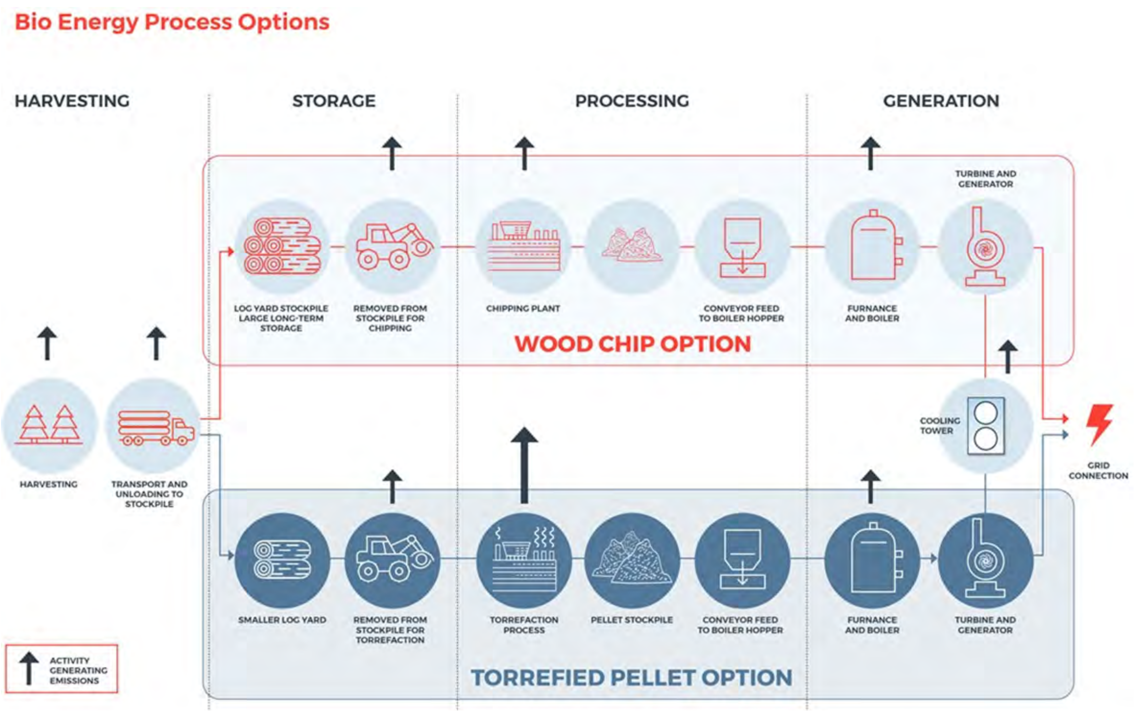
11. NZ Battery biomass option

11.1 Overview

Key features of the biomass option are based on those recommended by WSP, which are, converted to potential electrical terms where appropriate:

- A stockpile of white logs (debarked tree trunks) is kept at the generation site, with a stockpile when full sufficient for 1 TWh of generation output
- Logs are harvested and supplied to the stockpile at a steady rate of 1000 tonnes (about 46 trucks) daily through a routine supply contract. This daily rate can, with three months' notice, be flexed up by 50% through a combination of flex in the routine supply contract chain and purchasing ready-for-export logs
- There would be 500 MW of log-fired generation on site, consisting of two 250 MW Rankine cycle plant, for which the logs would be chipped 'just in time'
- The maximum lifetime of a log in the stockpile is three years, within which time they would need to be burned for generation or passed on to another, higher-value use
- An alternative option has been considered (illustrated below), which would utilise torrefied wood - a more heavily processed biomass fuel. However, this is not being modelled, to focus on the preferred option.
- The generation site would balance the proximity to the forest resource with the availability of land transport and transmission infrastructure. Many areas could be possible for this, but for modelling purposes we will assume a site in the central North Island.

Figure 22: Biomass scheme overview (from WSP)



11.2 Modelling assumptions

Table 61: Biomass scheme stock and flow modelling parameters

		Per tonne of logs	Routine inflow			Maximum stockpile
			Day	Three months	Year	
Log stockpile lifetime	*Years*					3
Log supply	*t*	1	1,000	91,000	370,000	1,100,000
Energy in logs	*GJ / t*	10.3				
Energy in gross	*MWh*	2.85	2,900	260,000	1,000,000	3,100,000
Chipping loss	*%*	0.18%				
Rankine efficiency	*%*	32%				
Potential generation	*MWh*	0.91	910	82,000	330,000	980,000

In addition to the routine supply as above, we assume that supply can be flexed up by 50% through diverting logs from other uses e.g. export. The costs and prices for routine and flex-up supply are shown below. Unused logs, which would almost always be from the routine supply after their three-year stock life, have a resale value.

Table 62: Biomass scheme SRMC

		Routine	Flex-up
Maximum per day	*t*	1000	500
Log price delivered	*$ / t*	$ 112	$ 136
VOM	*$ / MWh*	$ 3	
SRMC	*$ / MWh*	$ 120	$ 150

Table 63: Biomass scheme unused log resale price

Reduction relative to routine price	**%**	**40 %**
Unused log resale price	*$ / MWh*	$ 74

Table 64: Biomass scheme modelling parameters

Generation	500 MW
Location	North Island
Operating mode	Flexibility mode

In the NZ Battery biomass option, the standard market green peaker assumptions are used in addition.

11.3 Transmission implications

As noted above, the biomass generation site would balance the proximity to the forest resource with the availability of land transport and transmission infrastructure. Many areas could be possible for this, but for modelling purposes we assume a site in a plantation forest area of the central North Island, in the eastern Waikato or Southern Bay of Plenty region.

There will need to be a strong substation to support the 500 MW of generation, and we assume three possibilities for connecting this substation to the 220kV grid, accepting that there could be others:

- New 600MW double circuit line 220kV line of 50 Km to 70Km, to the Whakamaru or Wairakei substation
- Reconductoring the 115 Km Ohakuri-Edgecumbe-A line (as may be required for the geothermal reserve option).

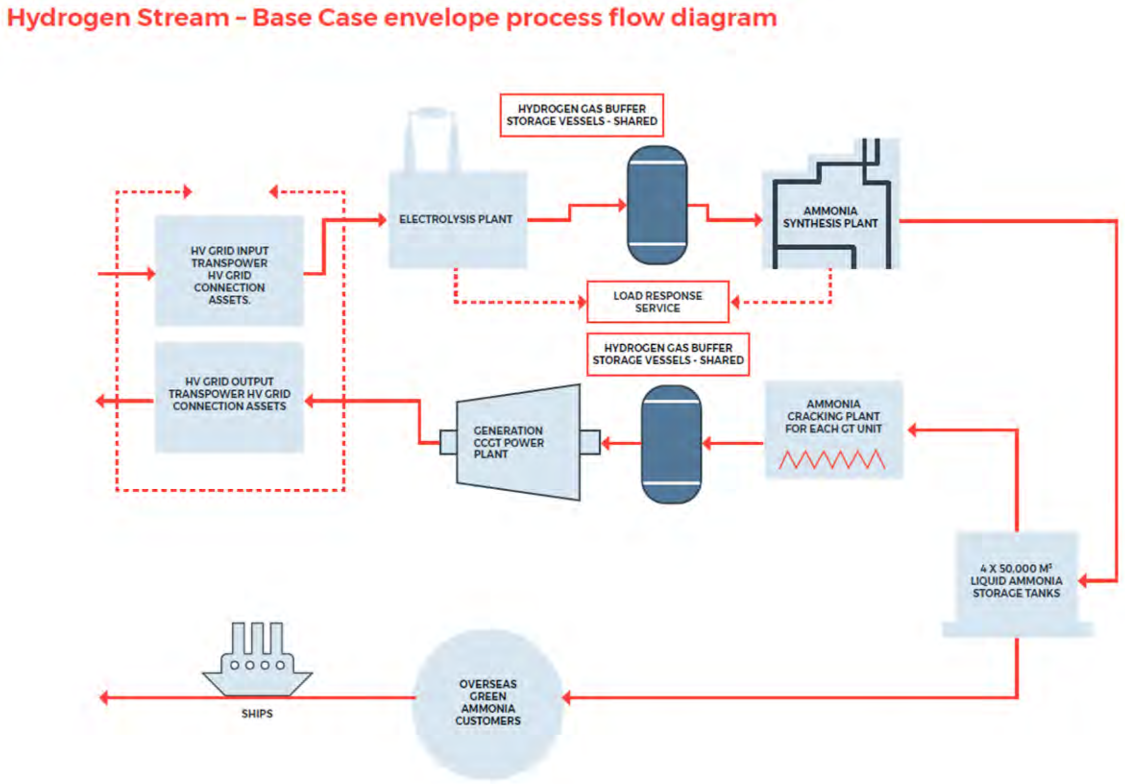
12. NZ Battery hydrogen and ammonia option

12.1 Overview

Key features of the hydrogen-ammonia option are based on those recommended by WSP in its Other Technologies Feasibility Study:

- Electrolysis of water into hydrogen using a fully flexible electrolyser, with buffer storage of hydrogen equivalent to about twelve hours of production at full electrolyser output
- Ammonia synthesis plant, sized to match the electrolyser plant hydrogen output. Ammonia production which can drop to part-load rapidly, or turn off with a two-day re-start time
- Bulk ammonia storage using above ground containment tanks, plus supplementary storage to support an export terminal
- Cracking of ammonia back into hydrogen to feed electricity generation through two 75 MW CCGT plants
- Most of the response is provided by turning off the electrolyser, but significant response also from the hydrogen-fuelled generation.

Figure 23: Hydrogen-ammonia scheme overview (from WSP)



12.2 Modelling assumptions

Table 65: Hydrogen-ammonia scheme cumulative efficiencies

		Energy from grid	**Electrolysis**	**Hydrogen storage**	**Ammonia synthesis**	**Ammonia storage**	**Ammonia cracking**	**Hydrogen storage**	**Generation**
Capacity	*MW*		350 MW		19 MW				150 MW
Efficiency	*%*		66%		84%		77%		60%
Via ammonia storage	*MWh*	369		231		194		149	90
	%	*100%*		*66%*		*53%*		*40%*	*24%*

The hydrogen-ammonia option provides for up to 200,000m^3 of liquid ammonia storage. This is equivalent to around 380 MWh of potential generation from the CCGT. Production is assumed to be stored and/or provided to the CCGT as priority. ‘Spill’ from continued production when storage is full is diverted to export (via supplementary storage).

In setting the electrolyser bid and CCGT offer prices into the electricity market, we have assumed:

- Export-parity pricing, given our assumption that excess green ammonia is exported
- A liquid market develops for this product by 2035
- A green ammonia price (distinct from costs):
  - Derived from IEA projections for green ammonia and international renewable electricity costs
  - Determined by the capability of technology investments made in 2030, with those investments being necessary to meet increasing demand for green ammonia - even as green ammonia production technology improves - and hence being the marginal price setter through-out our modelled period
  - Declining over time, on the assumption the price of the renewable energy used to produce it declines over time
- The international ammonia price informs the willingness to pay for electricity to produce it, reflecting
  - An exchange rate of 0.65 NZD/USD
  - The efficiency of the production process
  - An assumption that electricity comprises 90% of short-run marginal costs
- Similarly, the international ammonia price informs the CCGT offer price, adjusted for the exchange rate and cracking and generation efficiency.

This results in the bid and offer prices in the table below.

There is massive uncertainty around green ammonia prices into the future. The numbers below are far from definitive, but provide a reasoned estimate for modelling purposes, with the IEA references providing a touchstone.

Table 66: Hydrogen-ammonia scheme prices

		2035	2050	2065
International electricity input cost	*USD/MWh*	$ 60	$ 35	$ 25
International ammonia price (export)	USD/t_{NH3}	$ 750	$ 500	$ 400
Electrolyser bid price	*NZD/MWh*	$ 92	$ 61	$ 49
CCGT offer price	*NZD/MWh*	$ 400	$ 266	$ 213

12.3 Transmission implications

The hydrogen-ammonia option is assumed to be located close to a port and transmission. Transmission is required to service a range between a 370 MW load and 150 MW generation.

13. NZ Battery portfolio options

The NZ Battery portfolio options are to explore a portfolio of the other three options (geothermal reserve, biomass, and hydrogen-ammonia) as:

- Individual options are size- or capability-constrained in meeting the range of dry year scenarios that could unfold
- If the Government were to procure such options, it may be through a form of technology-agnostic tender process, with a combination of solutions as a likely or at least possible outcome
- A portfolio might also reflect a market or regulated provision of such services, or some combination thereof.

For modelling, we consider the following three portfolio options:

Table 67: Portfolio options considered

Portfolio	Geothermal reserve	Biomass	Hydrogen-ammonia	NZAS load curtailment	Gross benefit relative to:
1	✓	✓	✓	✗	Counterfactual (Tiwai out)
2	✓	✓	✗	✓	NZAS-in base case
3	✓	✓	✗	✗	Counterfactual (Tiwai out)

Portfolio 1 includes all three individual non-hydro NZ Battery options identified.

Portfolio 2 explores how a portfolio solution might change if NZAS remains in:

- NZAS already has a load curtailment capability, of some 80 MW for 130 days

- We assume that this level of response will continue in the ‘NZAS-in’ base case
- In Portfolio 2, we assume also that NZ Battery has contracted with NZAS for the same magnitude of response but triggered at a lower risk level.
- For NZAS load curtailment response trigger we use the Waitaki water offer curve, reflecting the state of the major storage in the South Island, at the $500 level for the NZAS-in base case, and at the $250 level for Portfolio 2 (this is the same SOS Mode approach used for geothermal reserve, but with higher prices for more conservative operation).

Portfolio 3 has neither the hydrogen-ammonia nor NZAS load curtailment present, to explore the value of significant demand response in a portfolio solution.

14. Generation investment stacks

This section presents our assumptions on specific generation investment and retirements. These are used explicitly in the SDDP modelling, and inform some of the generic generation assumptions.

14.1 Fossil fuel retirement

Table 68: Fossil fuel generation retirement assumptions (SDDP)

Plant	Type	Capacity (MW)	Retirement year (1 January)
Taranaki Combined Cycle	CCGT	380	2025
Huntly C1	Coal/Gas Steam turbine	243	2025
Huntly C2	Coal/Gas Steam turbine	243	2025
Huntly C4	Coal/Gas Steam turbine	243	2025
Whirinaki	Diesel	155	2029
McKee	OCGT	100	2033
Edgecumbe	Cogeneration	10	2033
E3p	CCGT	403	2035
Huntly P40	OCGT	50	2035
Stratford Open Cycle Gas Turbine	OCGT	200	2035
Junction Road	OCGT	100	2035
Bream Bay Peaker	Diesel	9	2035

14.2 Wind

Wind specific generation opportunities assumptions use the generic CAPEX (with transmission CAPEX added), FOM and VOM from section 3.2, and add:

Table 69: Wind specific generation opportunities assumptions

Name	Capacity	Location	Available	Transmission costs	
	Max MW	*GIP*	*Start of year*	*$/kW*	*$M*
Turitea	221.4	LTN220	2022 fixed	212	47
Harapaki	176.3	WRK220	From 2023	165	29
MtCass	92.4	WPR066	From 2023	115	11
Puketoi	300	LTN220	From 2025	444	133
CastleHill	500	LTN220	From 2026	220	110
KaiwDwns	200	NMA220	From 2025	203	41
Awhitu	25	HLY220	From 2025	141	4
CentralWind	150	BPE220	From 2025	293	44
MtMunro	100	MGM110	From 2026	250	25
Waitahora	150	LTN220	From 2026	490	73
KaimaiWind	100	HAM110	From 2026	186	19
Flemington	100	FHL110	From 2026	340	34
Mahiner_s2	150	HWB220	From 2026	321	48
Hurunui	80	ISL220	From 2026	567	45
BOPTaupo_1	300	TRK220	From 2026	102	31
Kaiwaikawe	75	MPE110	From 2026	103	8
Northland_1	300	MDN220	From 2026	484	145
Waikato_1	180	OHW220	From 2026	434	78
Waikato_2	200	OHW220	From 2026	355	71
Marlboroug_1	50	BLN110	From 2026	201	10
Wellington_1	15	WIL220	From 2026	341	5
Manawatu_1	150	BPE220	From 2026	381	57
BOPTaupo_2	300	WRK220	From 2026	100	30
Wellington_2	100	HAY220	From 2026	261	26
Auckland_1	100	HPI220	From 2026	509	51
Manawatu_2	150	BPE220	From 2026	246	37
Auckland_2	100	HPI220	From 2026	312	31
Northland_2	150	MDN220	From 2026	260	39
CentralPla_1	250	TKU220A	From 2026	118	30
BOPTaupo_3	150	WRK220	From 2026	285	43
Eastland_1	50	TUI110	From 2026	65	3
Northland_3	100	MDN220	From 2026	319	32

Name	Capacity	Location	Available	Transmission costs	
	Max MW	*GIP*	*Start of year*	*$/kW*	*$M*
BOPTaupo_4	100	WRK220	From 2026	603	60
Southland_1	100	NMA220	From 2026	219	22
BOPTaupo_5	75	WRK220	From 2026	320	24
FarNorth_1	75	MDN220	From 2026	454	34
Otago_1	500	ROX220	From 2026	166	83
Waikato_3	20	WRK220	From 2026	256	5
Southland_2	25	NMA220	From 2026	441	11
FarNorth_2	75	MDN220	From 2026	487	36
Eastland_2	75	TUI110	From 2026	691	52
Southland_3	150	NMA220	From 2026	200	30
Waikato_4	50	WKM220	From 2026	361	18
Wairarapa_1	100	MGM110	From 2026	582	58
Eastland_3	200	TUI110	From 2026	508	102
Otago_2	300	HWB220	From 2026	186	56
Manawatu_3	150	BPE220	From 2026	144	22
Southland_4	100	NMA220	From 2026	348	35
BOPTaupo_6	75	WRK220	From 2026	498	37
Marlboroug_2	75	BLN110	From 2026	392	29
Southland_5	50	NMA220	From 2026	492	25
SouthernWa_1	100	BPE220	From 2026	433	43
Southland_6	150	NMA220	From 2026	449	67
CentralPla_2	150	TNG220	From 2026	192	29
Southland_7	100	NMA220	From 2026	529	53
FarNorth_3	200	MDN220	From 2026	545	109
Waikato_5	75	WKM220	From 2026	115	9
Canterbury_1	15	ISL220	From 2026	384	6
Otago_3	150	HWB220	From 2026	210	31
BOPTaupo_7	10	ARI110A	From 2026	774	8
WestCoast_1	75	DOB110	From 2026	353	26
Northland_4	100	MPE110	From 2026	639	64
Otago_4	150	HWB220	From 2026	634	95
BOPTaupo_8	150	WRK220	From 2026	195	29
Northland_5	150	MDN220	From 2026	348	52

Name	**Capacity**	**Location**	**Available**	**Transmission costs**	
	Max MW	*GIP*	*Start of year*	*$/kW*	*$M*
Manawatu_4	100	BPE220	From 2026	362	36
Canterbury_2	150	ISL220	From 2026	479	72
Canterbury_3	100	ISL220	From 2026	647	65
Eastland_4	150	TUI110	From 2026	1110	166
CentralPla_3	125	TKU220A	From 2026	618	77
Taranaki_1	100	SFD220	From 2026	279	28
Wellington_3	100	LTN220	From 2026	321	32
Taranaki_2	200	SFD220	From 2026	224	45
Northland_6	100	MDN220	From 2026	207	21
Auckland_3	125	HLY220	From 2026	363	45
SouthernWa_2	150	BPE220	From 2026	422	63
HawkesBay_1	100	RDF220	From 2026	373	37
Auckland_4	150	HLY220	From 2026	392	59
Canterbury_4	200	ISL220	From 2026	247	49
Taranaki_3	200	SFD220	From 2026	173	35
Manawatu_5	300	BPE220	From 2026	110	33
TOTAL	**11,285**				

14.2.1 Repowering of existing wind farms

In our time horizon, we can expect many existing wind-farms to be repowered, probably with a higher capacity as technology advances.

Table 70: Wind specific repowering assumptions

Name	Capacity	Location	Available	Transmission	
	Max MW	*GIP*	*Start of year*	*$/kW*	*$M*
MillCrk_Rpwr	105	WIL220	2044 fixed	35	4
TaraW1_Rpwr	100.8	BPE220	2029 fixed	35	4
TaraW2_Rpwr	140	LTN220	2034 fixed	35	5
TaraW3_Rpwr	125	TWC220	2037 fixed	35	4
TeApiti_Rpwr	220	WDV110	2034 fixed	35	8
TRrHau_Rpwr	82	TWC220	2041 fixed	35	3
TRrHau3_Rpwr	82	TWC220	2041 fixed	35	3
TRrHau4_Rpwr	81	TWC220	2041 fixed	35	3
TeUku_Rpwr	110	HAM110	2041 fixed	35	4
WstWnd_Rpwr	250	WIL220	2039 fixed	35	9
Mahiner_Rpwr	50	HWB220	2041 fixed	35	2
WhtHll_Rpwr	115	NMA220	2037 fixed	35	4

14.3 Utility solar

Utility solar specific generation opportunities assumptions use the generic CAPEX, FOM and VOM from section 6.4.1, and add:

Table 71: Utility solar specific generation opportunities assumptions

Name	Capacity	Location	Available
	Max MW	*GIP*	*Start of year*
Solar_OHA_1	200	OHA220	From 2025
Solar_OHC_1	200	OHC220	From 2025
Solar_OHB_1	200	OHB220	From 2025
Solar_BEN_1	200	BEN220	From 2025
Solar_AVI_1	200	AVI220	From 2025
Solar_STK_1	200	STK066	From 2025
Solar_KAW_1	200	KAW110	From 2025
Solar_CYD_1	200	CYD220	From 2025
Solar_WHI_1	180	WHI220	From 2025
Solar_ARG_1	100	ARG110	From 2025
Solar_BLN_1	140	BLN110	From 2025
Solar_TWH_1	200	TWH220	From 2025
Solar_GLN_1	200	GLN220	From 2025
Solar_ASB_1	200	ASB066	From 2025
Solar_WTU_1	200	WTU220	From 2025
Solar_RDF_1	200	RDF220	From 2025
Solar_BOB_1	200	BOB110	From 2025
Solar_WHU_1	120	WHU110	From 2025
Solar_HUI_1	120	HUI110	From 2025
Solar_SVL_1	200	SVL220	From 2030
Solar_ISL_1	200	ISL066	From 2030
Solar_ISL_2	200	ISL066	From 2030
Solar_ISL_3	200	ISL066	From 2030
Solar_MAN_1	200	MAN220	From 2030
Solar_LTN_1	160	LTN220	From 2030
Solar_BPE_1	160	BPE220	From 2030
Solar_HLY_1	200	HLY220	From 2030
Solar_HLY_2	200	HLY220	From 2030
Solar_KPU_1	120	KPU066	From 2030
Solar_BRB_1	120	BRB220	From 2030
Solar_TNG_1	120	TNG220	From 2030

Name	Capacity	Location	Available
	Max MW	*GIP*	*Start of year*
Solar_OAM_1	120	OAM110	From 2030
Solar_TMK_1	100	TMK110	From 2030
Solar_WRK_1	100	WRK220	From 2030
Solar_CUL_1	60	CUL220	From 2030
Solar_ASY_1	80	ASY066	From 2030
Solar_HWB_1	200	HWB110	From 2030
Solar_MST_1	120	MST110	From 2030
Solar_HAM_1	200	HAM220	From 2030
Solar_BRY_1	200	BRY066	From 2030
Solar_FKN_1	140	FKN110	From 2030
Solar_ARI_1	100	ARI110A	From 2030
Solar_HIN_1	60	HIN110	From 2030
Solar_NMA_1	120	NMA220	From 2034
Solar_INV_1	200	INV220	From 2034
Solar_TKR_1	180	TKR110	From 2034
Solar_CST_1	140	CST110	From 2034
Solar_TMU_1	80	TMU110	From 2034

14.4 Geothermal

Geothermal specific generation opportunities assumptions use the generic CAPEX, FOM and VOM from section 6.5, and add:

Table 72: Geothermal specific generation opportunities assumptions

Name	Capacity	Location	Available	Emissions
	Max MW	*GIP*	*Start of year*	*Kg C / MWh*
Tauhara2a	168	WRK220	2021 fixed	61
Tauhara2b	82	WRK220	2026 fixed	61
Ngawha4	25	KOE110	From 2031	0
Mangakino	25	WKM220	From 2030	0
Mokai4	25	WRK220	From 2030	61
Ngatamariki2	50	WRK220	From 2030	61
Rotokawa3	50	WRK220	From 2030	61
Kawerau2	50	KAW220	From 2030	0
Rotoma1	25	EDG220	From 2030	0
TokaanuGeo1	20	TKU220A	From 2030	0
Tikitere1	50	TRK220	From 2030	0
Taheke1	25	EDG220	From 2030	0
Reporoa1	25	WRK220	From 2030	0
Tauhara3	30	WRK220	From 2034	61
Horohoro	5	TRK220	From 2034	0
AtiamuriGeo	5	ATI220	From 2034	0
Rotokawa4	50	WRK220	From 2034	0
TokaanuGeo2	100	TKU220B	From 2034	116
Tikitere2	50	TRK220	From 2034	116
Taheke2	25	TRK220	From 2034	0
Reporoa2	25	WRK220	From 2034	116
Ngawha5	25	KOE110	From 2034	0
Taheke3	25	TRK220	From 2034	116
Reporoa3	25	WRK220	From 2034	116
Ngawha6	25	KOE110	From 2034	0
TOTAL	**1010**			

14.5 Green peakers

Green peaker specific generation opportunities assumptions use the generic CAPEX, FOM and VOM from section 6.6, and add:

Table 73: Green peaker specific generation opportunities assumptions

Name	Capacity	Location	Available
	Max MW	*GIP*	*Start of year*
HLY_BioPkr1	500	HLY220	For 2035
SFD_BioPkr	200	SFD220	From 2035
OTOBioPkr_s1	120	OTO220	From 2030
OTOBioPkr_s2	120	OTO220	From 2030
OTOBioPkr_s3	120	OTO220	From 2030
HLY_BioPkr2	1000	HLY220	From 2035
TOTAL	**2060**		

Appendix F Multi-Criteria Analysis

Assessment Criteria	Option 1: Counterfactual	
	Score	***Description***
Confidence of security of supply	-1	**Description:** The counterfactual option relies on an 'overbuild' of renewable capacity such that no inter-seasonal storage is required to address dry year risk. i.e., there is enough renewable energy generation capacity to cover total energy demand in times of low hydrological inflow. Renewable generators built under this scenario would spill significant amounts of electricity in years of normal hydrological inflow but be utilised more effectively in dry years when energy from hydro generators is scarce. Defining the counterfactual build profile over time is challenging given it is technology agnostic, location agnostic and market led. However, EMM gives an indication of the build profile required – it is estimated that ~1,150MW of otherwise displaced wind and solar generation, and ~230MW of generation from green peakers (in 2050) would need to be delivered to maintain security of supply in dry years similar to what Lake Onslow can provide. The above generation is described as otherwise displaced as this is the amount of renewable generation that is no longer needed where the system includes Lake Onslow. These requirements are slightly different for the 2035 and 2065 years. **Deliverability:** There are two aspects of deliverability that should be considered with this option. These are: • Achievability of the overbuilt renewable generation required to cover dry year risk. • Achievability of the green peakers required to make the option feasible. **Achievability of renewable generation:** The Strategic Case, leveraging material from the Climate Change Commission and citing commentary from industry, highlights that it is unlikely the sector would be able to reach 100% renewable electricity without some form of government intervention (most likely commercial or financial incentive). It is expected that renewable build out also becomes harder to deliver with more renewable generation in the system for two reasons: 1. As more renewable generation is built (without a commensurate build out of firming capacity) average GWAPs for solar and wind generators will likely be pushed lower, negatively impacting the economic value of current and subsequent renewable generation assets. 2. There are finite locations for wind and solar generation assets, it is assumed the best (most economic) sites will be built on first, with subsequent build out moving down the chain to less optimal sites. The above reasons are particularly true for generation that is likely only to be required in times of scarcity. For these reasons there is a lack of confidence in the ability of the modelled option to practically come to fruition. **Achievability of green peakers:** The counterfactual is expected to require significantly more generation from 'green peakers' than the other options (as this option does not have a dedicated storage and dispatch solution that could be used for intermittent firming embedded within it). This could be as much as 500MW of additional green peaker capacity by 2065. While green peakers in the counterfactual scenario are technology agnostic, a credible generation source could be imported ethanol or biodiesel. An

<table>
<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 1: Counterfactual</th></tr>
<tr><th>*Score*</th><th>*Description*</th></tr>
<tr><td></td><td></td><td>
assessment by WSP of potential green fuel options suggests a $480/MWh offer price would be at the low end of what is likely for these fuels and securing enough to meet the scale required in the counterfactual is expected to be challenging.

Green peaker definition: Green peakers are a modelling tool to help balance supply and demand in the EMM. A green peaker is a technology agnostic peaker that works to cover shortfalls in energy over days to weeks (within day can be handled by grid scale batteries). This could be biomass, hydrogen, flexible geothermal, load reduction or any other technology that can provide flexible peaking capabilities. This is simply and consistently modelled as a standard combustion turbine running on high priced “green” fuel. As a result, green peakers have low(er) capital costs but high running costs. Green peakers are technically feasible, however there are no current examples of these assets in the New Zealand market at any relevant scale.

Shortage & curtailment metrics:
<table>
<tr><th>Description</th><th>Unit</th><th>2035</th><th>2050</th><th>2065</th></tr>
<tr><td>**System curtailment**</td><td>**GWh**</td><td>**0.34**</td><td>**3.34**</td><td>**0.51**</td></tr>
<tr><td>**Green peaker fuel use**</td><td>**TWh**</td><td>**0.09**</td><td>**0.34**</td><td>**0.51**</td></tr>
<tr><td>**Demand curtailment**</td><td>**GWh**</td><td>**16.4**</td><td>**43.4**</td><td>**50.3**</td></tr>
</table>

Dispatchability: wind and solar generation are subject to weather conditions. E.g., they cannot always generate electricity on demand. This makes them less able to meet dry year cover in sub-optimal generation conditions.
</td></tr>
<tr><td>***Pathway to 100% renewables***</td><td>0</td><td>
The counterfactual option is modelled / assumed to achieve the 100% renewables target by 2035. However, due to the lack of a meaningful battery in the system, it is expected that there will be considerable spill – which will affect the economic viability of future renewable build out.

Spill: Overbuilding wind / solar to cover dry years is likely to generate significant spill - estimated at (4.3TWh in 2035 – 8.9TWh in 2065). This is roughly 50% higher than in the Lake Onslow option. All things being equal, a greater amount of spilled energy should reduce the revenue that solar and wind providers receive (disincentivising additional renewable build out).
</td></tr>
</table>

Assessment Criteria	**Option 1: Counterfactual**	
	Score	***Description***
Retaining Option Value	2	The counterfactual option does not assume a single significant investment in capacity or storage at one time. Instead, the counterfactual models a staggered build out of smaller scale renewable generation assets over ~40 years. A staggered construction period provides natural stage gates to enable the system to respond to advancements in technology during the build phase (and to pivot or halt planned investments where they become uneconomic). It is assumed that the generation profile will be determined by market forces. **Modular:** The counterfactual option does not assume a single significant investment in capacity or storage at one time. Instead, the counterfactual predicts a **staggered build out of renewable generation over ~40 years.** **Technology:** Staggered construction allows for significant option value throughout the build out period as every decision to build additional generation will act as a stage gate for investors to reconsider the build of additional generation or a new / different technology option (it is assumed that the generation profile will essentially be determined by market forces). **Alternate use case:** 'Overbuilt' wind and solar generation are assumed to be the primary generation capacity avoided / otherwise displaced (under a Lake Onslow solution). Unlike a lake, which might have other commercial uses (e.g., recreational, or agricultural use) wind and solar generation does not have a clear alternate use case where other technologies make their use redundant. This risk is why the option does not score a '3'.
Reducing wholesale electricity prices	0	Without the addition of significant storage of firming generation, renewable overbuild is expected to increase wholesale electricity price volatility – increased volatility is anticipated to translate into higher electricity prices for the majority of industrial and retail consumers through a higher risk premium on spot prices and forward contracts. EMM indicates that Time Weighted Average Prices (TWAPs) under the counterfactual could be around $77MWh in 2035 growing to $91MWh in 2065. This is 6.8% higher than Lake Onslow option and 6.4% higher than the Portfolio option.
Reduced emissions	0	**Embedded carbon emissions:** The counterfactual is expected to require significant overbuild of wind and solar generation. **Supply chain:** Green peaker use (TWh): **2035:** 0.0928 **2050:** 0.3254 **2065:** 0.5073 **Supply chain emissions:** The Counterfactual makes significant use of green peakers (in excess of the amount of green peaker utilisation by other options). Green peakers are technology agnostic. However, it is anticipated that they may make use of technology that runs on fuels with associated supply chain emissions. GP fuel use figures: **Wider economy emissions:** The counterfactual is not expected to reduce wholesale electricity price volatility or wholesale electricity prices. Therefore, when compared with other options does not incentivise electrification of industrial processes and process heat.

Assessment Criteria	Option 1: Counterfactual	
	Score	***Description***
Socio-economic impacts	0	Given renewable generation build out is required nationwide, the counterfactual option has widespread socio-economic impacts (both positive and negative). The key assumption behind the scoring of this criterion is that, when compared to the other options, a distributed (negative) socioeconomic impact is likely better than a concentrated one. At a high-level the socio-economic impacts associated with the counterfactual are anticipated to be largely neutral (both negative and positive impacts will be felt - on balance these are expected to be similar to the status quo and considered neutral) but with a focus on the following areas: • Land use: The counterfactual will require a significant amount of land to be used to house wind and solar assets, this will have impacts on the amenity value of the surrounding area and may not be considered an appropriate land use for mana whenua. • Employment: it is anticipated that this option will require a significant workforce. This could have stimulatory impacts on regional centres where large scale build out is required but may also negatively impact local communities due to the disruption this construction might cause. These points are outlined in greater detail below: **Land use** • In isolation, wind turbines and their supporting infrastructure do not take up much physical land space. However, when placed in a farm, individual turbines need to have a sufficient space between them. This can add up for large-scale wind farms. Analysis of existing operational and consented wind farms in New Zealand indicate wind farm capacity density (MW/ha) is typically 0.1 MW / ha. However, this analysis includes several older farms - newer farms have turbine density in the range of 0.16 to 0.24 MW/ha.[64] • New wind farms can be set up to allow for multiple land-uses. This means that sites can serve as pastureland for livestock, cropland for farming, hiking trails, and wind generation. Multi-use application can reduce the impacts felt by local communities. • Solar projects are also able to accommodate multiple land uses. Companies such as Lodestone are collaborating with New Zealand farmers to create solar farms on working livestock farms. Built at a height of 2.3 meters and 10 meters apart solar panels allow for livestock farming equipment to access paddocks in a normal manner. The ability to collaborate with, and be built on, existing farmland maximises the site potential for solar farms in New Zealand. **Cultural** • An overbuild of wind, solar and green peakers will require significant land-use. This land-use may impact on the rights and interests of hapū and iwi associated with that land. Engagement with mana whenua will be critical to ensure that build out minimises negative impacts on these rights and interests. • Māori land trusts are actively engaged in renewable energy production across New Zealand. There is potential for increased collaboration and investment with iwi to meet renewable generation needs - leading to increased job creation, skills training,

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[64] https://www.mbie.govt.nz/assets/wind-generation-stack-update.pdf

Assessment Criteria	Option 1: Counterfactual	
	Score	***Description***
		workforce development and indigenous-led innovation. Increased involvement from iwi also enables greater connection between uri (descendants) and the environment. • Renewable build out required is anticipated to be achieved through both commercial scale and smaller community-scale projects that provide distributed electricity resources (DER) that are community owned. Community-scale DER projects can help communities address energy hardship and have been implemented successfully within rural Māori communities. In this way DER projects have shared objectives with sustainable housing, decarbonisation and addressing energy hardship goals. **Visual amenity** • Visual amenity impacts are routinely contested as some people like the aesthetics of wind farms and others do not. Depending on the recreational or cultural value of the land, the visual amenity impact could be significant for local communities. However, it is worth noting that there are established consenting processes in place when land is used for structures such as wind farms to help mitigate this impact[65]. **Economic impact and workforce** • The geographical spread of the asset types required for this option mean that there will be construction throughout the entire country. A "Wind generation Stack Update" completed by MBIE in June 2020 identified 81 different sites, over approximately 26 different sub-regions, for the potential for wind generation[66]. This helps spread the local workforce requirements over New Zealand rather than concentrating them in one location. • It is anticipated that this option will be delivered across a range of these sites and will be staggered subject to labour and resource availability. Given the magnitude of the build out required it is expected that renewable development industry would be developed and expertise might reasonably move between sites to help build out the renewable generation required (minimising the total number of workers required to build out the required generation). • It is likely that the economic benefits from increased economic activity in the region will be felt across the country. With no permanent worksite, a single communities' resources will not be overly strained for a prolonged amount of time.

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[65] https://environment.govt.nz/assets/publications/Fast-track-consenting/Section-17-Report_2021.077_Te-Rere-Hau-Wind-Farm-Repowering_Redacted.pdf

[66] https://www.mbie.govt.nz/assets/wind-generation-stack-update.pdf

Assessment Criteria	**Option 1: Counterfactual**	
	Score	***Description***
Resilience to shocks and stresses	3	As the counterfactual is distributed across NZ, it is considered highly resilient to shocks and stresses. The individual generation assets are also anticipated to be small to medium in scale and numerous, this further reduces single point of failure and natural disaster risks. Climate change modelling also suggests that wind and solar generation is unlikely to be affected on a net basis. The resilience of the option is assessed against 3 main risk factors. • **Centralisation:** The source of generation in the counterfactual is by definition decentralised which makes this option naturally more resilient to single point of failure risks. • **Natural Disaster:** The geographical spread is also advantageous from a natural hazard perspective as it diversifies generation across multiple geographies. As a result, it is highly unlikely that all generating structures will be affected a single event. • **Climate change:** Current climate change modelling indicates that wind and solar generation (on a net basis) will be unaffected.
Potential value for Money	-3	The counterfactual does not have a formal benefit cost ratio given that it generates no additional benefits. However, it is expected to have a material net present cost of PV $1,780.9 As expressed in the CBA Annex, the Counterfactual is expected to incur costs associated with: • Construction / CAPEX • OPEX • System administration A key factor impacting the value for money score for the counterfactual is the likely inability to deliver on the Investment Objectives and provide confidence of security of supply in dry years. This is supported by the significant use of green peaking technologies and / or shortage in the EMM results. While the cost of the resulting shortage has not been calculated[67], EMM results indicate this would be higher than the other options. Additionally, the cost of delivering the counterfactual has been developed using the outputs of the EMM but does not include detailed consideration of the technical and commercial feasibility of delivering the degree of overbuild assumed in the counterfactual. As a result, it is expected that the true cost of implementing the counterfactual is likely understated.
Affordability	-1	As noted above, the expected net present cost of the counterfactual is expected to be PV $1,780.9. This cost has been developed using outputs of the EMM and does not include a detailed assessment for the technical and commercial feasibility of delivering the

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[67] Detailed cost of shortage analysis has not been calculated for the options as part of the IBC but has been considered qualitatively as part of the Confidence in Security of Supply assessment. Further quantification of the whole of economy cost of shortage for each option in a future highly electrified society and economy is expected to be developed through the DBC.

<table>
<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 1: Counterfactual</th></tr>
<tr><th>Score</th><th>Description</th></tr>
<tr><td></td><td></td><td>degree of overbuild included in the counterfactual. As a result, it is expected that actual the cost of delivering the counterfactual would be higher.[68]</td></tr>
<tr><td>Supplier capacity and capability</td><td>2</td><td>Major national build out of wind and solar generation to meet increasing electricity demand is required under all options. As a result, it is expected that New Zealand will need to build out a significant workforce and industry that specialises in wind and solar installation regardless of which option is preferred. Although large in total scale, the overbuilt portion of wind and solar generation will be relatively minimal for each given year (when compared to the base line build out required).
The workforce that is currently building out New Zealand’s renewable generation is expected to be the backbone of the workforce that builds out the additional generation, it is anticipated that any additional support can be sourced within the New Zealand job market. However, three elements pose some significant challenges, (which is why this scores a ‘2’) these are::
1) Generation build out: The counterfactual option requires large scale build out of renewable generation, roughly 420MW of generation is required every year to 2065 to meet expected demand. Net supply growth has averaged only 60 MW per year from 1990 – 2020. Given this, there is significant uncertainty around the ability for construction and labour markets to deliver this in time. Further, there is uncertainty around the market providing all required generation without significant fiscal or economic incentive – this is particularly pertinent for otherwise displaced generation (~1,160MW) that is required for dry years given that this generation is likely to be the least economic.
2) Green peaker build out: As a result of a heavy reliance on renewable generation to cover dry year risk, the electricity system under the counterfactual option would be subject to periods of intermittency (this will lead to both generation spill and periods of energy scarcity). To mitigate this risk and provide peaking capabilities, the counterfactual places a much greater reliance on ‘green peakers’ than the other options. As an example, the counterfactual requires twice the level of green peaker generation than the Lake Onslow option.
The counterfactual is expected to require significant generation from ‘green peakers’ (this could require as much as 250MW of additional green peaker capacity by 2065). While green peakers in the counterfactual scenario are technology agnostic, a credible generation source could be imported ethanol or biodiesel. An assessment by WSP of potential green fuel options suggests a $480/MWh offer price would be at the low end of what is likely for these fuels. Further, securing enough green</td></tr>
</table>

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[68] Further analysis on the cost of delivering the counterfactual is expected to be developed through the DBC.

<table>
<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 1: Counterfactual</th></tr>
<tr><th>Score</th><th>Description</th></tr>
<tr><td></td><td></td><td>peaker fuel to meet the scale required in the counterfactual is expected to be challenging. For example, international biodiesel / ethanol markets are relatively small (in comparison to other energy markets) and are anticipated to become increasingly competitive. This is important as there is currently no clear domestic sources of sufficient scale.

The challenge of the build out is exacerbated by uncertainty around the market’s ability to provide all required generation without significant fiscal or economic incentive – this is particularly pertinent for otherwise displaced generation required for dry years given this generation is likely to be the least economic.

The scale of green peaker investment required and the likely need for regulatory incentives (across all generation types) to encourage this investment, should be acknowledged as a material uncertainty in the achievement of the security of supply objectives without NZ Battery.
3) The purchase and consent of sufficient land to implement the level of generation required is likely to be challenging. As an example, wind farm developers from the New Zealand Wind Energy Association investigate potential wind farm sites with good wind speeds and proximity to the transmission network throughout New Zealand. They have currently investigated 9 new sites across New Zealand that are available for consent application and have 8 more that are still under investigation.[69] The current sites identified do not have enough capacity to facilitate enough wind turbines, and there is a real challenge to identify enough appropriate onshore locations in New Zealand to build out wind farms to the extent required. This same challenge applies to solar farms – although to a lesser extent given the lower comparable capacity of solar required.
While the displaced generation from NZ Battery is comparably small (to the total system build out required) it is likely to be the least economic and that which is in the least desirable locations from an energy generation perspective. Specifically, it is assumed that 179MW of displaced wind, 910MW of displaced solar, and 250MW of displaced green peakers (in 2050) would need to be delivered.</td></tr>
<tr><td>Localised environmental impacts</td><td>-1</td><td>By definition, the counterfactual is location agnostic, and the impacts of the option are not expected to be significantly attributable to one, or a small number of locations. In addition, most environmental impacts are in relation to construction as renewable generation assets generally do not degrade the environment when operational. As the scale of build out grows, it will become increasingly challenging to find sites that balance energy source requirements with a desire to minimise local impacts from construction – this may drive investment activity offshore (offshore wind is assumed to be a viable generation option within the modelling period) or will add cost to projects. The implementation of offshore wind is likely to have resource management implications.
A sample of generic localised impacts is provided below:</td></tr>
</table>

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[69] https://www.windenergy.org.nz/proposed-wind-farms

<table>
<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 1: Counterfactual</th></tr>
<tr><th>Score</th><th>Description</th></tr>
<tr><td></td><td></td><td>Species and habitats
• Wind energy can have adverse environmental impacts, including the potential to reduce, fragment, or degrade habitat for wildlife, fish, and plants. Furthermore, spinning turbine blades can pose a threat to flying wildlife like birds and bats. However, the exact impact on local bird and bat life can vary. Correctly siting wind farms (to avoid migratory paths) can often help eliminate most of these concerns.[70]
• Additionally, building wind farms can disrupt the natural habitat of several different animal species: constructing wind farms requires human accessibility to otherwise remote areas. This can sometimes mean building new roads or clearing land. This can result in habitat segmentation and loss for certain local animal populations.[71]
Land use
• Depending on their location, larger utility-scale solar facilities can raise concerns about land degradation and habitat loss. Total land area requirements vary depending on the technology, the topography of the site, and the intensity of the solar resource.
• Concentrating solar thermal plants (CSP), like all thermal electric plants, require water for cooling. CSP plants that use wet-recirculating technology have cooling towers, these towers use between 2,270 and 2,460 litres of water per megawatt-hour to cool the plant.
• The coastline and oceans are held in very high esteem in New Zealand with many New Zealanders feeling passionate and connected to our beaches and waters. Offshore wind developments will need to manage this issue under RMA and EEZ legislation and the upcoming offshore renewable regulatory system.</td></tr>
<tr><td>Legislative, regulatory and market risks</td><td>0</td><td>The land requirements for the counterfactual pose potential legislative and regulatory risks – i.e., the amount of land required for the counterfactual will be hard to consent. If locations cannot be found onshore, offshore options may be investigated and there are likely additional legal and regulatory implications for these types of projects (policy is still being developed on offshore renewable energy development in New Zealand). There would, however, be expected to be a level of piggybacking associated with the legislative and regulatory efforts required in the wider energy transition which is why this scores a ‘0’. Moreover, this option does not create any fundamental change to the way the current market operates.</td></tr>
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[70] https://www.energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects#:~:text=As%20with%20all%20energy%20supply,wildlife%20like%20birds%20and%20bats.

[71] https://www.windenergy.org.nz/store/doc/WindFarmDevelopmentinNZ_AFrameworkforBestPractice.pdf

<table>
<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 2: Lake Onslow</th></tr>
<tr><th>Score</th><th>Description</th></tr>
<tr><td>Confidence of Security of Supply</td><td>2</td><td>
<p>The size of storage, generation, and speed of energy dispatch make the Lake Onslow option an effective solution to manage dry year risk (as well as shorter term intermittency issues) – this is evidenced by lower system curtailment, green peaker use and demand curtailment metrics than the other options. Lake Onslow also makes use of mature technology and is considered feasibly deliverable by 2037.</p>
<p>The base case configuration of Lake Onslow includes 5TWh of energy storage and 1000MW of installed capacity. This is in addition to the wider renewable investment required to meet an increase in the expected demand for electricity.</p>
<p>Deliverability: Investigative and feasibility work to date provides a reasonable level of confidence that a Lake Onslow option is deliverable by in the mid-2030s and would be effective at mitigating dry year risk. Further, the fact that this option is assumed to be driven by government provides further support to the assessment that this will be delivered (in a way that a pure market delivered solution does not).</p>
<p>Shortage & curtailment metric: It is expected that the presence of a battery solution will better solve the dry year risk problem than the counterfactual.</p>
<table>
<tr><th>Description</th><th>Unit</th><th>2035</th><th>2050</th><th>2065</th></tr>
<tr><td>System curtailment</td><td>GWh</td><td>0.24</td><td>0.07</td><td>0.33</td></tr>
<tr><td>Green peaker fuel use</td><td>TWh</td><td>0.05</td><td>0.19</td><td>0.32</td></tr>
<tr><td>Demand curtailment</td><td>GWh</td><td>15.6</td><td>36.4</td><td>38.3</td></tr>
</table>
<p>Dispatchability: Hydro-electric power plants can dispatch electricity within seconds, Lake Onslow is expected to be able to dispatch electricity in a comparable timeframe. This speed means Onslow is able to provide short-, medium- and long-term firming (including addressing dry year risk). Note, it is not anticipated that Lake Onslow would need to switch rapidly between pumping and generation (ramping from maximum load in either pumping or generating to the opposite mode is anticipated to take between 10-15 minutes). However, rapid ramping in either mode is expected to be possible. This speed means Onslow is able to provide short-, medium- and long-term firming (including addressing dry year risk).</p>
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Assessment Criteria	Option 2: Lake Onslow	
	Score	***Description***
		Analysis of 89 years of hydrological inflow sequences show that the ‘driest’ year could have been managed with 5TWh of generation capacity. In this sense, and assuming appropriate inflows in the year required, Lake Onslow could have managed the dry year risk in all of the previous 89 years[72].
Pathway to 100% renewables	3	The Lake Onslow option is anticipated to significantly support the pathway to 100% renewable generation. This support is expected to manifest in the following ways: 1. It is expected that Lake Onslow will help to mitigate wholesale electricity price volatility – by purchasing electricity when prices are low and generating when prices are high. This is expected to provide greater certainty of revenue for intermittent renewable generators and improve the overall revenue they can expect to receive (generators will have a buyer in times of abundance). 2. In having significant capacity and on demand storage, Onslow has the ability to offer derivative electricity products (e.g., Onslow could offer generation options – akin to a call option - to renewable generators to hedge their intermittency exposure). Where Onslow operates in this way it is expected that Onslow could both reasonably reduce the price of derivative instruments (by significantly increasing supply with a low SRMC generation source [hydro]) and improve the economic conditions for renewable generators. **Spill:** the amount of ‘spill’ estimated in a system that includes Lake Onslow is (2.3683TWh in 2035 – 4.5937TWh in 2065). This is roughly 50% lower than in the Counterfactual.
Retaining option value	-1	The Lake Onslow option retains less option value flexibility than the other options for three key reasons: 1. The fixed costs associated with the build of this option (e.g., the construction of pumping and generation tunnels, tail races, lower reservoir etc.) make it difficult to meaningfully stage the build in an economically efficient way – pumped hydro systems have a significant degree of economies of scale associated with them. 2. Once construction starts it is difficult to adjust for technological improvements and once completed, there is very limited change that can be implemented. 3. Where an option materialises that is better able to manage dry year risk, then there are few ways in which Lake Onslow could meaningfully pivot to play a significantly different role. **Scoring against the criteria:**

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[72] In reality, each dry year is always different, historic inflows are not strictly predictive, and there are other system issues to consider (i.e. calm, cloudy). However, having a battery that in theory is large enough to manage all historic dry years encountered should be considered supportive of scoring for this criteria.

Assessment Criteria	**Option 2: Lake Onslow**	
	Score	***Description***
		Modular: There are limited practical options for modular building of a large scale asset such as a dam. When construction starts, there is a large commitment and cost associated to the project. Building in provisions to cease construction, should it be required, would be expected to attach significant cost premiums. **Technology:** once construction starts it is difficult to adjust for technological improvements. Additionally, when construction has been completed there is very limited change that can be implemented. **Alternative use case:** If other technologies materialise that are better able to address dry year risk and meet firming requirements, Lake Onslow has limited alternative use cases. **Foreclosure of opportunity:** Lake Onslow will likely reduce the incentive for the market to build out other peaking technology – however, EMM suggests that green peakers will still be built (just in lesser values than is expected for the counterfactual). Lake Onslow is effective at reducing spill (although some spill is still expected to occur in normal hydrological years – particularly in the North Island). For example, it may reduce the economic incentive to develop a domestic hydrogen production market (noting however that it is acknowledged the development of hydrogen technology at scale is has significant uncertainty).
Reducing wholesale electricity prices	3	A Lake Onslow pumped hydro scheme would be expected to reduce price volatility in the market with potential flow on benefits for consumers. Further, EMM estimates that the inclusion of Lake Onslow within the electricity market could lead to a roughly 6.8% reduction in average wholesale prices over the modelling period as compared to the counterfactual. **TWAP figure ($/MWh): 2035:** 73.59 **2050:** 80.67 **2065:** 83.51
Reduced emissions	1	Lake Onslow is expected to have significant embedded carbon emissions associated with the build of the dam but significantly lower green peaker use than the counterfactual and portfolio options and no operational emissions (although there will be a small amount of emissions that will be released from the lake). Further, Lake Onslow is expected to have a greater useful life than the generation assets built under the other two options – improving the overall emissions profile (as embedded carbon emissions associated with expected asset renewal will be lower). **Embedded carbon emissions:** Finer details of the dam are yet to be finalised hence there is some uncertainties regarding emissions, however emissions analysis undertaken by NIWA indicate that embedded emissions over the lifetime of the project could be as high as: 1,949,696t of C02-eq. This is made up of the below: • 1,006,815 tonnes of CO_2eq for the upper dam materials • 340,200 tonnes of CO_2eq for the upper reservoir • 338,188 tonnes of CO_2eq for the operational energy • 264,493 tonnes of CO_2eq for the headrace and tailrace tunnels materials

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<tr><td></td><td></td><td>Supply chain emissions: The Lake Onslow option makes use of green peakers (albeit at a much lower rate than the counterfactual and portfolio options). Green peakers are technology agnostic. However, it is anticipated that they may make use of technology that runs on fuels with associated supply chain emissions. GP fuel use (TWh): 2035: 0.0450 2050: 0.1870 2065: 0.3220
Wider economy emissions: Lake Onslow is expected to reduce wholesale electricity price volatility and wholesale electricity prices when compared against the counterfactual. This is expected to incentivise electrification of industrial processes and process heat leading to wider economy emissions reduction.
Operating emissions: research conducted by NIWA indicates that there are post-impoundment emissions associated with Lake Onslow as a result of inundating land. It is estimated that the net GHG emissions predicted as a result of the inundation of Lake Onslow (at 760mRL) are 1,590 tonnes of CO2-eq per year.</td></tr>
<tr><td>Socio-economic impacts</td><td>-1</td><td>Being one large solution, the Lake Onslow option will have significant and material localised impacts. Some of these are expected to be positive (in terms of growth in economic activity in the area during construction and the possibility for co-investment with mana whenua) but many are expected to be negative. These include increased pressure on local services, reduced recreational opportunities, and impacts on significant heritage sites. On balance it is anticipated that Lake Onslow will have a negative socio-economic impact on the local community.
Recreation
Lake Onslow is used for recreational boating, swimming, fishing, and picnicking while Lake Onslow Road is used by cyclists. The impacts to each are outlined below:
• There is concern about potential adverse impacts on the Roxburgh Gorge and Clutha Gold Cycle Trail along the Mata-Au/Clutha River which could include rerouting, creating a less desirable route and disruption during construction which may deter visitors from the area.
• Lake Onslow has a high number of brown trout. There are approximately 17 privately or club-owned angling huts on private land (or on the marginal strip) surrounding Lake Onslow. Club competitions and fishing research are held annually. Angling also occurs on the tributaries to Lake Onslow and Te Awa Makarara/Teviot River.
• While it may be possible to relocate the angling huts the new reservoir would likely be a poor fishery and the huts would at times of drawdown be some distance from the shore. The new reservoir would have almost no spawning habitat and fluctuating water levels would mean littoral zones (stable lake edges with weed beds) would also be compromised at drawdown.
• Analysis completed by Rob Greenway & Associates (RGA) concludes that, when viewed at a regional level, the recreation value of the activities at or around the Lake are high (cycling and sightseeing) and moderate (all others). The proposed inundation of the Lake will result in the loss of connection and/or severance of public access to a range of locations around the Lake which in some instances will remove the ability for some existing recreational activities to continue in the future.</td></tr>
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<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 2: Lake Onslow</th></tr>
<tr><th>Score</th><th>Description</th></tr>
<tr><td></td><td></td><td>Potential mitigants:
• Retaining access and the use of the upper reservoir for fishing, boating, swimming and picnicking would avoid or at least mitigate the loss of those values at Lake Onslow. However, the ability to carry out these activities would depend on safety, lake levels, and how frequently and the magnitude of lake draw downs.
• There may be an increase in recreational infrastructure tourism that could occur as a result of the build of the
• The provision of alternative road access to Lake Onslow, both during construction and once the project is operational, may also help mitigate the loss of access to the Lake and provide options for recreational activities.
Heritage
• Eight recorded archaeological sites sit within the proposed inundation area, including one assessed as having ‘high’ significance. An additional six recorded archaeological sites within 1km of the inundation area may also be adversely impacted as a result of changes in lake water levels (which can cause high levels of erosion).
Potential mitigants: A range of mitigations would be required to limit the heritage impacts:
• Full excavation of the sites under the supervision of a qualified archaeologist and/or appropriate mana whenua representative, including careful recovery of any identified archaeological objects for further review, protection and restoration. A Social Impact Management Plan (SIMP) is prepared and followed throughout all phases of the project. There needs to be continued engagement and communication.
• A full and comprehensive Social Impact Assessment is undertaken following the requirements and approach set out in the Interim Assessment
• An archaeological assessment of the inundation area should be completed along with detailed engagement with mana whenua (facilitated through Aukaha).
Farmland
• Inundation of the Onslow basin to form the upper reservoir is expected to lead to the potential loss of up to 6,000 hectares of farmland. Additional farmland would also be required for the build out of key pieces of infrastructure including the dam, lower reservoirs, road improvements and construction areas. Through community consultation, landowners and farmers have raised concerns that the loss of land could affect the integrity of farm operations, as a range of low, medium and high-country land is optimal to a high-performing farm in the region.
Visual amenity</td></tr>
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<tr><td></td><td></td><td>• The physical works within the project area, both during construction and operation, could generate adverse effects that could in turn reduce or erode amenity values within the area. Those effects include visual changes in the landscape, and increased noise, dust, rubbish, signage, and traffic.
Local community
• An influx in construction workers and others associated with the project could cause social disruption and additional demands on the housing market, social services, community services and social cohesion. During early consultation community members have raised concerns that this could affect the attractiveness of the area for retirement living, remote workers, and workers in sectors other than construction.
There are also a range of positive socioeconomic impacts expected from such an investment, these include:
Future general recreation
• There are potential positive impacts for future recreational and tourism opportunities brought about by the increased profile of the area from the project. This could include opportunities for local farm-based tours and accommodation, four-wheel drive tours and cycle tours. There is potentially even an opportunity for ‘infrastructure tourism’.
Economic
• A large construction workforce will be required, for example, which is estimated to be up to 2,500 people over seven years, with a peak of over 1,000 workers at any one time. This influx of workers will stimulate economic activity in and around the region. This will provide positive economic opportunities for many local businesses.
Local Community
• New short-term accommodation and a form of construction camp would likely be required (and is costed) to accommodate the incoming construction workers. Community consultation raised queries as to what would happen to this infrastructure and new housing supply once the project complete, and whether that accommodation and infrastructure could be repurposed or integrated into the existing community (such as for seasonal workers or visitors).
Partnership
• The scale of the build out required to implement the Lake Onslow option will provide significant opportunity for co-investment with mana whenua. There also exists significant opportunity for iwi / maori more generally through achievement of government indigenous sourcing targets during the procurement stage. Finally the complexity of the project may provide meaningful opportunities for employment and training of rangatahi.
This analysis has been informed by community consultation as well as analysis completed as part of the feasibility assessment. Potential mitigations have not been materially incorporated into cost estimates and this should be (one of many focuses) for the DBC should this option progress.</td></tr>
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<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 2: Lake Onslow</th></tr>
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<tr><td>Resilience to shocks and stresses</td><td>0</td><td>The Lake Onslow option, is a single dry year solution located in the South Island – this creates a single point of failure risk, and also exacerbates the national electricity system’s reliance on the HVDC link. However, it is worth noting that none of the options completely remove the national electricity system’s reliance on the HVDC link. For example, New Zealand's electricity system will still be vulnerable to HVDC link failure regardless of the implementation of any of the options – each option will just impact the degree to which New Zealand is impacted where the link fails.
Although Lake Onslow increases risks around single points of failure, the Lake Onslow option is not considered at higher risk of natural disasters than the other options as it has been designed to be highly resistant to seismic shocks.
The resilience of the option is assessed against 2 main risk factors:
Centralisation
• This is a highly centralised asset located in the South Island. It has scored poorly on this basis.
Natural Disaster
• The preferred dam type (low cementitious roller compacted concrete) is highly resilient to earthquakes, and is among the type of dam that has the lowest failure rate of all dams worldwide. Should the structure be damaged as a result of an earthquake, this dam type is less likely to suffer a piping failure that would require a rapid draw down of the reservoir to avoid a catastrophic dam failure (compared to an earth dam). An earth dam structure normally requires dewatering if post-earthquake leakage occurs as ongoing seepage can progress to piping failure.
• Although the site is in a relatively low seismicity area of New Zealand, stringent seismic criteria have been applied, and the design of the structures has been made to NZSOLD (NZ Society of Large Dams) design guidelines and risk classifications, and used ICOLD (International Commission on Large Dams), ANCOLD (Australian National Committee of Large Dams) and USBR (United States Bureau of Reclamation) design criteria and guidelines to deliver a world class standard of safety. Seismic design criteria was provided by Prof. Mark Stirling, a recognised expert in regional seismicity, and reflect the direction of travel of increasing seismic hazards used in structural design in New Zealand (the applied criteria is more stringent than current public databases suggest).
• The HVDC inter-island transmission link has redundancy of assets throughout: the major risk identified is an earthquake large enough to generate a Tsunami that could flood one of the two cable termination stations. These stations are designed to withstand 1 in 2500 year events, and an earthquake in this location and of that magnitude would likely cause extensive regional damage.
Current climate
• Current climate change modelling indicates that New Zealand‘s climate will reduce the amount of water falling as snow (increasing the amount of water for hydro generation in winter) which is advantageous for this option.</td></tr>
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Assessment Criteria	**Option 2: Lake Onslow**	
	Score	***Description***

Potential value for Money	-3	The Lake Onslow option has a Benefit Cost Ratio (BCR) of 0.42. This option ranks as best of all options, but is still, in economic terms, a poor BCR.
		• The assumed Benefit Cost Ratio (BCR) for Lake Onslow is 0.42. This represents a scenario where 42 cents of public value is returned for every dollar spent. This BCR is reflective of only those cost and benefit items that could be monetised.
		• The primary monetised benefits from a Lake Onslow solution are:
		  • PV $1,818.1 in electricity market benefits accruing from avoided total system generation costs (and reduced shortage) as compared to the counterfactual.
		  • An assumed increase in productivity for electricity dependent firms and businesses that is estimated at PV $1,236.9M.
		  • Terminal value of hydro assets at the end of the modelling period (PV $948.2M)
		• The total economic cost of a Lake Onslow solution is estimated at PV $9,585.3M.
		• This consists of the following major inclusions:
		  • PV $8,536.6 for construction CAPEX and renewal and replacement CAPEX
		  • PV $1,048.7 for OPEX
		• Transmission costs includes the direct cost of connecting the to the transmission grid and a proportional cost of wider transmission upgrades required over the modelling period. These are included in the construction CAPEX and OPEX figures above.
		• The presence of a significant new generation (and demand) asset on the South Island will put extra pressure on the HVDC. This inherently raises the consequence of outage which is assessed at being a $1m p.a. risk adjusted economic cost.
		• A new entity, or possibly multiple entities, will be required to develop the project and manage the corporate operations. It is assumed that this would equate to a roughly PV $158.2M.

Affordability	-2	It is assumed that a Lake Onslow Solution would incur an NPC of $9.5B which is why this option scores a -2. This is the second most expensive option behind the Portfolio option. • The CBA demonstrates that Lake Onslow has an NPC of $8,536.6m for CAPEX and an NPC of 1,048.7m for OPEX.
Supplier capacity and capability	1	This option has been investigated in greater detail than the other options and therefore there is a higher level of confidence in the technical deliverability of the solution. That said, Lake Onslow is a technically complex and resource intensive project with a number of significant risks and impacts that will need to be carefully managed. Key risks to the project are: • Supplier capacity

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<tr><td></td><td></td><td>• Supplier and workforce capability (both technically and from a physical number perspective)
• Supply chain – Lake Onslow is not close to any significant ports and supply chain disruptions could have a significant impact on the timeline of the project.
• Legislative – an empowering act that alters the RMA is likely required to consent Lake Onslow.
These factors are explored in detail in the associated technical feasibility reports. A high level summary of key considerations is provided below, grouped by theme.
Supplier capacity
• A construction period of 7 years has been forecasted for Lake Onslow. It is then anticipated that it could take between 1 and 3 years to fill. For the purposes of this assessment, it is assumed that Lake Onslow could be operational in the mid-2030s. One of the recommended environmental mitigation actions is to use a smaller upper reservoir (3TWh) and ensure it ‘slowly’ fills (which could take over a decade), this would reduce the environmental footprint and provide time for mitigation works and species adaptation. However, it is noted that ‘slow’ filling of the lake is contrary to the specific purpose of the project, and it is accepted that such a timescale is not likely to be feasible given the drivers to advance expediently with the project.
• An assessment of construction work force numbers has been made to inform the construction compound and village sizes and requirements together with the demand for temporary power, water and wastewater services. It has been assessed that the skillsets and capacity is available.
• A list of construction materials and equipment required to deliver the project has been compiled. The focus has been on identifying ‘routine’ materials that can be sourced from within New Zealand and the local supply chain. Suppliers of materials have been approached for pricing and this has been used in the cost estimates.
• Processing for things such as aggregates, roller compacted concrete (RCC) formation and concrete batching will occur at the main dam and lower reservoir construction sites using locally quarried material. Materials for concrete batching will be sourced from existing or new quarries close to the dam.
Dam design and facilities
• Construction of the scheme will require power that is not currently available near the proposed work sites, and potable water sources for both human and construction consumption. New infrastructure will need to be put in place so that adequate power can be sourced from Transpower’s Roxburgh substation. Furthermore, the wastewater produced by the construction process as a whole (workers and equipment by-product) requires an adequate treatment system to meet the production demand and not contaminate the surrounding environment.
• At peak construction, 8 million litres of water will be required each day for the likes of worker consumption and construction processes. Water will be supplied by Lake Onslow and the Mata-Au/Clutha River. Water treatment plants would be created to facility water recycling where possible.</td></tr>
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<tr><td></td><td></td><td>Workforce
• As a base case for feasibility assessment, it has been assumed that from a social impact perspective that the project supports regional development by upskilling and providing long term employment to locals as a primary focus, but that the majority of the workforce will be “fly in-fly out” (FIFO) and will be accommodated in the constructed temporary workforce accommodation. In practice, there is optionality about the precise workforce mix.
• The estimated workforce at the peak of construction is anticipated to be approx. 1,320. This will be made up of a diverse workforce that has a wide range of skill sets. From specialist plant operators, construction, contract and project managers, site and supervising engineers, to qualified trades people, large plant operators, general construction supervision, and comprising experienced labour, gatemen, small general operators, drivers, administrative.
Supply chain
• The rural location of Lake Onslow creates a number of issues, some of which are explained above. Ports to import large machinery from overseas have been identified and deemed as appropriate.
• Early assessments shows the largest lead time for any machinery is up to 24 months and that the NZ Government Procurement Rules will apply as per normal.
Legislative
• There is a considerable risk that even with mitigation, environmental off-setting and/or compensation in place, a decision maker may determine that the adverse effects of the project on important natural, physical and mana whenua values are too high, particularly given the legislative and planning framework within which that decision is to be made (principally the Resource Management Act 1991 (RMA)) does not specifically elevate broader climate outcomes.
• Within that context and if the project is to begin construction as soon as possible, the Consenting Strategy determines that the only sufficiently timely and certain option for obtaining the necessary consents is to put in place project-specific bespoke legislation. Such legislation would need to provide the project with an altered decision-making framework that reflects the importance and urgency of Aotearoa New Zealand’s climate response and provides an appropriate weighting for the benefits of the project in responding to those climate challenges, effectively bringing forward the expected outcomes of legislative reform and national policy direction currently underway.
It is noted that all of the issues noted above have been included/used to inform the cost estimate for the project.</td></tr>
<tr><td>Localised environmental impacts</td><td>-3</td><td>The Lake Onslow option has significant and widespread localised environmental impacts. Specifically, Lake Onslow is expected to irreparably impact wetlands, threaten local species (including the Teviot flathead galaxias and the Burgan skink), impact local farmland and waterways, and create a significant amount of overburden that must be disposed of locally. There are options to</td></tr>
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Assessment Criteria	Option 2: Lake Onslow	
	Score	**Description**
	🟧	mitigate and offset some of these impacts – but many mitigations are complex and costly and require more detailed consideration at DBC stage. On balance, the Lake Onslow option is expected to significantly negatively impact the local environment. There is an extensive range of potential negative environmental impacts owing to the Lake Onslow option. These have been thematically grouped below. **Loss of habitat, species and wetlands** • The population of Burgan skink in the inundation area is of national significance. It is threatened nationally and endangered. Increasing the size of Lake Onslow through inundation to create the proposed upper reservoir would result in the loss of existing habitat for the lizard species identified above, as well as the loss of individual lizards. Inundation could also affect the habitat of as yet unidentified lizard species inhabiting the area. Nationally threatened and vulnerable birds, terrestrial invertebrate, and plant species face the same threats. • Negotiations [redacted] [redacted] • The unavoidable loss of extensive, diverse, and rare wetlands within the inundation area will be one of the most significant adverse effects arising from the project. Wetlands will not re-establish around the new lake because of the fluctuating water levels that are proposed. Protecting areas of significant indigenous vegetation and significant habitats of indigenous fauna is a matter of national importance within the RMA. The potential impacts on indigenous biodiversity are significant due to the scale of the proposed inundation of land, the types of habitats and species that are present in the impacted areas, and the conservation status (or value) of some of those species. • Large wetland complexes in upland basin floors in Central Otago have historically been significantly reduced in extent because water storage reservoirs were often located in these basins. The filling of the current Lake Onslow, the Greenland Reservoir and the Loganburn Reservoir inundated the three largest of these wetland complexes that historically were present in this part of the Otago uplands. This loss is consistent with the national experience, with approximately 90% of Aotearoa New Zealand wetlands having been drained since human settlement. Between the period 2001-2016, at least 214 individual wetlands with an area of 1247ha were lost. As a result, national policy direction (NPS-F) requires the avoidance of any further loss of natural wetlands. • Negotiations [redacted]

Assessment Criteria	Option 2: Lake Onslow	
	Score	Description
		• Negotiations [redacted] **Water ways and water quality** • The main tributaries will lose several kilometres of their length to the Lake and some sub-tributaries draining into those will also lose substantial amounts. Under the 5TWh option, 215km of stream length would be lost. This inundation will result in the loss of some freshwater habitats and alteration of some ecosystems. Further, some remaining streams may become too short to support certain fauna or ecosystem services. This loss is therefore considered to have a very high level of effect. • As previously noted, different water sources and supplies will be mixed, because of this there is the potential for didymo and other aquatic pest plant species to become established in the outflowing Te Awa Makarara/Teviot River. • Water temperature is the dominant influence on density in freshwater systems (water is at its most dese at 4°C), which determines whether the water column is stratified or well mixed. Feeding one water source into another increases the risk of stratification in Lake Onslow. It is more likely that the lake will split into layers due to differences in temperature, this can lead to a reduction in dissolved oxygen levels, which can be detrimental to fish health and the health of other biota. Increased periods of stratification can be expected to increase the risk of the lake becoming hypoxic in some layers (levels of dissolved oxygen are too low to support life) • This is particularly important given the levels of dissolved inorganic nitrogen in the Mata-Au/Clutha River (as the proposed water source for the upper reservoir) are higher than those in Lake Onslow and its tributaries. Due to this there is an expected increase in the amount of algae produced and its effects will be even more detrimental if it sits at the top of the lake and staves the water of oxygen. • There is also a moderate risk that inundation of extensive areas of tussock peatland and farmland during the creation of the proposed upper reservoir could result in significant nutrient and dissolved organic compound influx, along with oxygen demand from flooded soils and tussock peatland vegetation. This process also has the potential to reduce the water quality in the proposed upper reservoir. • The excavation of material for the intake, tunnel and dam construction could intercept groundwater. Change to the hydrological regime could adversely affect ecology (such as disrupting the source for spring/ground fed tributaries or wetlands, which would indirectly affect habitat for fish species) and reduce the quantity and contaminate groundwater available for water supply **Contamination** • The project could generate adverse contamination effects in two ways. The first is through the disruption of existing contamination that could result in further effects on human health and the surrounding environment. The second way is by causing contamination of land through the discharge of contaminants into the ground.

Assessment Criteria	Option 2: Lake Onslow	
	Score	*Description*
	🟧	• The project includes activities which will result in discharges to air at both the construction and commissioning/operation stages. It is possible that those discharges may have some effects on air quality. In the absence of appropriate management, these discharges all have the potential to adversely affect human health (respiratory), values of significance to Kāi Tahu, the health and functioning of eco-systems, plants and animals, cultural, heritage and amenity values, and surrounding farming practices (including crop production). • Earthworks required will be substantial and may result in the loss of some, if not all, nutrient soils in the Lake Onslow Area. Earthworks may also lead to a loss of vegetation cover, which could increase susceptibility of the project area to erosion. These are problematic as disruption to and loss of topsoil, increases the risk that other soils could be discharged into nearby water bodies. **Cultural** • Kai Tahu ki Otago[73] is the relevant iwi authority for the Clutha / Mata-au catchment, where Lake Onslow is situated. Individual papatipu rūnaka[74] will have specific interests in particular areas and should be engaged with directly during DBC stage if this option is progressed.[75] A preliminary cultural values assessment has been produced by Aukaha to support the report by Te Rōpū Matatau. Note that the current cultural impact assessment is high level and there has been no detailed assessment of how and to what extent the project would adversely affect mana whenua values within the project area. • The following cultural values for ka rūnaka were identified: Wai (water), Wetlands, Wāhi tupuna (ancestral landscapes of significance to iwi), Ara tawhito (traditional travel routes), Other archaeological features, Ecology, Matters of equity. • Lake Onslow and Te Awa Makarara/Teviot River is listed within the Otago Regional plan as being a wāhi mahika kai. The Mata-au/Clutha River and its tributaries are an important habitat for native fish, bird and plant species, many of which are nationally threatened or at risk. A number of taoka species are found at Lake Onslow and are listed as a taoka in the Ngāi Tahu Claims Settlement Act 1998. Loss of biodiversity and taoka species is a threat and significant priority for ka rūnaka. Freshwater degradation through damming, inundation, wetland removal, introduction of exotic species and other human activities has impacted on mahika kai (practices, knowledge and activities related to food gathering), taoka specifies and significant ancestral sites. Both mahika kai and wāhi tūpuna are central to Ngāi Tahu identity and history creating a loss in mātauraka-a-iwi and connection to place. Ka Rūnaka are clear that this project should be undertaken in a way that protects threatened species, and will restore, retain and where possible improve native habitats.

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[73] The Ngāi Tahu dialect is used for the option 2 analysis replacing ‘ng’ with ‘k’.

[74] Ngāi Tahu adopts a Papatipu Rūnaka structure. There are 18 Papatipu Rūnaka that fall under Ngāi Tahu, reflecting the whānau and hapū layer.

[75] Clutha District Council, Mana Whenua Schedule, District Plan 2017. See Schedule 6.10 for issues affecting the Ngai Tahu Claims Settlement Act 1998.

Assessment Criteria	Option 2: Lake Onslow	
	Score	*Description*
	🟧	• Lake Onslow is in an area that was once an extensive wetland and important to mana whenua for mahika kai and mātauraka. Many of these wetlands have been destroyed through human activity. Wetland protection is important to mana whenua in terms of the role wetlands play for ecosystem health, biodiversity and the longevity of mātauraka-a-iwi (local iwi knowledge).The NPSFM provisions aim to prevent any further loss of natural wetlands. • There are archaeological sites of significance to mana whenua within the Matau-au/Clutha river catchment. There are many Kaika nohoaka (settlements) and ara tawhito (ancient accessways) in this catchment which are significant to Kai Tahu identity and history. Mana whenua have advocated for detailed archaeological investigations and assessments of the inundation zone which could be impacted by the project. • Ka rūnaka have responsibilities to protect and care for the environment which directly coincides with the status of mana whenua and the ability to exercise rangatirataka. There are a range of activities that have been considered to mitigate these impacts including: These include but are not limited to those mentioned below. **Loss of habitat, species and wetlands** • Populations of dusky and Teviot flathead galaxias to be affected by habitat reduction could be translocated into unaffected streams. Any translocation proposal would require the preparation of detailed translocation planning, management and monitoring plans; permissions and permits; and a risk assessment. Non-migratory galaxiids are rarely translocated and as such there is little information about the likely success of such a measure. Success or failure would not be known until at least two to three years post relocation. • The Otago Fish & Game Council has provided some comments on the potential to mitigate for brown trout habitat loss, noting that it would be difficult. • If the 5TWh option is selected, then salvaging of Burgan skink and the Korero gecko populations and transferring them to enhanced and protected habitats would be an important consideration. There is uncertainty of success associated with such measures, so research to address critical unknowns is necessary prior to undertaking these actions. • While there are options for the transfer of wetland biota to new sites, these are associated with a high degree of risk. Consequently, seeking to address adverse effects on wetlands is considered to be best focussed on protecting and enhancing other similar wetlands in the local landscape, accepting that even this measure successfully implemented will result in a net loss of wetland extent due the sheer scale of wetland loss. Nine potential wetland protection and enhancement sites have been identified by Wildlands in the local area within approximately 20km of Lake Onslow **Water ways and water quality** • Wildlands consider that mitigation of the loss of stream length in the Lake Onslow catchment will require extensive restoration of greater lengths of stream.

Assessment Criteria	Option 2: Lake Onslow	
	Score	*Description*
		• The proposed multi-level intake from one water supply to another provides greater ability to control mixing and stratification by choosing the depth at which water is introduced to, or withdrawn from the Lake. Operation of the project should be guided by in-lake monitoring of temperature, oxygen, and water quality conditions as this will be important to inform which intake level to use, as well as the level at which water is best discharged into the Lake so as to manage water quality and stratification. • A Construction Environmental Management Plan would likely be required and would include measures to safely store and handle hazardous substances to avoid spills or the release of substances which could potentially enter and affect groundwater. • For activities forming part of the project which could potentially result in contamination of land, specific Management Plans would control how those activities occurred on site, including any storage or use requirements for sources of contamination. **Cultural** • If the option progresses, undertake detailed engagement with papatipu rūnaka to understand the potential impacts and ways to avoid or mitigate adverse actions. This analysis has been informed by community consultation as well as analysis completed as part of the feasibility assessment. Potential mitigations have not been materially incorporated into cost estimates and this should be (one of many focuses for) the DBC should this option progress.
Legislative, regulatory and market risk	-1	There are several legislative barriers that must be overcome to implement the Lake Onslow option, some of which will likely require bespoke adaptations of existing law (e.g., changes to existing consenting / RMA legislation). This is likely to be a time consuming and costly process. It is also anticipated that a significant policy and regulation process would be required to ensure successfully integration into existing electricity market structures. This is likely to require complex and bespoke regulation, as well as enforcement and monitoring tools. Negotiations [redacted] [redacted] [redacted] [redacted]

Assessment Criteria	**Option 2: Lake Onslow**	
	Score	***Description***
		Negotiations [redacted] [redacted] **Market Integration** • Delivery model to facilitate market integration is not yet determined. However, it is expected to able to be achievable in a way that allows for the benefits of Onslow to be capture whilst avoiding second order negative effects (based on work completed on potential operating models). It is expected that whichever market integration model is chosen will require the establishment of bespoke regulation / legislation to manage it.

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<tr><th rowspan="2">Assessment Criteria</th><th colspan="2">Option 3: Portfolio Option</th></tr>
<tr><th>Score</th><th>Description</th></tr>
<tr><td><i>Confidence of security of supply</i></td><td>1</td><td>The Portfolio Option includes three technologies that were identified by WSP as being the most feasible non-hydro options to provide dry year support – though in practice, the portfolio may involve a different set of technologies in a different combination. When combined in a portfolio, these technologies could provide both the necessary capacity, and energy storage and flexibility to maintain security of supply through long-term variation in hydro inflows, and help to support shorter-term variation in wind and solar generation. However, this option makes use of greater green peaker, system outage and demand curtailment than the Lake Onslow option.
Further, there are significant uncertainties surrounding the supply chain for biomass and the maturity of technology and markets for hydrogen, reducing confidence in the solution. For example, biomass and hydrogen are expected to have enough storage on hand to provide short – medium term cover. Additional feedstock, although possible to purchase, will be subject to commercial availability (this may be challenging given their potential alternative uses and the depth and existence of markets). Additionally, biomass and hydrogen are expected to have relatively slow recharge rates (biomass is expected to take ~ 2 years to replenish 1TWh of storage). This will reduce the ability for the portfolio option to be able to cover concurrent dry years.
As an additive portfolio the portfolio option provides ~1,260MWs of capacity, capable of providing around 2.4TWhs of generation over three months, with a smaller ongoing response. This generation and storage capacity can significantly address dry year risk.
The assumed configuration of the Portfolio Option includes:
• Biomass: A 500MW combustion turbine, and biomass storage with the potential to hold 1TWh of potential generation.
• Flexible geothermal: This includes the build out of 400MW of geothermal capacity, allowing 300MW of flexible generation with a physically unconstrained fuel supply. This option could therefore vary its electricity production by ~2.6TWhrs from year to year.
• Hydrogen: The hydrogen option has three elements that together could provide a net load benefit of ~0.79TWhrs over three months:
  • Energy storage capacity: This option includes storage of ~380MWh of green ammonia for dry year use.
  • Generation capacity: When using hydrogen in a combustion turbine, this option could feasibly produce 150MW of electricity generation.
• Load reduction: Where electrolysers are turned off, they are expected to provide ~220MW of load reduction on average.
Deliverability: Biomass and geothermal technologies are mature and currently in use in New Zealand. Despite some questions around the ability / economic value of acquiring biomass at the scale required to meet 1TWhr of storage (in the case of biomass, there is uncertainty around the competition for use of New Zealand’s biomass resource, both domestically and internationally, over the long-term, and how this would impact fuel price and accessibility) it is expected that these two components would be deliverable by ~ 2035.</td></tr>
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Assessment Criteria	Option 3: Portfolio Option	
	Score	*Description*

However, there are significant questions around the ability to deliver the hydrogen component given the lack of an existing market for green ammonia, and the scale of electrolysers and storage required.

Shortage and curtailment metrics:

Description	Unit	2035	2050	2065
System curtailment	GWh	0.00	0.20	0.19
Green peaker fuel use	TWh			
Demand curtailment	GWh	0.7	49.0	64.5

Dispatchability: The different technologies have different abilities to ramp up their response. Hydrogen electrolysers are expected to be able to respond within minutes, hydrogen and biomass generation facilities in hours, and flexible geothermal requires around 2 weeks to ramp up from turned down to turned up mode. In this sense, a Portfolio Option is somewhat less effective at managing short to medium security of supply issues than a pumped hydro system. However, it is worth noting that this IBC is not concerned with short to medium term energy fluctuations, and the ability to solve these issues are additional benefits.

Other considerations:

- It is also noted that green ammonia could potentially be imported in periods where there are limited supplies available domestically. This could provide additional flexibility in solving the dry year problem – and generally providing security of supply. However, most ammonia is currently produced from fossil fuels. A market for ‘green’ ammonia – while hypothesised – does not currently exist. This also has implications for the assumption that a hydrogen production facility could export surplus hydrogen and provide responsive demand. The price of green ammonia over time is similarly uncertain.

Assessment Criteria	Option 3: Portfolio Option	
	Score	Description
Pathway to 100% renewables	2	The Portfolio option is anticipated to significantly support the pathway to 100% renewables by 2035 – both as a meaningful contribution to renewable energy sources itself but also in terms of the support it provides to other renewable electricity generators. This support is expected to occur for two reasons: 1. It is expected that the portfolio option will help to mitigate price volatility – by purchasing electricity when prices are low and generating when prices are high (at full utilisation hydrogen plants in the portfolio option could purchase ~8.8GWh of electricity per day). This provides renewable generators with greater revenue certainty. 2. Purchasing electricity when prices are low is expected to support total revenue wind and solar generators will receive (incentivising further build out of renewable investments). **Spill:** 'spill' associated with this option (3.1566TWh in 2035 – 7.0971TWh in 2065). This is roughly 25% lower than in the Counterfactual. All other things being equal, a lower amount of spilled energy in a system will result in greater incentives to invest in renewable generation.
Retaining option value	3	While it is assumed that this option would be procured at once, the Portfolio Option could theoretically be built out over time. This would provide stage gates to enable the system to respond to advancements in technology during the build phase (and to pivot or halt planned investments). Further, as the Portfolio Option is assumed to be acquired through a technology agnostic tender process or capacity market, it is assumed this capacity market could be scaled up and down over time as needed – this embeds further optionality in the design. **Modular:** The portfolio option describes the build out of three different technologies. These could theoretically be split into multiple separate parts and delivered over time. The key benefits are: 1. It allows for staging of the portfolio e.g., the build out of mature technology options first (biomass and flexible geothermal) providing time for less mature technology elements (hydrogen) to be developed. 2. It provides stage gates at the end of each build phase to reconsider the value of continuing, pursuing the technologies chosen or switching technologies where new and better technologies are developed). **Technology:** An ability to stage construction allows different technology options to be used where a better alternative is developed. However, the hydrogen option has technology risks as this is an undeveloped space where technology and approach may evolve, creating the potential for redundancy or stranding risks. **Feedstock inflexibility:** Biomass and hydrogen generation assets have less flexibility than other options that do not use feedstock to operate (e.g., hydro and geothermal options) and may possibly have a higher risk of becoming stranded where feedstock sources become unavailable. Availability of fuel sources for biomass and hydrogen are contingent on competing uses – including exports (where prices for feedstock are high its use for electricity generation becomes less attractive).

Assessment Criteria	Option 3: Portfolio Option	
	Score	**Description**
		Alternative use: If new options for dry year security emerge, geothermal could be re-deployed and operated in a baseload role, and hydrogen/ammonia production could re-focus to supply markets for those products – noting that markets for green hydrogen and ammonia do not currently exist. **Other considerations:** • Similar to the counterfactual option, it is assumed that the generation profile will largely be determined by the market. Feasibility assessments by WSP identified flexible geothermal, biomass and hydrogen generation technologies as being the most feasible technologies to meaningfully address dry year risk. However, it is assumed that the use of these technologies would not be a requirement of any tender received and it could be that a different combination of technologies is used. • The specific procurement model for the Portfolio Option is unknown. However, some procurement options would allow optionality/flexibility, and the potential to adapt should issues arise or new technologies emerge.
Reducing wholesale electricity prices	2	It is assumed that this option would reduce wholesale electricity prices, against the counterfactual, by 6.4% on average over the modelling period. **TWAP figure ($/MWh): 2035:** 73.95 **2050:** 80.05 **2065:** 84.80
Reduced emissions	0	Although renewable, geothermal, biomass and hydrogen generation emit GHGs during operation. Geothermal production will attempt to minimise these with a closed-loop system. Over time biomass emissions are expected to be neutral due to the renewable nature of the biomass (biomass is effectively embedded within the carbon cycle) however, biomass is anticipated to have meaningful emissions associated with the supply chain required – there is expected to be a significant number of trucks required to transport biomass to site. Hydrogen operations may have leaks that emit GHGs. Each of these options will also have embedded carbon costs associated with construction. **Embedded carbon emissions:** Embedded emissions for the portfolio option relate to the amount of carbon emitted during the construction of the three components (totalling **890,000t of C02-eq):** 1. Biomass: 370,000t C02-eq 2. Flexible geothermal: 320,000t C02-eq 3. Hydrogen figure: 200,00t C02-eq **Supply chain / operational emissions:** Geothermal, biomass and hydrogen generation will emit GHGs during production. Geothermal production will attempt to minimise these with a closed-loop system (noting however, that this technology is not currently in use at scale but several geothermal operators are implementing this technology across their operations [WSP]).

Assessment Criteria	**Option 3: Portfolio Option**	
	Score	***Description***
		However, reinjection is not anticipated to remove all emissions. Residual operating emissions are expected to be between 36,000t C02 (in a dry year) and 20,500t (in a normal hydrological year). Biomass emissions will be net system neutral due to the renewable nature of the biomass (biomass is effectively embedded within the carbon cycle) although will very likely have meaningful supply chain carbon emissions given the amount of trucks that would be required to transport biomass to site. Supply chain emissions are estimated to amount to 14g C02-e / KWh Hydrogen operations may have leaks that emit GHGs. Each of these options will also have embedded carbon costs associated with construction, more analysis must be undertaken to accurately understand the embedded cost of each. **Expected Green peaker use (TWh): 2035:** 1.9658 **2050:** 0.2430 **2065:** 1.2016 **Wider economy emissions:** The portfolio option has a greater ability to reduce wholesale electricity price volatility in times of energy scarcity when compared to the counterfactual but less than the Lake Onslow option. It is expected that a reduction in price volatility will incentivise wider industry to electrify industrial activity and process heat leading to a reduction in wider emissions in the economy.
Socio-economic impacts	1	The distributed nature of the Portfolio and optionality around location, reduces the degree of negative localised socioeconomic impacts (as in some instances, where a particular site has specific negative local impacts that others do not, the site with the least negative impact can be chosen). However, it is still anticipated that all sites are expected to have a range of negative socioeconomic impacts that will still require trade offs to be made. The presence of the opportunity to establish supply chains that surround two of the three portfolio technologies provides potential for meaningful partnership with iwi / Māori as well as durable job creation and growth beyond the construction period. There are a range of negative impacts that could be expected to be felt by the local community throughout the construction periods of these generation types. It is difficult to be definitive about this given that the Portfolio option is technology and location agnostic. These impacts have been grouped below: **Land use** • Geothermal could require deployment across several sites and locations. Māori have rights and interests in geothermal resources and many geothermal resources are on Māori land / are operated by Māori land trusts. Engagement would be required to understand the cultural impacts of any specific proposal. • If forestry operations increase to meet heightened biomass demand, there is potential for more land to be turned into pine forests, and an increase in jobs within the forestry sector. However, this would also increase log transport movements, which may have roading and road safety impacts. Increased planting would also impact other land uses - potentially including farmland and recreation.

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<tr><td></td><td></td><td>There are also a range of positive socioeconomic impacts expected from such an investment, these include:
Partnership
• Prima facie, the Portfolio Option could provide a platform and opportunity for Māori collectives to enter commercial ventures for renewable energy generation. There are opportunities for Māori collectives (with land and resources that can be used for energy production and supply) and providers / investors to establish solar, wind, biomass, geothermal and hydrogen projects. This will create positive socio-economic impacts for Māori communities and the beneficiaries of these Trusts through jobs, employment and financial distributions.
• There are examples of Māori land trusts that are actively engaged in renewable energy production. There is potential for increased collaboration / investment between iwi and the Crown leading to increased job creation, skills training, workforce development and indigenous-led innovation. Increased involvement from iwi also enables greater connection between descendants and the environment.
• Examples of existing renewable energy production includes:
• Much of New Zealand's geothermal energy production occurs on Māori land and is operated by Māori trusts. Some examples of current operation of geothermal generation include: Tauhara North No. 2 Trust, Tūaropaki, Taheke 8C, Te Rūnanga o Ngāi Tahu, Murihiku Regeneration, Tiki Tere Trust.
• Māori collectives and iwi are actively engaged and interested in green hydrogen development. Tūaropaki Trust has a joint venture with Obayashi to encourage the commercial production and use of hydrogen as a transport fuel. Murihiku Regeneration and Fortescue Future Industries have entered into a collaboration agreement to develop a large scale Green Hydrogen plant in Southland.
Economic prosperity
• New Zealand has an already established forestry industry. Increasing domestic demand for low-value wood products may strengthen this industry by creating more durable supply chains that are less reliant on overseas markets and trends. This will in turn mean there is better job stability and more jobs in general. Iwi/Māori are the single largest owners of forestry lands. The use of low-value timber as fuel for biomass solutions would add further value to iwi commercial forestry returns and contribute to iwi economic growth.
• The biomass generation option has flexibility surrounding where and how many generation sites it will include. This means construction and operations could be better directed to take place in communities that would most benefit from an increase in economic activity.
• The presence of a significant hydrogen production asset could provide economic benefits for New Zealand. For example, it could create new jobs, increase exports, or potentially support a domestic market for hydrogen which can contribute to wider decarbonisation goals</td></tr>
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<tr><td></td><td></td><td>• The geothermal component would build on New Zealand’s existing geothermal skills and expertise, which are recognised globally.</td></tr>
<tr><td>Resilience to shocks and stresses</td><td>2</td><td>The portfolio option is a distributed set of storage and generation assets that are anticipated to be spread across New Zealand (although likely predominately based in the North Island). The distribution of the option and the use of fuels / non weather dependent feedstocks to generate electricity make this option highly resilient to weather based shocks and climate change related stresses. However, many of the fuels used to generate electricity also have alternative uses (both exotic forests and hydrogen have secondary uses and values in other markets). This makes technologies that rely on international markets for fuel, exports, or parts subject to international shocks and stresses. In addition, in making use of woody biomass as feedstock, the biomass option is considered potentially vulnerable to wildfire and biological disease.
Centralisation and natural disasters
The Portfolio option rates highly on resilience because the generation sources are expected to be decentralised, which reduces negative impacts from single points of failure and natural disasters.
Climate change
The option is also expected to be largely resilient to climate change as generation relies on the use of fuels or geothermal heat. However, there is the potential for biomass feedstocks to be affected by wildfire or biological disease, which may be exacerbated by climate change.
Technologies that rely on international markets for fuel, exports, or parts are also subject to international shocks and stresses.</td></tr>
<tr><td>Potential value for Money</td><td>-3</td><td>The Portfolio option has a Benefit Cost Ratio (BCR) of 0.4. This is worse than the Lake Onslow option.
• The assumed Benefit Cost Ratio (BCR) for the Portfolio Option is 0.4. This represents a scenario where 40 cents of additional public value is returned for every dollar spent. This BCR is reflective of only those cost and benefit items within the electricity sector and that could be monetised.
• A BCR of less than one is not surprising given the high upfront capital costs that are incurred relatively early in the modelling period and relatively high operating costs which are spread over the entirety of the modelling period.
• The primary monetised benefits from a Portfolio Option are:
  • PV $2,050M in electricity market benefits accruing from avoided total system generation costs (and reduced shortage) as compared to the counterfactual.
  • Operating revenue of PV $2,015.7M through the sale of hydrogen and un-used logs at the end of their storage life.
  • An assumed increase in productivity for electricity dependent firms and businesses that is estimated at PV $1,395M.</td></tr>
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<tr><td></td><td></td><td>The total economic cost of a Portfolio Option is estimated at PV $13.6B. This is the mid-range cost for all options modelled.
This consists of the following major inclusions:
PV $8,291.2M for CAPEX, including construction CAPEX and renewal and replacement CAPEX
PV $5,257.5M for OPEX
Transmission costs include the direct cost of connecting the to the transmission grid and a proportional cost of wider transmission upgrades required over the modelling period and are included in the construction CAPEX and OPEX figures above.
System administration costs are assumed to equal roughly PV $1,138.4M.</td></tr>
<tr><td>Affordability</td><td>-3</td><td>The Portfolio solution has an NPC of $13.6B which is the most expensive option. The CBA demonstrates that the Portfolio Option has an NPC of $8,291.2M for CAPEX and an NPC of $5,257.5M for OPEX.</td></tr>
<tr><td>Supplier capacity and capability</td><td>1</td><td><p>Biomass and geothermal technologies are mature with well established OEMs and suppliers. However, there is some uncertainty around how much geothermal could realistically be developed by 2035 (given potential resource, consenting, and industry constraints) and the ability to purchase biomass from New Zealand at the scale and price to make this option reasonable (given the competing uses for this biomass).</p><p>The production and storage of green hydrogen at scale is currently immature. However, it is being pursued globally as an enabler to decarbonise hard-to-electrify elements of the energy system, and is seeing significant R&D and technology advancement. WSP predicts that by 2027 the scale required for the portfolio option is expected to be within the manufacturing capability of OEMs. Given interest in hydrogen developments, procurement strategies will be required to ensure the required plant can be secured in line with current project timeframes.</p><p>Geothermal</p>
Geothermal is currently used within the electricity generation market and utilises mature technology. Traditional geothermal power generation technologies could be used for a NZ Battery solution with the inclusion of some technically proven additional engineering design, operating and maintenance features. New Zealand has access to suppliers able to deliver the necessary equipment.
Geothermal is a familiar and well-established technology in New Zealand, with over sixty years of operating history and engineers and scientists recognised globally for their skill and experience.</td></tr>
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<tr><th>Score</th><th>Description</th></tr>
<tr><td></td><td>🟩</td><td>• There is some uncertainty around how much geothermal could realistically be develop by 2035, given potential resource, consenting, and industry constraints, and without displacing plant that would be expected to be built through normal market development.
Biomass
• Mature technology options exist to combust biomass and generate the dry year energy needs. Mature technology is also available to achieve both harvest and processing of fuel and good practices for minimisation of forest residues exist. A significant number of international firms can offer woody biomass processing and generation equipment, (e.g., Babcock, Foster Wheeler, Mitsubishi Heavy Industries and General Electric).
• New Zealand currently has a primary supply of biomass through its long-rotation exotic forestry. This can meet the large-scale requirements of this project, both in terms of the large quantities of harvest and flexibility in the timing of extraction. However, biomass resources are currently commercially contracted and so access to this resource would require negotiation. It is difficult to firmly establish what volume of logs may be available for a NZ Battery solution from 2030 onwards, given competing biomass demands and the practicalities of log trucking and storage. The biomass option that WSP has identified navigates these challenges.
Hydrogen
• Green hydrogen is being pursued globally as an enabler to decarbonise hard-to-electrify elements of the energy system, and hence is seeing significant R&D and technology advancement.
• WSP has identified a hydrogen solution that would utilise the most technology-ready methods and componentry. A development at the scale considered would be considered large based on current manufacturing capacity, but by 2027 is expected to be within the manufacturing capability of OEMs.
• Given interest in hydrogen developments and the nascency of the industry, there are long lead-times on key equipment. Procurement strategies will be required to ensure the required electrolyser plant and key Balance of Plant can be secured in time for installation and commissioning by 2035.
• Green hydrogen production is energy intensive and will rely on sufficient spare electricity generation to operate.
• There is a risk that ammonia export is not possible at the expected volume or price by 2035, as the international market is not yet established.</td></tr>
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Assessment Criteria	Option 3: Portfolio Option	
	Score	***Description***
Localised environmental impacts	-2	All technologies within the Portfolio Option impact environmental and local amenity through their construction and associated supply chains. In addition, some components of the portfolio option also pose a hazardous risk to humans (ammonia storage). However, as the portfolio option is location agnostic (to some degree), the environmental impacts can be potentially mitigated by placing elements of the portfolio option in locations better suited to handle these risks. However, it is important to note that even better suited sites will face significant environmental degradation as a result of the build out the portfolio option. There are a range of potential negative environmental impacts due to the construction and operation periods linked to this option. These have been grouped below **Land use** • All technologies within the Portfolio Option present risks to land from the construction of new facilities. • Geothermal generation has a minimal to modest effect on the environment, because it makes use of shallow geothermal resources. Geothermal should cause only small temperature changes to the groundwater or rocks and soil in the ground. In closed-loop systems the ground temperature around the vertical boreholes is slightly increased or decreased. • The environmental effects of geothermal development and power generation include the changes in land use associated with exploration and plant construction, noise and sight pollution, the discharge of water and gases, the production of foul odours, and soil subsidence. Most of those effects, however, can be mitigated with current technology so that geothermal uses have a minimal environmental impact. **Water use** • Biomass is expected to generally make use of trees as their fuel. New Zealand plantation forests are reliant on rainfall but planting trees in new areas can reduce stream outflows downstream due to water take up by exotic forests. On a large scale, this exacerbates drought conditions, impacting aquatic habitats and the amount of water supply available for other purposes (food crops, drinking, hydropower, etc.). • Hydrogen and biomass both require a water take so may impact river flows. Geothermal uses underground water sources and can present a subsidence risk if the resource is not well managed. • Development of new port berths and facilities (if required) to support hydrogen exports may present a risk of harm to waterways or the marine environment. **Hazardous to humans** • Hydrogen is an explosive gas, and there is the risk of blast damage from compromised equipment. • Ammonia is a toxic chemical, and its production and handling in traditional sectors is regulated. It must be treated carefully as it is corrosive and may ignite / burn with explosive force. Poisonous gases are produced, and containers may explode if a fire occurs. It should be noted this is similar to many fossil fuels currently extracted, transported and stored in New Zealand. The

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<tr><td></td><td></td><td>Portfolio Option assumes ammonia storage that is similar in scale to the largest existing storage of hazardous products in New Zealand.
Cultural
• The portfolio option will include a mix of different renewable energy production projects distributed across different locations. Due to this, it will be important to understand cultural impacts on a case-by-case and local basis. Given the uncertainty around locations, this cannot be readily assessed at this time. However, it is noted that the geothermal resource, forestry and water resources are considered taonga, with all likely implicated in the Portfolio Option.
Potential contamination
• For hydrogen generation, the potential for release or spillage must also be managed carefully. Environmental issues can be caused during a containment event, due to its poisonous nature.
• Ammonia production, storage and generation sites need specific location selection to ensure environmental and safety mitigations can be put in place (bunding, large buffer zone areas, etc.).</td></tr>
<tr><td>Legislative, regulatory and market risk</td><td>-2</td><td>There has been limited analysis done on the legislative and regulatory impacts of the portfolio option. The potential hazardous effects of hydrogen and ammonia storage could have on both people and the environment will mean this generation type will likely have to be heavily regulated. Moreover, procuring of services that support mitigation of dry year risk, or the establishment of a capacity market, would be a significant regulatory and market facing exercise.
Market
• At the core of the solution will be a regulatory framework that sets out the rules for the market. This will be on things such as determining any capacity payments, subsidies for feedstock, or compensation for demand response. These rules will be dependent on how the portfolio is procured. For example, if the portfolio option is procured via a capacity market payment mechanism then rules will need to be set around the level of service those payments cover.
• For flexible geothermal a security of supply threshold will need to be set for when operations should be ramped up. Compensation may also be appropriate to reflect increased OPEX and equipment wear for geothermal operating flexibly. These rules will be dependent on how the portfolio is procured.
• An independent industry regulator would likely be needed to monitor and report on the efficacy of the facilities and the conduct of the operator and participants and to set maximum return thresholds on the facility operators to ensure market power is not being exploited to make excessive profits.
Consenting
There are consenting risks to all options. Some of these are well traversed and are unlikely to require special legislation. However:</td></tr>
</table>

Assessment Criteria	Option 3: Portfolio Option	
	Score	*Description*
	🟧	• Biomass generation can emit a range of pollutants. Schedule 1 of The Resource Management (National Environmental Standards for Air Quality) Regulations sets the ambient air quality standard for carbon monoxide, nitrogen dioxide, ozone, PMio, and sulphur dioxide; with exceedances requiring permission. This may impact upon the ability for biomass generators to operate. • The biomass option involves significant log vehicle movements that may impact operations • The RMA will be a large legislative consideration going forward for hydrogen generation. This will need resource consent from the relevant district and regional councils to a potentially hazardous and harmful piece of infrastructure in the community. In this context, HSNO regulations will be critical to adhere to.

Appendix G Assessment Criteria

The assessment criteria are attributes considered essential for the successful delivery of the investment. The detailed scoring rationale for the assessment criteria are noted below.

Table 74: Definition of each assessment criteria

<table>
<tr><th colspan="7">Confidence in security of supply</th></tr>
<tr><td colspan="7">This criterion is informed by EMM, technical reports, and scores each option based on:
• Consideration of how confidently the option could be delivered as described (e.g., within a reasonable timeframe).
• A quantitative metric demonstrating the amount of demand curtailment, shortage, and green peaker fuel that the option uses (these metrics will work to help stratify the options). It is noted that these metrics represent system average. Therefore, they should be considered indicative only of the ability of an option to respond in a dry year.
• Qualitative description of the ability of an option to provide large-scale, long-term flexibility or storage for dispatch in dry years.
• Qualitative description of the ability of the option to dispatch electricity quickly to support short term intermittent needs.</td></tr>
<tr><td>+3</td><td>+2</td><td>+1</td><td>0</td><td>-1</td><td>-2</td><td>-3</td></tr>
<tr><td colspan="3">• Options that rely less on system outage, green peaker use and demand curtailment will score higher on this scale.
• Options that the project team assess as being credibly able to be achieved within a reasonable timeframe (within the 2030s).
• Options with greater technology certainty will score higher. However, to score positively, at a minimum, the option should largely be able to be delivered.</td><td>Options that the Project team assess as being credibly able to be achieved within a reasonable timeframe (within 2030).</td><td colspan="3">• Options that the Project team do not assess as being credibly able to be achieved within a reasonable timeframe (within 2030).
• For an option to score negatively, there must be significant concerns around its deliverability.</td></tr>
</table>

<table>
<tr><th colspan="7">Supports a pathway to 100% renewable generation</th></tr>
<tr><td colspan="7">This criterion is informed by EMM, technical reports, and scores each option based on:
• A quantitative assessment of each option’s ability to provide system-wide economic incentives that support renewable build out. This is measured based on modelled spill in normal hydrological years. All else being equal, a reduction in spill implies greater use of electricity generated from renewable sources. This will provide renewable generators with additional revenue (improving the economic conditions for renewable generators).
• A qualitative assessment of the impact the option might have on electricity derivative product markets.</td></tr>
<tr><td>+3</td><td>+2</td><td>+1</td><td>0</td><td>-1</td><td>-2</td><td>-3</td></tr>
</table>

• Spill: Options that provide expected demand sinks for renewable generation that would otherwise spill. A lower spill metric will progressively improve the option's score. • The option is able to support supply of derivative products in the market that support intermittent renewable generation	Spill metrics are in line with the counterfactual	• Higher spill metrics than the counterfactual – options with greater levels of spill will score progressively worse.

Retaining option value						
This criterion is informed by technical assessments and assesses whether the option: • Is modular in construction / has off ramps prior to significant decisions or investments being made. • Is able to maintain optionality to switch to new technologies or feedstocks as they emerge and mature (either by design, scale or timing of delivery). • Can be repurposed (does it have a future use or plant that can be used with multiple feedstocks)?						
+3	+2	+1	0	-1	-2	-3
The option meets all three option value criteria.	The option meets two option value criteria.	The option meets one option value criteria.	The option does not meet any option value criteria.	The option forecloses opportunities or reduces the investment signals required to build out peaking or firming technologies. The score will be determined by a qualitative assessment of the degree to which the option forecloses these opportunities.		

Reduced wholesale electricity prices						
This criterion is informed by EMM and scores each option based on expected time-weighted average wholesale prices over the modelling period. Without the addition of a significant energy storage and firming source, a 100% renewable electricity system is expected to suffer increased wholesale electricity price volatility – increased volatility is anticipated to translate into higher electricity prices for the majority of industrial and retail consumers through a higher risk premium on spot prices and forward contracts.						
+3	+2	+1	0	-1	-2	-3
TWAPs are on average >5% lower than the counterfactual	TWAPs are on average 5%>2% lower than the counterfactual.	TWAPs are on average <2% lower than the counterfactual.	TWAPs are on average equivalent to the counterfactual	TWAPs are on average <2% higher than the counterfactual.	TWAPs are on average 2%<5% higher than the counterfactual.	TWAPs are on average >5% higher than the counterfactual

<table>
<tr><th colspan="7">Reduces carbon emissions</th></tr>
<tr><td colspan="7">A reduction in carbon emissions is informed by technical assessments of:
• The embedded carbon emissions in the construction required for each option;
• The operational carbon emissions for each option;
• Green peaker use - Green peakers are technology agnostic. However, it is anticipated that they may make use of technology that runs on fuels with associated supply chain emissions.
• A qualitative assessment of how each option might facilitate decarbonisation of the wider economy.
It is assumed that there would be major positive emissions benefits for all options when compared to a true Do Nothing option given the use of thermal fuels in the Do Nothing option.</td></tr>
<tr><td>+3</td><td>+2</td><td>+1</td><td>0</td><td>-1</td><td>-2</td><td>-3</td></tr>
<tr><td>The option has low embedded carbon emissions and minimal operational emissions. The option likely creates conditions that significantly positively impacts wider industry decarbonisation rates.</td><td>The option has low embedded carbon emissions values and minimal operational emissions and creates an environment that may positively impact upon wider industry decarbonisation rates.</td><td>The option has significant embedded carbon values but broadly offsets these by having low operational emissions. The option creates an environment that may positively impact upon wider industry decarbonisation rates.</td><td>The option has significant embedded carbon emissions and makes use of fuel sources that are renewable but have significant associated supply chain emissions. The option creates an environment that is neutral on wider industry decarbonisation rates</td><td colspan="3">This option has significant embedded carbon emissions and makes use of fuel sources that are non-renewable. This is reflective of the do nothing option – as all NZ Battery options are renewable, no NZ Battery investment option can score below 0.</td></tr>
</table>

Has socio-economic impacts

This criterion is informed by technical assessments, social and cultural impact assessments, and project team judgements, and scores each option based on:

- Estimated impacts on number of jobs created – primarily where there are durable opportunities to grow new industries or support existing industries, but also in the construction phase.
- Impacts on local communities – this can be positive and negative implications for local services, local amenity, and local businesses.
- Impacts on recreational activities.
- Cultural implications and opportunities for partnership.

+3	+2	+1	0	-1	-2	-3
Options that are expected to create durable opportunities to grow new industries or support existing industries score positively. Options that have significant employment opportunities for locals score positively. Options that are expected to support opportunities for local businesses score positively. Options that have precedent, or stated opportunities, for partnership with mana whenua score positively.			Socio economic impacts are considered to be balanced	Options that are expected to be resourced through a FIFO workforce score negatively. Options that are expected to create disruption for local communities, or put unnecessary pressure on local services score negatively. Options that disrupt known recreational activities score negatively. Options that have impacts on sites of cultural significance score negatively.		

Resilient to threats

This criterion is informed by technical assessments, and project team judgements, and scores each option based on:

- Resilience to natural disasters
- Resilience to expected changes in climate
- Whether the option is a single point of failure – i.e. is it centralised or decentralised (decentralised assets will meet this criteria while centralised options will not).

+3	+2	+1	0	-1	-2	-3
The option meets all three resilience criteria.	The option meets two resilience criteria.	The option clearly meets at least one resilience criteria.	The option partially meets one or does not meet any resilience criteria.	The option creates additional resilience issues associated with one of the resilience criteria.	The option creates additional resilience issues associated with two of the resilience criteria.	The option creates additional resilience issues associated with all three of the resilience criteria.

Potential value for money

This criterion is informed by monetised cost benefit analysis and scores each option based on expected Benefit-to-Cost Ratios (BCR). A key omission from the BCR calculation is the lack of detailed estimate for the cost of shortage. While average system-wide shortage values are produced in the electricity market modelling, this does not take into account the 'true costs' across the economy in a dry year.

+3	+2	+1	0	-1	-2	-3
The option has a BCR of >2	The options has a BCR of 2>1.5	The option has a BCR of 1.5>1	The option has a BCR of ~1	The option has a BCR of 1>0.75	The option has a BCR of 0.75>0.5	The option has a BCR of <0.5

Affordability

This criterion is informed by monetised cost benefit analysis and scores each option based on the expected net present cost (NPC) of each option[76].

+3	+2	+1	0	-1	-2	-3
The option has no NPC			The option has an NPC of < 1,000M	The option has an NPC of $1,000M – $5,000M	The option has an NPC of $5,000M – $10,000M	The option has an NPC of >$10,000M

Supplier capacity and capability

This criterion is informed by technical assessments and scores each option based on:

- A qualitative assessment of the ability of the market / potential suppliers to deliver the required services to the quality, cost and timeframes estimated.
- A qualitative assessment of the availability of feedstock.

+3	+2	+1	0	-1	-2	-3
• Options that are expected to be supported by deep supplier and contractor markets to help provide services and expertise required score progressively better. • Only those options where the project team has tested the market to confirm availability of key suppliers and contractors (and are satisfied that there is an accessible market for the services required) will score a 3.			The option is considered potentially deliverable but there are concerns around availability of supply both in terms of feedstock and key technology that create uncertainty	• To be negative, in general the option (or a majority of an option's technology) is not considered deliverable as the expertise and technology required are either not available or are not yet feasible. • Options with long lead times on key elements will score progressively worse. • Options with significant workforce requirements will score progressively worse.		

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[76] Note, this metric implicitly includes the revenue generated by each option (as derived from EMM undertaken), however, a more detailed analysis of this is included in the Financial Case.

• Options that spread out demand for labour and services over time will score positively. • Options with greater certainty around maturity of supplier capability will score progressively higher.	around the deliverability of the option.	

<table>
<tr><th colspan="7">Environmental and local impacts</th></tr>
<tr><td colspan="7">This criterion is informed by technical assessments, environmental impacts studies, and project team judgement, and scores each option based on impacts to:
• Local waterways (including water quality and biosecurity).
• Local fisheries, bird, invertebrate, reptile, and other fauna (impacts to threatened species will be considered more significant).
• Local flora (including wetlands, specific vegetation types) (impacts to threatened species will be considered more significant).
• Protected areas and reserves.
Please note that only residual localised impacts are being scored. This means, only those impacts that have not been mitigated as part of the current cost estimates for delivery.
The total quantum of impacts has been considered in this analysis. Therefore, options that have more distributed localised impacts have not been scored ‘better’ just because there are a higher number of ‘lower impact’ activities. However, where options have choices about location, this has impacted consideration. For example, an option that <u>must</u> be located in a location (and which has negative localised impacts) scores ‘worse’ than an option that could be located somewhere to avoid the same or similar localised impacts.</td></tr>
<tr><td>+3</td><td>+2</td><td>+1</td><td>0</td><td>-1</td><td>-2</td><td>-3</td></tr>
<tr><td colspan="3">Options that create positive localised environmental impact.</td><td>Options that have balanced localised environmental impacts (or no discernible localised impacts)</td><td colspan="3">Options that have negative localised impacts on:
• Local waterways (including water quality).
• Local fisheries, bird, invertebrate, reptile, and other fauna (impacts to threatened species will be considered more significant).
• Local flora (including wetlands, specific vegetation types) (impacts to threatened species will be considered more significant).
• Protected areas and reserves.</td></tr>
</table>

<table>
<tr><th colspan="7">Legislative and regulatory impacts</th></tr>
<tr><td colspan="7">This criterion is informed by technical assessments, market analysis, and project team judgements, and scores each option based on:
• Expected consentability challenges
• Requirements for national legislative changes or material changes to National Policy Statements
• Ability to satisfy Hazardous Substances and New Organisms (HSNO) requirements
• The complexity of integrating the option into the current electricity market.</td></tr>
<tr><td>+3</td><td>+2</td><td>+1</td><td>0</td><td>-1</td><td>-2</td><td>-3</td></tr>
<tr><td colspan="3">• Options that are expected to reduce regulatory, legislative or market integration burden score positively</td><td>Options that are expected to broadly operate within existing legislative, regulatory and market constructs</td><td colspan="3">• Options that are expected to require the establishment of standalone legislation to mitigate consenting challenges.
• Options that are expected to require changes to / introductions of other regulatory instruments like National Policy Statements.
• Options that have complex market integration challenges.
• Options that are expected to face other regulatory challenges – including meeting HSNO requirements.</td></tr>
</table>

Appendix H Quality of cost and benefit estimates

General

The unique nature of the NZ Battery investment proposition means that there are not directly comparable ‘off the shelf’ cost or benefits that can easily be incorporated in the IBC. The costs and benefits included have therefore been based on the latest information available and compiled from the scope of works delivered by the following external consultants with assistance, validation from MBIE, TRG, stakeholder engagement to date, and other parties as relevant.

- Te Ropu Matatau
- WSP
- John Culy
- Ernst & Young
- Jacobs
- Transpower.

The costs have been subject to benchmarking, where possible, and independent assurance.

Te Ropu Matatau

Following a multi-stage procurement process, drawing on external experience and assurance, TRM (a consortium of consultants led by Mott MacDonald) was engaged by MBIE in September 2021 to conduct a technical feasibility study for the Lake Onslow Pumped Storage Scheme. The principal consultants were Mott MacDonald, GHD and Boffa Miskell, supported by a number of other sub consultants. Their scope of work included the following:

- Collect, collate, and analyse input data and technical information that is required to facilitate the feasibility study and any future design development.
- Identify a wide range of possible options/alternatives for the Lake Onslow solution that can achieve the overarching energy storage and generation capacity requirements.
- Prepare an initial long list of concept/pre-feasibility designs to facilitate risk assessments, cost, and schedule estimates to a commensurate level (for example AACE Class 5) to undertake screening and shortlisting of possible options.
- Undertake a high-level environmental analysis using available baseline data against known statutory imperative to identify least impactful alternatives to support the screening and short-listing process screening.
- Shortlist possible options and recommend a preferred option(s) for second phase of feasibility assessment.
- Undertake physical investigations for short listed options to sufficiently identify and characterise risks for the preferred option(s) and commensurate with the required design output class (AACE class 4).
- Undertake design work to analyse technical feasibility of short-listed options to verify that design, construction, and operation aligns with accepted or normative practices with respect to:
    - Safety to the public and project personnel
    - Mitigation of site hazards (geological and seismic)

  - Technical standards, codes, and guidelines
  - Construction methods, sequencing, and duration
  - Technology selection
  - Hydraulic performance.
- Benchmark performance and operational capability of preferred option(s) against the overarching objectives and any additional operational flexibility that could be delivered.
- Prepare cost and schedule estimates to the required accuracy class (AACE class 4) for a wide range of options to allow MBIE to quantify cost-benefits in the interim business case and to allow a sufficient basis to optimise the scheme configuration once economic modelling workstreams conclude.
- Undertake risks assessments for the project development and execution phases commensurate with level of study for each option to allow quantitative risk adjustments for cost and schedule.
- Benchmark the cost of key project components against relevant local and international projects, where possible
- Identify key environment values and potential extent to which these values would be impacted by preferred option(s).
- Identify consenting pathways.
- Identify data gaps and make recommendations for future phases of investigation, design, and consenting.

TRM deliverables were subject to independent assurance by relevant subject matter experts, including Turner and Townsend Consulting Limited.

WSP

Following a multi-stage procurement process, drawing on external experience and assurance, WSP was engaged by MBIE to review several alternative, non-hydro technologies that could potentially help to manage, or mitigate, the dry year problem by storing 1–5 TWh of electricity (or equivalent schedulable generation releasing energy only when required) from 2030.

The Other Technologies Feasibility Study comprised of two main stages:

- The first is the Options Analysis, which focused on the review of five non-hydro renewable technologies, to recommend two or three Prospective Options for further study. During this stage Biomass, Geothermal Energy and Hydrogen converted to ammonia for storage were selected as Prospective Options. Air Storage and Flow Batteries were excluded from further consideration
- The second is the preliminary Feasibility Assessment comprising of technical and commercial feasibility assessments of the Prospective Options, including the viability of integration and deployment by 2030 in New Zealand.

The work performed by WSP was performed (1) over a broader scope of works (2) over a shorter period of time and (3) to a lower level of detail when compared to the TRM work. For each of the Prospective Options, WSP prepared cost and schedule estimates to an AACE class 4 level of accuracy.

WSP deliverables were subject to independent assurance by relevant subject matter experts, including Turner and Townsend Consulting Limited.

John Culy

Following a multi-stage procurement process, drawing on external experience John Culy was engaged (initially with Concept Consulting, then independently) to develop an electricity market model for the options selected by TRM, WSP and MBIE work with the following purpose:

- Explore whether a particular NZ Battery option could work operationally within the electricity system over timeframes of hours to years (with operation at shorter timeframes being considered, where necessary, separately through detailed power systems analysis)
- Quantify the economic benefit that an NZ Battery option could provide, relative to a counterfactual without NZ Battery.
- Understand how an NZ Battery would integrate with the market and supporting work on resilience and power system integration.

Ernst and Young

Following a multi-stage procurement process, Ernst and Young (EY) were engaged to develop the IBC in collaboration with MBIE. For the CBA, where the economic benefits were not quantified by the electricity market modelling (for example productivity improvements and terminal value), EY were to identify and quantify them.

Jacobs

An independent power system and market modelling program was instigated using ‘SDDP’ modelling to conduct transmission analysis, support Transpower’s power system analysis, and provide assurance of John Culy’s economic modelling methodology. Transpower provided its SDDP grid database for this. This was initially a contract with EY, then with Jacobs after the lead analyst changed employers.

Transpower

Transpower, as grid owner and system operator, was engaged to provide feasibility-level designs and costings of grid connection and enhancements, and to provide power systems analysis to ensure that Lake Onslow can be operated securely in the power system.

Cost and Benefit estimates

General

In general, costs and benefits are uncertain. The uncertainty associated with these reduce over time, and a project moves through the development and delivery phases, in line with the increasing detail or analysis and understanding. It is noted that in general for NZ Battery, estimating the expected financial and economic costs of each investment has a number of inherent challenges:

- The commercial viability at scale, of some technologies included in portfolio option is more uncertain than others, for example Hydrogen
- The investigative work performed for Lake Onslow is far more advanced and therefore detailed than portfolio options, leading to relatively greater uncertainty with the portfolio options. Therefore, comparing on a like for like basis may be challenging

- The technical design of each option is still being optimised resulting in uncertainty associated with the construction costs. Similarly, the operating model is still being optimised resulting in uncertainty associated with revenue and operating costs
- Market sounding for the delivery of each option has not yet been undertaken in detail. This leaves some uncertainty on how each option will be delivered. Uncertainties such as this are addressed through the quality and risk analysis and the preparation of P50 and P90 costs including a contingency
- The extent to which these assets will be deemed obsolete by 'new' technology or reduced price points for existing technology. Whilst this has been considered in the modelling performed by John Culy, it is inherently difficult to predict
- The turbulent nature of the current economic climate resulting in increased inflation and interest rates.

There are however several positive activities that help to determine an appropriate estimate for the purposes of the financial and economic costs and befits:

- Several of the operating cost components are 'general' in nature and there are good market proxies or industry benchmarks that exist for these
- A bottom-up estimate of the costs (both construction and operational costs) for the physical infrastructure works has been prepared by the external consultants
- Furthermore, John Culy and Jacobs have performed extensive electricity market modelling to form the basis upon which all costs and benefits have been prepared.

Class of cost estimates

According to industry best practice TRM and WSP have prepared cost estimates according to the AACE International standards which provide general principles for estimate classification (i.e. cost estimates that are used to evaluate, approve, and/or fund projects). The following table is an extract from the standard which summarises the Cost Estimate Classification System and maps the phases and stages of project cost estimating together with a generic maturity and quality matrix.

Table 75: Class of cost estimates

	Primary characteristic	**Secondary Characteristic**			
	Level of project definition	**End usage**	**Methodology**	**Expected accuracy range**	**Preparation effort**
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgement, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorisation, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 75%	Control or Bid/Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20

	Primary characteristic	**Secondary Characteristic**			
	Level of project definition	**End usage**	**Methodology**	**Expected accuracy range**	**Preparation effort**
Class 1	65% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Note 1: The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Note 2: Preparation effort: If the range index value of “1” represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools

Based on the AACE International standard classifications, the table below provides a summary of the costs included in the Economic and Financial case.

Table 76: Costs in the Economic and Financial case

Costs		**TRM**	**WSP**	**MBIE**	**MBIE**
		Lake Onslow	**Portfolio**	**Lake Onslow**	**Portfolio**
Construction CAPEX	The expected capital costs associated with constructing the NZ Battery option.	Class 4 cost estimates. Benchmarking, where possible	Class 4 cost estimates	Assurance of costs by independent experts, benchmarking where possible	Assurance of costs by independent experts, benchmarking where possible
Transmission connection CAPEX	Cost to connect to the Transmission grid	n/a	n/a	Transpower, Class 4 estimates	Transpower, Class 4 estimates
Maintenance and renewal CAPEX	The expected capital costs associated with maintaining the NZ Battery option over its lifespan and reflect	Class 4 cost estimates. Benchmarking, where possible	Class 4 cost estimates	Assurance of costs by independent experts, benchmarking where possible	Assurance of costs by independent experts
OPEX	The expected costs to operate NZ Battery and deliver electricity under the selected operating model.	Class 4 cost estimates. Benchmarking, where possible	Class 4 cost estimates	n/a	n/a
Transmission connection OPEX	OPEX associated with assets to connect to the Transmission grid	n/a	n/a	Transpower 4 estimate	Same percentage of substation costs as Lake Onslow

Costs		**TRM**	**WSP**	**MBIE**	**MBIE**
		Lake Onslow	**Portfolio**	**Lake Onslow**	**Portfolio**
System transmission OPEX	Estimate of Lake Onslow's contribution to expected system transmission upgrades required (apportioned).	n/a	n/a	TPM assumption in discussion with Transpower	TPM assumption in discussion with Transpower
System administration	The expected upfront and operating cost of the government related entity that will manage and / or operate the NZ Battery option.	Input from engineering studies, high-level estimates. Class 5 cost estimates.	Class 5 cost estimates.	n/a	n/a
Resilience	The costs associated with some NZ Battery options being more resilient to failures in other parts of the electricity system than others. Specifically, the extent to which a solution exacerbates the consequence of HVDC failures.	n/a	n/a	MBIE and Transpower analysis	n/a

Class of Benefit estimates

Due to the nature of the benefits, electricity market modelling was performed to quantify them. Whilst for the benefits there is not the same industry standard for defining the estimate classification, it is noted the underlying modelling assumptions and limitations are clearly understood and documented in Appendix E.

The table below provides a summary of the benefits included in the Economic and Financial case and the basis upon which they have been prepared.

Table 77: Class of benefits

Benefits		**John Culy Consulting**	**TRM**	**WSP**	**EY**	**Jacobs**
Electricity system benefits	The gross economic benefit, relative to the counterfactual, of the avoided electricity system costs from implementing an NZ Battery option. In practice this primarily manifests in avoided fixed capital and operating costs associated with ‘overbuild’ of solar, wind, and green peakers. This category also captures the benefits of reduced electricity system emissions, reduced demand curtailment, and reduced shortage.	Outputs from Electricity Market Modelling (EMM)	n/a	n/a	n/a	While we have not used SDDP modelling to determine electricity system benefit directly we have used it to validate the accuracy of EMM.
Productivity improvements	The productivity improvement of large electricity consumers as result of reduced electricity prices from implementing the NZ Battery option.	Outputs from Electricity Market Modelling for percentage reduction in TWAP	n/a	n/a	High-level consumption estimates based on input/output tables	
Operating revenue	The expected operating revenue from the NZ Battery option.	Outputs from Electricity Market Modelling	n/a	n/a	n/a	

Benefits		**John Culy Consulting**	**TRM**	**WSP**	**EY**	**Jacobs**
Economic terminal value	The terminal value of the NZ Battery at the end of the model timeframe (FY65).	n/a	Class 4 estimates for construction CAPEX, renewal and replacement CAPEX and useful lives	Class 4 estimates for construction CAPEX, renewal and replacement CAPEX and useful lives	Straight-line depreciation over the useful life of the asset.	n/a

Appendix I Cost Benefit Analysis assumptions

Overview

An Economic CBA supporting the quantification of the value for money criteria is concerned with the national level, economic costs and benefits of a decision, over a prescribed time period. We highlight five key implications of an Economic CBA and how it differs from the financial assessment performed as follows:

- Economic CBA includes effects on all sectors of the economy, while fiscal costings focus upon the government sector only. In the context of NZ Battery this means the economic case does not distinguish between private or public sector investment in generation.
- Economic CBA uses discounting and often looks beyond the five-year horizon that is reported in the Crown financial statements.
- Economic CBA reflects real resource use, while fiscal costings can include inflation, resource transfers, and accounting items such as depreciation and capital charge. In the context of NZ Battery this means the economic case does not consider the impacts of inflation and includes depreciation only to the extent it is needed for determining terminal value.
- Economic CBA does not need to distinguish between capital and operating costs. However, in practice, the capturing of CAPEX and OPEX information is often required to understand full project costs.
- Sunk costs are not included as part of an economic case; but are included in the financial case.

While economic CBA includes effects on all sectors of the economy, our Electricity Market Modelling has focused on cost to the electricity sector and direct effects on electricity consumers only.

Assumptions

Global assumptions across all options

The monetised cost benefit analysis undertaken in this Business Case has the following core features which apply across all options:

- **Timeframe:** A timeframe of 42 years has been assessed as an appropriate timeframe for the CBA analysis for the following reasons:
    - *Electricity market modelling alignment.* MBIE engaged John Culy Consulting to estimate the operating revenue, gross benefits, and a number of other parameters for the NZ Battery options. These are estimated for three representative years: 2035 (early in project life but after any fill period), 2050 (when decarbonisation has lifted non-Tiwai electricity demand by around 50%) and 2065 (when electricity demand has almost doubled)
    - *Asset life considerations:* 42 years corresponds to approximately half of the Lake Onslow asset life, and broadly corresponds to the end of life for some Portfolio assets
    - *Time value of money considerations.* Costs and benefits that occur a long way into the future have a lower impact on the CBA due to the time value of money. We have

therefore selected a timeframe that for all options that is (1) long enough to include, for example, a sufficient operations period and mid-life upgrades or replacement and (2) short enough to exclude immaterial values.

- **Discount rate:** A typical discount rate of 5% has been utilised for this assessment.[77] There are credible arguments to use a lower discount rate given that this investment will have multi-generational benefits (and costs). At this time both lower and higher discount rate values have been used for sensitivity testing
- **Currency:** All figures in this assessment are presented in New Zealand dollars, given that this is fiscal 'cost' to New Zealand. Furthermore, all figures are prepared on a real basis as at 31 March 2022
- **Costs:** All cost figures presented throughout this Appendix are P50 assuming the base schedule
- **Exclusions**: In line with Treasury expectations, the following items have been excluded from the CBA: inflation, GST, depreciation, capital charges and financing costs. Treatment of depreciation and capital charges have been included in the Financial Case
- **Precision**: The detailed numbers that are generated through the various economic models employed in this analysis may give a false sense of accuracy because of the inherent uncertainties in forecasting costs and benefits in the infrastructure sector. Some discretion has been afforded when rounding results and presenting findings.

Scenarios

The following scenarios for each NZ Battery option were included in the CBA:

- **Base Case**: The base case for the CBA is considered to be the counterfactual scenario
- **Lake Onslow configuration**: The CBA has been performed for one configuration of Lake Onslow, (1) Negotiation 3.0TWh, 500MW and lower storage capacity of 0Mm^3 (2) Negotiations 5.0TWh, 1,000MW and lower storage capacity of 5Mm^3 and (3) Negotiations 7.5TWh, 1,250MW and lower storage capacity of 10Mm^3. Figures for option 2 are presented throughout this Appendix unless otherwise stated
- **Portfolio configuration**: The CBA has been performed for the hydrogen, biomass and geothermal generation mix configuration.

Timing

Table 78: CBA timing assumptions

CBA item		Lake Onslow	Portfolio
Construction period	Given the nature and location of the generation assets for each option is different, the construction period varies across all options.	11 years from FY2024 (starting 1 July 2023) to FY34 (ending 30 June 2034). This also includes reasonable assumptions about fill periods.	6 years from FY24 (starting 1 July 2023) to FY29 (30 June 2029).
Benefits period	Benefits resulting from the three investment	Starting from FY35 (1 July 2035).	Starting from FY30 (1 July 2029).

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[77] https://treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

CBA item		Lake Onslow	Portfolio
	options occur from the completion of construction to the end of the modelling period.		

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Appendix J Ownership Model Assessment

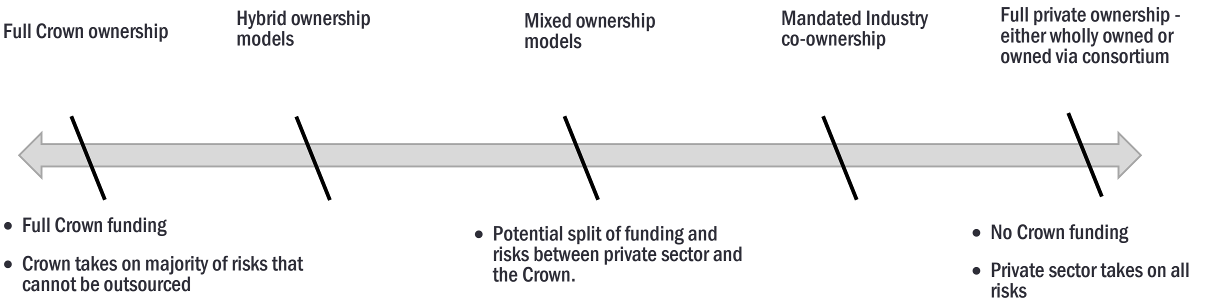
Ownership in the NZ Battery context describes who legally holds the physical energy storage and electricity generation assets that make up both the portfolio option and the Lake Onslow option (**Intervention Options**), including land. This Appendix contains a description of the range of ownership models considered, the assessment criteria used to assess the ownership models and the outcomes of the assessment.

Ownership model types

There is a range of potential ownership models available to deliver and own the Intervention Options. Broadly, these models fall on a spectrum ranging from full Crown ownership to full private ownership. Where an option sits on this spectrum also dictates the level of funding and risk being taken on by either the Crown or private sector.

Figure 24 provides a high-level representation of this spectrum and the different operating models considered as part of this IBC[78].

Figure 24: Ownership model spectrum



- Full Crown ownership and control: This describes direct Crown ownership and control of the Intervention Options. This could be achieved through a range of different entity types, including: Statutory entities and corporations e.g. (Crown agents, Autonomous Crown Entities, and Independent Crown Entities). This ownership model would allow the achievement of non-profit driven considerations.
- Hybrid ownership models: This describes an ownership model that is Crown owned but has characteristics of private ownership e.g., a greater degree of autonomy and a profit motive. An example of this model is a State-Owned Enterprise.
- Mixed ownership models: This is an ownership model that is driven by a profit motive and allows for multiple different ownership groups (this could include private parties, the Crown, Regional Councils or Iwi).

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[78] This is not an exhaustive list of all available ownership structures that could possibly be considered to deliver the preferred investment option or Lake Onslow option. Instead, this list is illustrative of a high-level range of options that fall across the ownership / risk / funding spectrum.

- Mandated, industry co-ownership: This option represents a mandated ownership model (through empowering regulation or legislation) that requires key industry players to hold shares in an entity holding the assets of the Intervention Options.

  The potential benefit of this option is its ability to align the interests of major industry players and the success of the Intervention Option. New Zealand has had several examples of the structure used in its history[79]. This ownership model would also operate to maximise profit.

- Full private ownership. This is private ownership of the Intervention Options' assets. This could be achieved through a range of different structures e.g., trust, company, or partnership.

Evaluation of ownership models

A list of five criteria have been developed to score each ownership model. These criteria have been developed with reference to the asset lifecycle. These are:

1. **Risk allocation:** Who is best placed to hold the following risks associated with the ownership of the electricity generation and storage assets of the Intervention Options throughout their lifecycle:

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[79] A current example of this ownership model is the Marsden point refinery.

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[redacted]

2. **Cashflows:** Who is entitled to, and responsible for, ongoing revenues and costs associated with asset ownership over the asset lifecycle?

3. **Control and future use:** Operational control is dealt with separately to ownership, as ownership does not necessitate control over the Intervention Option’s energy capacity. Where the Crown wished to retain control over the dispatch of the assets’ energy capacity (likely for market power reasons) this could be done via regulation, regardless of ownership. Conversely, the Crown may choose to retain ownership, but cede operational control of the asset. See section 3.2.7 for greater discussion on market power and operational models. As such, this has not been used as a criterion to score the ownership models.

4. **Future use:** Although operational control could be delivered through regulation, some ownership models may restrict the design of the operating model or the asset’s future use.

5. **Financing:** this refers to the ability for the owning entity to finance the capital costs associated with the build out of an option and any associated operational outgoings. The implications of financing (including accounting treatments) are described in greater detail in the Finance Case. Key questions for each ownership model in this section are:

    a. How does the ownership model impact upon the ability to finance the delivery of the Intervention Options?

    b. How does the ownership model impact upon the ability to finance the working capital of the Intervention Options throughout their lifecycle?

6. **Te Tiriti o Waitangi - partnership:** Given the Lake Onslow option will require the creation of a significant asset that will impact upon water assets and water rights, it is important that an ownership model allows for genuine partnership with Iwi. Commercial Information [redacted]

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Appendix K Lake Onslow Option Services and Packaging Options

In reviewing the scope of the Project, including technical disciplines and geographical locations, we consider that there is the potential to package works. The possible packages are as follows:

- **EN – Enabling Works:** Required to permit the subsequent works packages to commence. These are works on public infrastructure such as roads, tracks, electrical distribution, water supply and discharge and other limited scopes.
    - These works may be further packaged and contracted out to constructors via traditional, D&C or EPC etc contracts, not necessarily in keeping with the same approach as Packages 1 – 3 (below).
- **EA – Early Work:** Required to permit the main packages of work to commence. These works include any major bridge widening, major infrastructure improvements or temporary works, construction camps, water supply and transmission upgrades.
    - These works may be further packaged and contracted out to constructors via traditional, D&C or EPC etc contracts, not necessarily in keeping with the same approach as Packages 1-3 (below).
- **Package 1 – Main Dam**
    - The main storage dam located at Lake Onslow
- **Package 2 – Underground and Powerhouse**
    - Tunnelling and underground works from the main dam through to the lower reservoir, including all surge shafts
    - Underground powerhouse structural works, which we would generally expect to be combined with the tunnelling and underground works
    - Underground powerhouse electrical and mechanical works including the installation of the pump / turbines, main transformers, gates and commissioning of all equipment
- **Package 3 – Lower reservoir and Pumphouse**
    - Lower reservoir civil works
    - Pump house / river offtake structural works
    - Pump house / river offtake electrical and mechanical works.
- **Package 4 – Grid and transmission works** including grid connection the new 220kV transmission lines, these works are expected to be delivered by Transpower regardless of the procurement approach under a Transpower works agreement

While the above is an initial assessment of packaging, we would anticipate a fully mapped packaging strategy will be required as part of the DBC. This strategy should also take into consideration the further developed procurement drivers and market sounding / engagement as part of a complete procurement strategy.

Appendix L Developing Procurement Evaluation Criteria from Drivers

Old Procurement Drivers	Duplication with New Drivers	Stage Gate	Definition
Cost Certainty (at FID)	**Cost Certainty (at FID)** (The extent to which a model provides confidence regarding the ability to deliver the project against budget)		While there is no current approved budget envelope, models that allow for increased cost certainty from construction commencement through the life of the asset provide benefits to NZ Battery (as a major capital investment) and the owner more broadly.
Lowest Cost (at FID)	**Lowest Cost (at FID)** (The extent to which a model provides more timely commencement of a project)		Lowest cost is key to ensuring that project objectives are met overall, this has a trade-off with quality and risk transfer.
Time Certainty (at FID)	**Time Certainty (at FID)** (The extent to which a model provides more timely commencement of a project)		While there is no definitive date for getting the project to market, NZ Battery may benefit from models that allow early procurement of long lead time components and/or better enables early work packages.
Shortest Time Shortest Time (to FID and from FID to completion)	**Shortest Time (to FID and from FID to completion)** (The extent to which a model provides more timely commencement of a project)		Delivery of the project relatively quickly will enable the project objectives to be realised early.
Ease of Partnering with Mana Whenua		✓	This is considered a non-negotiable for the project, and so should be negotiated into any of the delivery models, rather than set as a procurement model screening criteria.
Risk Allocation to Constructor	**Risk Transfer** (The extent to which a model supports effective risk management by allocating risks to the parties best placed to manage them)		The majority of the risks associated with the design and construction are risks that need to be well understood by the Owner, alongside the potential market participants, allowing risks to be properly allocated and managed to minimise total project cost.
Greatest Flexibility for Change	**Flexibility** (The extent to which a model provides flexibility to address future changes in strategic direction)		NZ Battery requires flexibility to enable new ways of working for the owner, through a yet-to-be developed new operating/services model. Flexibility is required through the specification phase for development of this model and through the operations phase for iterative improvement.
Innovation / Value Release	**Innovation and Incentives** (The extent to which a model incentivises innovations that can assist in delivering desired outcomes)		The primary innovation desired through the delivery of the project is determined by the Client and should be incentivised accordingly to optimise delivery of the new operating/service model. Models that effectively incentivise innovation from the private sector would be highly beneficial.
Degree of Control / Autonomy	**Flexibility** (The extent to which a model provides		NZ Battery requires flexibility to enable new ways of working for the owner, through a yet to be developed new operating/services model. Flexibility is

	flexibility to address future changes in strategic direction)		required through the specification phase for development of this model and through the operations phase for iterative improvement.

Appendix M Procurement Model Evaluation

Eight potential procurement models were identified for delivering the Lake Onslow option, as follows:

- Traditional
- Design and Construct
- Engineer Procure Construct
- Engineer Procure Construction and Management
- Two-stage Early Contractor Involvement into an EPC
- Alliancing
- Design Construct Maintain Transfer
- Public Private Partnerships.

These are outlined in further detail in the following section, along with an overview of the evaluation of these models for delivery of the Lake Onslow option.

Traditional (Design, Bid, Build)

Traditional or Design, Bid, Build procurement is typically used for tightly specified, fully designed solutions with limited complexity. They are typically contracted on a lump sum basis[80].

The client is responsible for designs up to a detailed level of definition and then issues for bidding to which the constructor must deliver the works. A main constructor takes on the responsibility for as-built design and construction.

Advantages

- The well-known traditional procurement model gives the client the autonomy to control the project and the flexibility to adapt to changes and influence outcomes.
- Quantity risk sits with the constructor under lump sum, however some traditional contracts permit a re-measurable quantity where risk sits with the Client for items that are not as per the detailed design.

Disadvantages

- The client carries almost all risks of design, ground conditions, interface management, overall performance, while the contractor only carries risks for items that should have been accounted for by a competent contractor (productivity etc).
- With this model there is almost limited opportunity for constructor involvement in innovation due to the late appointment of the constructor, so the designer and client are responsible for innovation.
- The separation of the design and construction workstreams limits the opportunity for the design and constructions teams to optimise the design prior or during the construction stage.

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[80] A full description of this model can be found at Traditional delivery model – Information sheet (procurement.govt.nz).

- There is an increased risk around knowing the total cost prior to committing to build, with a long lead time required to get to the tender stage to give the design team time to develop the design to a level sufficient for completion with the relevant tender documentation.

Table 92 presents the assessment of the traditional procurement model against the set procurement model evaluation criteria. The model did not align with the time, innovation and risk criteria and therefore will not be considered further.

Table 92: Traditional Procurement Model Assessment

Time certainty (at FID)	🟥
Shortest time (to FID and from FID to completion)	🟥
Flexibility	🟩
Price certainty (at FID)	🟨
Lowest cost (at FID)	🟨
Innovation and incentives	🟥
Risk transfer	🟥

Design and Construct (D&C)

A design and construct approach is commonly used for well-defined projects, including large scale complex projects. In principle, design and construct contracts are fixed price lump sum where the constructor accepts and manages the majority of risks having been fully informed during the single stage tender process and contract negotiation[81]. The client is responsible for designs up to a developed level of definition against which the constructor must deliver the works.

Design and construct contracts are typically used where there is limited scope for change after contracting and as such, there is limited flexibility for changing or directing the project function. We note that, in particular, ground risk transfer for complex projects almost certainly will not be accepted by the market based on similar reference projects. Therefore, an extensive geotechnical basis report (GBR) and compensation mechanism for departures would be expected to form part of any successful D&C contract.

Advantages

- A main constructor takes on the responsibility for both detailed design and construction interfaces within their scope.
- The single point of responsibility and can aid in minimising interface risks for the client.
- The contractor's early involvement can lead to potential fast-tracking as main works may commence with design not being completed.
- Risk for the detailed design sits with the constructor, as does the solutions performance that is built based on compliance with the Principals Requirements.

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[81] A full description of this model can be found at Design and build delivery model – Information sheet (procurement.govt.nz).

- The contractor is able to provide innovation during the bid stage with their early involvement and ability to warrant the design.

Disadvantages

- With the main contractor responsible for both detailed design and construction interfaces, this may lead to potentially longer tender periods to review design, pricing and assess risk transfer and relevant premiums.
- The design team are accountable to the contractor rather than the client, which requires additional client-side oversight to ensure requirements are met, and may therefore be liable for time and cost overruns from changes to scope.
- Once the contract is awarded, the scope for innovation is reduced and the contractor is focussed on delivering against the contract design.
- As the design is expected to be defined to a greater degree early on, the responsibility for the overall performance rests to predominately with the client. In addition, the often lack of emphasis on lifecycle costs leads to the client retaining the risk of operational costs too.

Table 93 presents the assessment of the design and construct procurement model against the set procurement model evaluation criteria. The model did not align with the shortest time, flexibility, innovation and risk criteria and therefore will not be considered further.

Table 93: Design and Construct Procurement Model Assessment

Time certainty (at FID)	🟨
Shortest time (to FID and from FID to completion)	🟥
Flexibility	🟥
Price certainty (at FID)	🟨
Lowest cost (at FID)	🟩
Innovation and incentives	🟥
Risk transfer	🟥

Engineer Procure Construct (EPC)

An Engineer, Procure Construct approach is similar to a Design and Construct option; however, generally reflects a greater degree of design responsibility and risks allocated to the Constructor. In addition to productivity, price escalation and detailed design, under an EPC contract selection, procurement of long lead items and overall performance (time/efficiency) are typically the responsibility of the constructor.

The client is responsible for delivering a very well-defined project brief from the outset, designs up to a concept or preliminary level of definition and a performance specification against which the constructor must deliver the works. These requirements are occasionally defined as a minimum functional/performance specification to reflect that the constructor’s responsibility is widened from that of a design and construct model[82].

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[82] A full description of this model can be found at Standard types of construction contract – Information sheet

As the contractor is appointed on capability and experience rather than price, the involvement of expert cost estimators is vital to minimising additional costs from being imposed from the non-competitive nature of the model.

Based on similar reference projects, such as Snowy 2.0, an extensive geotechnical basis report (GBR) and compensation mechanism for departures would be expected to form part of any successful EPC contract, similar to D&C above. As the main constructor takes on the responsibility for both developed and detailed design, interfaces and construction, this preliminary information allows the 'buildability' of the design to be considered and construction efficiencies to be explored.

Advantages

- Risk for the developed and detailed design sits with the constructor, as does the solutions performance that is built based on compliance with the Principals Requirements. This approach can support shorter delivery timeframes through identification of design and construction efficiencies and increased opportunities for innovation.
- An EPC is suitable for large or complex projects, like NZ Battery, where an uncertain scope may benefit from the early involvement of a specialist contractor.

Disadvantages

- The contractor is able to provide innovation during the bid stage, but once the contract is awarded the scope for innovation is reduced and the contractor is focussed on delivering against the contract design.

There is not a direct reference in current government procurement options. It is recommended that reference is made to either the FIDIC EPC/Turnkey Contract (Silver Book) or the NEC4: Engineering and Construction Contract.

Table 94 presents the assessment of the EPC procurement model against the set procurement model evaluation criteria. The model did not align with the flexibility criterion and therefore will not be considered further.

Table 94: EPC Procurement Model Assessment

Time certainty (at FID)	🟨
Shortest time (to FID and from FID to completion)	🟨
Flexibility	🟥
Price certainty (at FID)	🟨
Lowest cost (at FID)	🟩
Innovation and incentives	🟨
Risk transfer	🟨

Engineer Procure Construction and Management (EPCM)

The Engineer, Procure, Construction Management approach provides for a professional services consultant to act as a Management Consultant to manage the engineering design, procurement process and the various construction, supply, and installation contracts. This approach has been used primarily in the resources, mining, oil and gas sectors in order to deliver large complex projects.

The client is responsible for delivering a very well-defined project brief from the outset, and designs up to a concept or preliminary level of definition against which the Managing Consultant must deliver the works by acting as an agent of the client. A Managing Consultant takes on, with the owner's input, the responsibility for:

- Developed and detailed design
- Constructability, logistics and scheduling
- Procurement and contract management
- The integration of various equipment supply and constructor packages.

Advantages

- The managing consultant, owner, designer and, to a lesser degree, each package constructor, all contribute to the buildability and optimisation of designs, allowing for the opportunity for significant innovation[83] to be incorporated.
- The overall responsibility for the project, including that of the detailed design and performance, sits with the Managing Consultant, as does the solution that is built based on compliance with the Principals Requirements.
- The main benefit that EPCM delivers for clients over EPC is the sense of ownership as it allows for greater flexibility for the client, which can ultimately lead to a better overall outcome for the project. As EPCM does not necessitate a very well-defined brief and scope from the beginning, it is well-suited to projects which are less defined or face variables that need to be considered.

Disadvantages

- With limited ability to make adjustments once the project kicks off, this model is deemed unsuitable for new, complex, innovative and/or technical projects like NZ Battery.
- The risk of the Management Consultant's performance and ground-based risk will ultimately rest with the client.

Table 95 presents the assessment of the EPCM procurement model against the set procurement model evaluation criteria. The model allowed all criteria to be met and therefore will be further considered in the DBC.

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[83] A full description of this model can be found at Package based delivery model – Information sheet

Table 95: EPCM Procurement Model Assessment

Time certainty (at FID)	🟨
Shortest time (to FID and from FID to completion)	🟨
Flexibility	🟨
Price certainty (at FID)	🟨
Lowest cost (at FID)	🟨
Innovation and incentives	🟩
Risk transfer	🟨

Two Stage Early Contractor Involvement (ECI) into an EPC

While not a procurement contract in the strictest sense, the two-stage ECI is a mechanism for enhancing Traditional, D&C or EPC contracting. A two Stage ECI approach involves the procurement of either a single or multiple constructors to develop a fully scoped and priced solution in collaboration with the client.

The client is responsible for designs up to an initial preliminary design and performance requirements (initial Principals Requirements) against which the client further develops in the first stage of the ECI with input from the constructor into a developed functional and technical performance set of requirements (final Principals Requirements)[84].

A constructor takes on the responsibility for detailed design through to construction. Quantity risk sits with the constructor. Ground risk transfer for this project may be accepted by the market based on similar reference projects, with a geotechnical basis report (GBR) and compensation mechanism for departures expected to form part of any successful EPC contract similar to D&C above.

Advantages

- Involvement from a constructor into the buildability and optimisation of designs allows for significant innovation, schedule development and time certainty.
- The extended upfront engagement with the constructor should enable better risk transfer.
- Risk for the detailed design sits with the constructor as does the solution that is built based on compliance with the developed Principals Requirements as per a D&C or EPC.

Disadvantages

- The client is expected to advance the design requirements to the point the necessary for the constructor to prepare an optimised bid.

Table 96 presents the assessment of the two-stage ECI to EPC procurement model against the set procurement model evaluation criteria. The model allowed all criteria to be met and therefore will be further considered in the DBC.

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[84] A full description of this model can be found at Early contractor involvement – Information sheet (procurement.govt.nz)

Table 96: Two Stage ECI to EPC Procurement Model Assessment

Time certainty (at FID)	🟩
Shortest time (to FID and from FID to completion)	🟨
Flexibility	🟨
Price certainty (at FID)	🟨
Lowest cost (at FID)	🟩
Innovation and incentives	🟩
Risk transfer	🟩

Alliance (Pure and Competitive)

The client is responsible for designs up to a Preliminary / Reference level of design functional and technical performance requirements (Principals Requirements) to which the Alliance must deliver the works. The Alliance delivery entity comprises of the Client, Owner's Verifier, Design Consultant and Constructor and takes on the responsibility for developed design and construction[85]. This requires all parties to commit to honest collaboration, with the overall design, operation and price risks sitting with the public sector.

The Alliance forms a consortia Interim Project Alliance to develop the design and agree a final Target Out-turn Cost (TOC); in the case of the pure alliance, this includes the client. In a competitive alliance, multiple consortia are involved in producing the TOC and bid for the final Project Alliance.

Advantages

- Involvement from a constructor, client and designer into the buildability and optimisation of designs allows for significant innovation and incentivises the parties to make best-for-project decisions.
- The alliance structure provide flexibility for the design to be modified and incorporated during construction.
- Risks for the project sits with the Alliance which may package the works and pass that risk through to sub-contractors.

Disadvantages

- One design is developed by the collective Alliance parties, leading to the potential lack of incentive in achieving an innovative final design that maximises operational benefits.

Table 97 presents the assessment of both the pure and competitive procurement models against the set procurement model evaluation criteria. The model allowed all criteria to be met and therefore will be further considered in the DBC.

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[85] A full description of this model can be found at Alliance delivery model – Information sheet (procurement.govt.nz)

Table 97: Pure and Competitive Alliancing Procurement Model Assessment

Time certainty (at FID)	🟩
Shortest time (to FID and from FID to completion)	🟩
Flexibility	🟩
Price certainty (at FID)	🟨
Lowest cost (at FID)	🟩
Innovation and incentives	🟩
Risk transfer	🟨

Design Construct Maintain (Build Own Operate / Transfer– BOO/T)

The design construct maintain or build own operate/transfer (BOO/T) model is a long term contract for the delivery of works and operating services to the client, based upon the provision of an asset or facility, which is typically transferred at the end of a contracted period.

The client is responsible for designs up to a concept or preliminary level of definition and a performance specification against which the constructor must deliver the works and maintain the service. These requirements are occasionally defined as a minimum functional/performance specification to reflect that the constructor's responsibility is widened from that of a design and construct model.

It is substantially similar to the PPP model below aside from that the finance for the project is provided by the client and that the specification of the works is more prescriptive.

Advantages

- This model allows for a main contracting entity with relevant expertise to design, construct and maintain the project asset, thus transferring a great deal of risk onto the contractor.

Disadvantages

- While the minimum functional/performance specifications provided by the Client are often considered an advantage for very complex projects with diverse stakeholders, it can be a challenge to achieve, leading to potentially higher cost of variations and compensable events (during construction) due to the financing arrangements and risk pricing.

Table 98 presents the assessment of the design, construct and maintain procurement model against the set procurement model evaluation criteria. The model did not align with the flexibility, shortest time and innovation criteria and therefore will not be considered further.

Table 98: Design, Construct and Maintain Procurement Model Assessment

Time certainty (at FID)	🟨
Shortest time (to FID and from FID to completion)	🟥
Flexibility	🟥
Price certainty (at FID)	🟩
Lowest cost (at FID)	🟨
Innovation and incentives	🟥
Risk transfer	🟩

Public Private Partnership (PPP)

The Public Private Partnership (PPP) model is a long-term contract for the delivery of a service to the client, based upon the provision of an asset or facility, which is typically transferred at the end of a contracted period and is implemented following a commonly competitive tender process. The private partner funds, builds and can operate the asset, and often transfers the control of the service of the asset to the public partner at the end of the contract.

The client is responsible for specifying the service required by the asset and the minimum functional specification of the works to be handed over to meet the service requirements[86]. The public sector then purchases the public services that are reimbursed based on performance of the asset, with the contract value typically confirmed before construction begins.

Advantages

- PPP approaches uses a competitive tender process
- Financing of major government projects allow them to be supported by private funding under a PPP.
- Public sector becomes a purchaser of public services that are paid for based on performance and locks in the price paid for services
- The private party assumes significant financial, technical and often operational risks in the project programme
- Utilising private sector capability, innovations and technology in combination with public sector incentives and public outreach.

Disadvantages

- The risk imposed on the public partner as the agreed-upon usage fees may not be sustained by the demand use of the asset.
- The private entity absorbs the risk of cost overruns, technical defects, and poor quality.
- Private delivery of some services may counter public sector policy.

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[86] A full description of this model can be found at Public private partnerships (PPP) – Information sheet

Table 99 presents the assessment of the public private partnership procurement model against the set procurement model evaluation criteria. The model did not align with the flexibility, shortest time and innovation criteria and therefore will not be considered further.

Table 99: Public Private Partnership Procurement Model Assessment

Time certainty (at FID)	🟩
Shortest time (to FID and from FID to completion)	🟥
Flexibility	🟥
Price certainty (at FID)	🟩
Lowest cost (at FID)	🟩
Innovation and incentives	🟩
Risk transfer	🟩

Appendix N Reference Projects

Asset / Project	Delivery Entity and Governance and Funding	Client Capability	Model	Risk Transfer	Constructor
Energy					
Snowy 2.0 Pumped Hydro with underground pumphouse Australia	Snowy Hydro – government owned commercially operated Similar to an Autonomous Crown Entity Funded through government debt and equity	Snowy Hydro – Significant operational and sustaining capital capability, more limited large scale construction project delivery capability ~1700 employees	Competitive ECI with two constructors and equipment suppliers to a single EPC JV between winning constructor and equipment supplier	Only ground risk remains with client but is managed through a geotechnical baseline report	Webuild and Lane (Salini Impregilo) Clough
Kidston Pumped Hydro with underground pumphouse Australia	Genex Energy – listed company AUD ~290 million market cap Privately funded	Genex Energy – Small development company 15 employees and 3 consultants	Limited upfront design ECI – to EPC Single constructor and equipment supplier	Full ground risk transfer	McConnell Dowell John Holland
Coire Glas Pumped Hydro with underground pumphouse UK	SSE plc – large listed company GBP 19 billion market cap	Significant project development, delivery, operational and sustaining capital capability. Circa 10,000 employees	Sole Constructor ECI to turnkey EPC Competitive for the first stage	Uncertain at this time	Strabag UK for first stage

Asset / Project	Delivery Entity and Governance and Funding	Client Capability	Model	Risk Transfer	Constructor
ITER Experimental Nuclear Reactor **France (Multi-national)**	Intergovernmental Organisation	Nil prior to establishment, currently 1000 directly employed with a further 200 project associates and 500 contractors	Extensive upfront design development, heavily packaged, multiple contracts: Design-bid-build. Design and Construct, Construction Manage etc	Limited due to packaging, client managed interfacing where not contracted to agents	Multiple constructors
Transport and Aviation					
City Rail Link Underground Heavy Rail **New Zealand / Aotearoa**	Auckland Council / Ministry of Transport Auckland Transport / Kiwirail Schedule 4A company	Originally Auckland Transport however migrated to a new schedule 4a company during procurement Extensive rail and transport operation procurement capability	Initially a design and construct Single Competitive Alliance	Managed by Alliance	Vinci Construction Grands Projects S.A.S, Downer NZ Ltd, Soletanche Bachy International NZ Limited, WSP New Zealand Limited, AECOM New Zealand Limited, Tonkin + Taylor Limited
Waterview Connection **Motorway including bored and cut and cover tunnelling** **New Zealand / Aotearoa**	Waka Kotahi (Transit NZ)	Waka Kotahi (Transit NZ) Extensive capability in transport project procurement	Single Competitive Alliance	Managed by Alliance	McConnell Dowell, Fletcher Construction, Obayashi Corporation, Beca, Parsons Brinckerhoff, Tonkin & Taylor

Asset / Project	Delivery Entity and Governance and Funding	Client Capability	Model	Risk Transfer	Constructor
Transmission Gully Motorway **Motorway bypass including multiple bridges and large scale earthworks** **New Zealand / Aotearoa**	Waka Kotahi	Limited capability in PPP procurement. Extensive capability in other transport.	Public Private Partnership	Unconsented project with inadequate transfer of consenting risk[87]	CPB & HEB in Joint Venture (CPB HEB JV)
Heathrow Terminal 5 **Airport terminal** **UK**	Heathrow Airport Holdings (British Airport Authority) Private company	Significant project development, delivery, operational and sustaining capital capability. Circa 6,500 employees	Alliance with 16 packages with 147 projects	Managed by Alliance	Laing O'Rourke, AMEC and MACE (tier 1)
Water					
Thames Tideway **Underground wastewater tunnel** **UK**	Thames Water via a Regulated infrastructure provider (Bazalgette Tunnel Ltd BTL)	Significant project development, delivery, operational and sustaining capital capability. Circa 7,000 employees	Three main tunnel packages: NEC3 Engineering and Construction Contract option C (target cost contract with activity schedule) for tunnels under alliance framework Option E (cost reimbursable) for systems integrations	Risk shared between delivery entity and constructor (target cost)	Tunnel Packages AM Nuttall, Morgan Sindall and Balfour Beatty Ferrovial Agroman and Laing O'Rourke Costain, Vinci and Bachy Soletanche

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[87] https://www.tewaihanga.govt.nz/assets/Uploads/Transmission-Gully-Interim-Review-2021.pdf

Appendix O Finance and funding models (Case Studies)

The following table provides a sample of different funding and financing models.

Financing Arrangement		Example	Advantages	Disadvantages
Example	**Cost**		**With respect to the commercial arrangement**	
Grant – Infrastructure Acceleration Fund (IAF)	$NZD 1b	• The IAF, administered by Kāinga Ora – Homes and Communities, is a contestable fund designed to help councils fund infrastructure to enable housing development in areas of need. • The fund of approximately $1 billion was launched in June 2021 and has received a great response from councils, iwi and developers across Aotearoa New Zealand. • Following a robust process to evaluate both initial expressions of interest and full responses to request for proposals, 35 proposals have now been invited to enter the final stage of the IAF process.	• Simple funding arrangement. • The parties receiving the funding are heavily incentivised to participate as they are not required to return the sum of money given to them.	• Government does not participate in any of the upside and revenue generated from the asset. • New Zealand specific legal and regulatory context. Hard to look overseas for inspiration on how these arrangements can be set up. • These can become highly political and contentious.
Operating Subsidy – Horizon Power	$AUD208m in subsidies FY 18/19[88]	• Horizon Power is a commercially focused, State Government owned energy utility that serves residents and businesses in remote and regional Western Australia by generating, procuring, distributing and retailing electricity • Government subsidy of $208 million for the 2018-19 financial year (around $3,800 per customer connection).	• Gives the private sector additional confidence to invest in risky infrastructure projects. • Attracts investors that may not have been interested previously. • Can fill in the gaps for the years that an entity or project is not profitable. • Similar to offtake agreement.	• Lowers incentive for the private sector to make real profits (before government intervention). • Most of the operating risk sits with the government.

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[88] https://web.horizonpower.com.au/media/4890/statement-of-corporate-intent-2018_19.pdf

Financing Arrangement		Example	Advantages	Disadvantages
Example	**Cost**		**With respect to the commercial arrangement**	
Guarantee on Debt - Airports Fiji	$AUD 68.4m	• In June 2021, the Australian Infrastructure Financing Facility for the Pacific (AIFFP) alongside ANZ Fiji, signed a AUD68.4 million loan to Airports Fiji Pte Ltd (AFL). The loan will fund essential maintenance and capital works at Nadi International Airport and several outer islands' airports, refinances existing debt and supports the infrastructure priorities of AFL. • The AIFFP's financing package consists of a AUD61.9 million guarantee to ANZ Fiji for ANZ's loan to AFL, and a direct AUD6.5 million loan to AFL. The AIFFP's innovative partnership with ANZ, utilising AIFFP's newly established guarantee instrument, ensured they could provide a local currency loan to AFL, which best supported AFL's operational needs.	• Simple funding arrangement. • Encourages the private sector to engage in risky projects they wouldn't have otherwise.	• The government takes significant financial risk. • The counterparty does not take much risk, which could create poor incentives. • This funding arrangement may mean the debtor is incentivised to take additional risk at the governments expense.
Debt Financing - Kiwi Rail Green Loan	$NZD 350m	• KiwiRail has taken a NZ$350m ($246.3m) green loan, the first for the shipping sector to be certified by the Climate Bonds Initiative. • It is to help buy new ferries that are expected to reduce carbon emissions by 40% compared with those from the current fleet. • KiwiRail's NZ$350m debt facility is financed by Westpac (the facility agent), Bank of America, National Australia Bank and Société Générale.	• The 'green' element of the loan may help attract overseas capital (point of differentiation). •	• New Zealand's market is unlikely to be mature or large enough to attract enough capital for this arrangement. •

Financing Arrangement		Example	Advantages	Disadvantages
Example	Cost		With respect to the commercial arrangement	
		• The company chose the loan format due to its flexibility over bonds and structured it as green. That means the proceeds are ring-fenced to the project, whereas the increasingly popular sustainability-linked format connects interest payments to company performance.		
Green Project Bonds – **Case study: Wind X and XI Projects**	$USD 850m	• In February 2017, MidAmerican Energy issued a US$850 million green bond to finance the construction of two Iowa wind farms. The total issuance comprised US$375 million of 10 year bonds and US$475 million of 30 year bonds. • The Wind X and XI Projects will be complete by the end of 2019, and will have a total generation capacity of 2551 MW. The wind farms will generate enough electricity to satisfy approximately 85% of Iowa's retail customer demand.[89]	• Ability to repay investors over a longer term and with a fixed interest rate, as set by the issuer according to its assessment of investor appetite. • Project bonds are often issued subject to covenants that are less onerous than the more restrictive covenant package typically imposed by banks under syndicated loans.	• Traditionally, capital markets have been reluctant to support projects in their planning and construction phase (i.e. greenfield investments), with bonds instead being focused on the refinancing of existing debt after a project is up and running (i.e. brownfield investments) • Bond holders also often lack the resources to effectively evaluate completion risk and monitor the project.
Debt Financing - Northern Australian Infrastructure Financing Facility (NAIF)	$AUD 2.6b for closed deals[90]	NAIF can provide debt or equity finance to projects that satisfy the relevant mandatory criteria in the Investment Mandate. The mandatory criteria require that each project must: • Involve the development or enhancement of infrastructure. • Be of public benefit.	• Multiple ways of funding a project such as issuing sovereign bonds or by accessing commercial bank credit.	• Typically provided on shorter terms than bonds, necessitating frequent refinancing over the life of the project and exposure to fluctuations in interest rates.

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[89] https://www.gtlaw.com.au/knowledge/green-project-bonds-why-project-bonds-will-be-bigger-part-australias-infrastructure

[90] https://naif.gov.au/

Financing Arrangement		Example	Advantages	Disadvantages
Example	Cost		With respect to the commercial arrangement	
		• Be in, or have significant benefit for, northern Australia. • For debt finance, be able to repay or refinance NAIF's debt. • Have an Indigenous engagement strategy. • For equity investments, generate a return to Government.		
Offtake Agreement / Power Purchasing Agreement Markbygden EET Windfarm	€800m ($USD 953m)	• The power generated from the Markbygden ETT windfarm will be purchased by a subsidiary of Norsk Hydro under a 19-year power purchase agreement (PPA), making it the world's biggest corporate wind energy PPA. • GE Energy Financial Services and Green Investment Group have invested more than €300m ($USD 356.45m) in equity of the project. • The remaining €500m ($USD 594.1m) was financed by European Investment Bank, Export Credit Garantees of the Federal Republic of Germany (Hermes Cover), NordLB (MLA advisor and ECA bank), KfW IPEX-Bank, and HSH Nordbank.[91]	• An offtake agreement serves an important role for the producer. If lenders can see the company has clients and customers lined up before production begins, they are more likely to approve the extension of a loan or credit. So offtake agreements make it easier to obtain financing to construct a facility. • The seller can negotiate a price that secures a minimum level of return on the associated goods, thereby lowering the risk associated with the investment. • Could be intertwined with another project finance or PPP agreement.	• All parties involved are likely to incur significant legal costs drafting an offtake agreement. • Hard to determine how much the government should offtake and guarantee the producer. • Added complexity given the variability/volatility of energy markets. • Requires sophisticated and experienced suppliers/asset managers to govern participate in such an arrangement. • PPA receivers may be reluctant to commit to a fixed price years in advance and because most projects are too large for a single offtaker.

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[91] https://www.power-technology.com/projects/markbygden-ett-windfarm/

Appendix P Funding and financing assessment

Evaluation criteria has been included below which could be used to narrow down the potential finance and funding options that are available to the New Zealand government and applied through the DBC.

Table 100: Evaluation criteria

Category	Assessment Criteria	Description
Key Risks	***Regulatory Approval***	- To what extent is the Option easy to approve and regulate?
	Budget	- To what extent the Option assists in delivering the project within budget?
	Demand	- Who bears the shortfall if the investment costs cannot be met by the forecasted revenue?
	Asset Performance	- To what extent the Option assists in achieving the service consistent with the design specifications?
Government Implications	***Government Ownership***	- To what extent the government owns the asset?
	Expected cost to the Government	- To what extent the government bears the risk and cost of the project?
	Expected Net Debt Impact	- To what extent the investment impacts on the net debt position?
Operational Implications	**Time to Completion**	- How long is it likely to take to implement this option?
	Legal Complexity	- What is the extent of legal and regulatory complexity? - To what degree of regulatory change required?
	Social Impact	- Derived cost and benefit delivered to direct and indirect stakeholders.
	Flexibility to Change / control	- To what extent the Option enables the Government to retain flexibility in terms of condition and outcome of the transmission investment?

Appendix Q Lessons learned analysis

The Treasury publishes lessons learned from Gateway reviews which highlight opportunities for project and programme management improvements in New Zealand Government agencies. Four reports have been issued as a result of these reviews, these reports are an analysis of 188 Gateway reviews conducted across 86 projects and 41 agencies, from the inception of Gateway in New Zealand in May 2008 through to May 2016. The findings of these reviews have been relatively consistent, and the themes of these lessons have been outlined below. These reviews are relevant to New Zealand Battery IBC as their findings come from other high to medium risk projects that have Government strategic objectives and are of a similar magnitude to New Zealand Battery. It is important that the New Zealand Battery project learns from previous mistakes and implements best practice protocols where possible.

Themes of lessons learned	Application to New Zealand Battery
Governance – The overall purpose of effective governance is to ensure that an organisation's project and change portfolio is aligned to the organisation's objectives, delivered efficiently, and is sustainable.	The governance structure for the New Zealand Battery project will remain largely consistent with current NZ Battery Team structures through phase 2a. However, as the project moves through phase 2a, governance will be considered in detail to ensure sufficient capability and structures are in place to secure the success of the project through to FID and beyond. Key elements that future governance arrangements should include consider: • Clear roles and responsibilities with clarity of purpose during the project and an efficient and predefined decision-making process. • Established and clear reporting arrangements and interfaces to ensure interagency consultation and knowledge sharing. • Terms of reference, reporting, delegations and accountabilities should be clearly defined to ensure project momentum is maintained and decision makers are receiving appropriate and timely project updates.
RAID (Risks, Assumptions, Issues & Dependencies) - The lack of process around the ongoing management of risks, including identification, assessment of likelihood, impact and residual impact after treatment, assigning ownership, and active iterative management throughout the project.	NZ Battery risk management processes are outlined in the Commercial and Management Cases. It is expected that current risk management processes (based on international standards) will be built on to manage phase 2a of the project. Broadly, risk management for the NZ Battery project is expected to include: • The use of risk / RAID logs to identify, allocate and track risks throughout the project's life • Explicit escalation thresholds for each tier of governance. • Reporting of risk that provides sufficient detail to inform timely and effective management and monitoring.

Themes of lessons learned	Application to New Zealand Battery
Business Case – This covers all aspects of the Better Business Cases framework	The IBC has been developed in accordance with the Better Business Cases framework and has been through the Gateway Review 1 process: Business Justification & Options. Further, the IBC is expected to go through inter-agency consultation (including with Treasury). All business case inputs have been developed by subject matter experts (e.g., technical engineering reports have been commissioned by qualified engineering teams).
Transition into Service - All activities and processes that must be designed and established before a project can be signed off, should be signed off in advance and included as part of the organisation's business-as-usual.	The New Zealand Battery project is still in the early stages of its lifecycle. As the project develops and moves towards phase 3 and FID the following documentation / assurances (at a minimum) should be in place: • Preparation of an integrated plan developed with, and agreed by, all key stakeholders to ensure a common understanding of the key activities, their timing, dependencies, and resourcing required during the transition period and into operation. • Service Operation capability should be in place and tested. • Business Continuity Plan. • Disaster Recovery Plan (tested).
Sourcing Strategy and Management - Covers the end-to-end procurement process.	Before the procurement begins, processes must be put in place to ensure: 1. That the team engage with the market early and follow robust probity rules. 2. Robust RFI documents are developed with an effective negotiation and contract management framework. 3. Due diligence is completed on vendors – e.g., the team should seek formal evidence that the vendor can successfully deliver the required services. If this evidence is not available, this needs to be clearly documented to enable risks to be identified, assessed and managed. 4. If the vendor is doing work for other government agencies, these are identified and contact is made to seek their perceptions and areas of concern. Consider the total scope of work and its timing, and, if necessary, seek formal commitment from the vendor that appropriate resourcing will be in place for the duration of the project. 5. Contract management arrangements should be put in place as soon as the business case is approved, and consideration given to resourcing and upskilling for supplier management.
Programme & Project Management – This concerns all aspects of project, programme and portfolio management including Master Plan and time / scope / quality management, but excludes Methodology and Project & Programme Planning, which occur frequently enough to warrant a separate category.	When the next phases of the project begin a dedicated project manager should be appointed. As a part of their role, they need to ensure that: 1. All decision makers have the required information needed to make prompt and appropriate decisions. 2. Decision making criteria and roles are clearly defined so that decision-makers have clear parameters. This is particularly important for key decisions, such as exercising an off-ramp.

Themes of lessons learned	Application to New Zealand Battery
Stakeholder Management - The relationships with all parties with an interest in the outcome of the project or programme, whether internal to the agency, internal to government or external.	It is important that communications with stakeholders are clear, frequent, and detailed. This helps to build a common understanding of key aspects, including design, plans, constraints, finances, reporting and decision-making lines of authority etc. Significant stakeholder consultation is expected to take place during phase 2a. See further detail in Appendix T.
Resource Management – There is a tendency to leave key project roles vacant until the project is well advanced.	Ensuring that the NZ Battery project team is adequately resourced and has sufficient capability is acknowledged as a key risk to the success of the Project. In recognition of this, it is expected that there would be a significant recruitment effort (utilising MBIE existing recruitment policies and practices) in advance of phase 2a beginning.
Benefits Realisation and Management – This is an undeveloped area on the majority of New Zealand government projects.	Benefits should be drivers for the project and documenting them needs to start early. Information should be documented in the Benefits Realisation Plan and further developed as the project progresses, and should include: • Clear lines of accountability for outcomes once the project is operational • The separation and dependencies between tranches • The linkages and dependencies between Statements of Work (SoWs), including offramps • Recognition of the requirement for early tracking of benefits from early releases. A Benefits Map linking the project deliverables to subsequent business benefits is also needed to help track the impact of changes on benefits when scope changes. To date, the benefits of a NZ Battery investment have been explored in the Strategic Case.
Management of Change - The work required in, and by, the business to make itself ready for the initiative, in terms of changes to business processes.	Phase 2a of the NZ Battery process is largely expected to be completed by MBIE as an extension of business-as-usual practices. However, phase 2b, to get to FID, and beyond is expected to require significant organisational change to ensure the project owners are best able to deliver on the project. Exactly what change is required to facilitate this is anticipated to be developed during phase 2a and put into practice prior to phase 2b work starting.
Financial Planning and Management - The trend to more complex multi-agency projects and programmes in the public sector introduces new complexity into financial arrangements. If not addressed early and carefully, these can cause significant difficulties and delays as a result of funding gaps.	The IBC covers off funding and financing at a high-level. It is expected that these would be developed and assessed in greater detail in phase 2a, before funding and financing is sought for FID and beyond.

Themes of lessons learned	Application to New Zealand Battery
Programme & Project Planning - ‘Planning’ here is used in the broad sense to encompass the detailed proposals for various types of activities that will lead to a successfully executed programme or project.	The NZ Battery Project has commissioned a significant amount of work from TRM to plan and phase the next steps for the project to get from IBC to commissioning. It is expected that more detailed scheduling and analysis of each option will be undertaken during the DBC to refresh current planning and ensure the project is well considered and able to be successfully completed.
Capturing Lessons Learned – This captures projects learning from their errors and successes and ensuring these learnings are actioned and made available to others, whether in the same project, or in later projects or tranches.	The NZ Battery project has a long-time horizon (the construction of the Lake Onslow pumped hydro scheme is expected to take +10 years from planning to commissioning). To ensure the project successfully captures and learns from itself, lessons learned should be sought and documented in a central repository early and often throughout the project. Further, all lessons learned should be actively made available to later phases of this programme and to other projects in the agency and sector.
Methodology - The use of structured proven approaches to programme and project management such as Managing Successful Programmes (MSP), Investment Logic Mapping (ILM), Quantitative Risk Analysis (QRA), or the Portfolio, Programme and Project Management Maturity Model (P3M3) as a tool for capability development.	Project methodologies provide a coherent set of proven structures, roles and practices, with supporting materials and practices. The NZ Battery project IBC to date has made use of tried and tested methodologies endorsed by Treasury such as MCA, ILM and QRA. It is expected that the project would continue to make use of similar tools through phase 2a, to FID, and beyond.

Appendix R Stakeholder groups and interests

Stakeholder category	Stakeholders	Broad interests
Central Government	• Prime Minister • Minister of Energy and Resources • Minister for the Environment • Minister of Conservation • Minister of Climate Change • Minister of Finance • Minister for Infrastruture • Department of Conservation • Climate Change Commission • Ministry for the Environment • Te Arawhiti • Parliamentary Commissioner for the Environment • Treasury • Commerce Commission • Land Information New Zealand • Waka Kotahi • Te Waihanga • NZDF • MPI • Opposition spokesperson for Climate Change • Opposition spokesperson for Conservation • Opposition spokesperson for Energy and Resources • MP for Te Tai Tonga • MP for Southland • MP for Invercargill • MP for Waitaki	• Cost and value • Electricity network operation and security • Project progress • Approvals • Job creation • Impacts and benefits • Legacy • Economic productivity • Robust decision-making process • Upholding TOW principles • Coordination of stakeholders

Stakeholder category	Stakeholders	Broad interests

Crown-legislated energy groups	• Electricity Authority including advisory groups:
	  • Market Development Advisory Group
	  • Innovation and Participation Advisory Group
	  • Security and Reliability Council
		• How a battery would impact efficiency of market operation
		• Security and reliability of supply
		• Investment environment

Investors and financial institutions	• Institutional investors • Green Investment Fund • Super Fund • Negotiations [redacted])	• Opportunity and impact for investment
Other Energy Sector Organisations	• Business Energy Council • Ara Ake • Energy Resources Aotearoa	• NZ energy market outcomes • Progress on climate change objectives • Investment environment
Gentailers	• Contact Energy • Meridian Energy • Mercury Energy • Genesis Energy • Nova Energy •	• Impact on business operation • Ability to operate profitably • Impact to generation • Future investment opportunity • Opportunity for investment in their assets / geographic area they operate in / areas of expertise
Independent electricity generators	• Independent Electricity Generators Association Incorporated • NZ Wind Energy Association • Sustainable Energy Association New Zealand • Solar Association of New Zealand • Manawa Energy • Pioneer Energy	• • Impact on business operation • Ability to operate profitably • Impact on generation • Future investment opportunity • Opportunity for investment in their assets / the area they currently operate in
Electricity network providers	• Electricity Network Association • Transpower • Aurora Energy	• Cost and value • Electricity network operation and security • Project progress

Stakeholder category	Stakeholders	Broad interests
Independent electricity retailers	• Electricity Retailers Association NZ	• Competitive retail electricity system • Impact to retail operations • Ability to operate profitably • Future investment opportunities
Electricity users	• Major Electricity Users' Group • Community Energy Network • Domestic Energy Users Group • New Zealand Aluminium Smelter (Tiwai)	• Financial savings • Security of supply • Energy hardship and fairness
ENGOs	• Environmental Defence Society (EDS) • Greenpeace • Forest and Bird • Fish and Game • New Zealand Climate Action Network • Our Energy • 350.org • Coal Action Network Aotearoa	• Environmental impact • Contribution to climate change objectives • Local benefits and impacts for option/s being investigated • Robust environmental investigation • Ability to feed into environmental investigations
Media	• Local • National • Key commentators	• Process • Impacts • Cost • Benefits • Timeframes • Progress • Economic evaluations
General public	• Lake/intake/tunnel landowners • Residents • Businesses • Chamber of Commerce • Teviot Business Groups	• Project legacy • Project impacts • Benefits • Security of supply • Electricity cost

Stakeholder category	Stakeholders	Broad interests
	• Irrigation companies • Recreational anglers	• Uncertainty for operations
International organisations	• Snowy 2.0 pumped hydro • International Energy Agency	• Lessons learned • Policy impact
Crown research institutes	• NIWA • Scion • DOC • GNS Science	• Completion of investigations at Lake Onslow
Local Government	• Otago Regional Council • Central Otago District Council	• Project legacy • Project impacts • Benefits • Security of supply • Electricity cost

Te Kāwanatanga o Aotearoa
New Zealand Government

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