MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Energy and Resource Markets (ERM)

The future of energy in New Zealand

July 2021

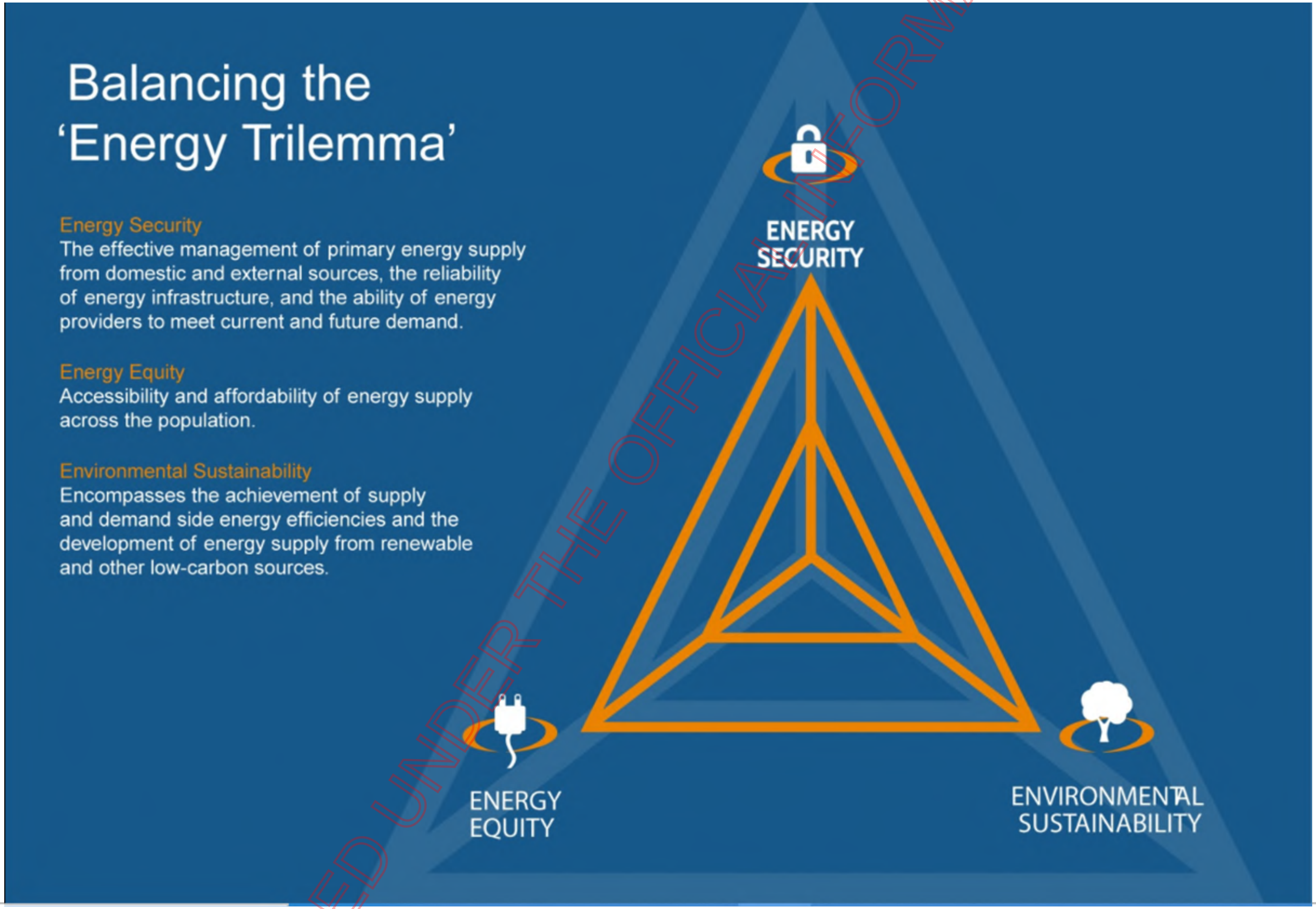
New Zealand Government

The energy system is on the verge of unprecedented change…

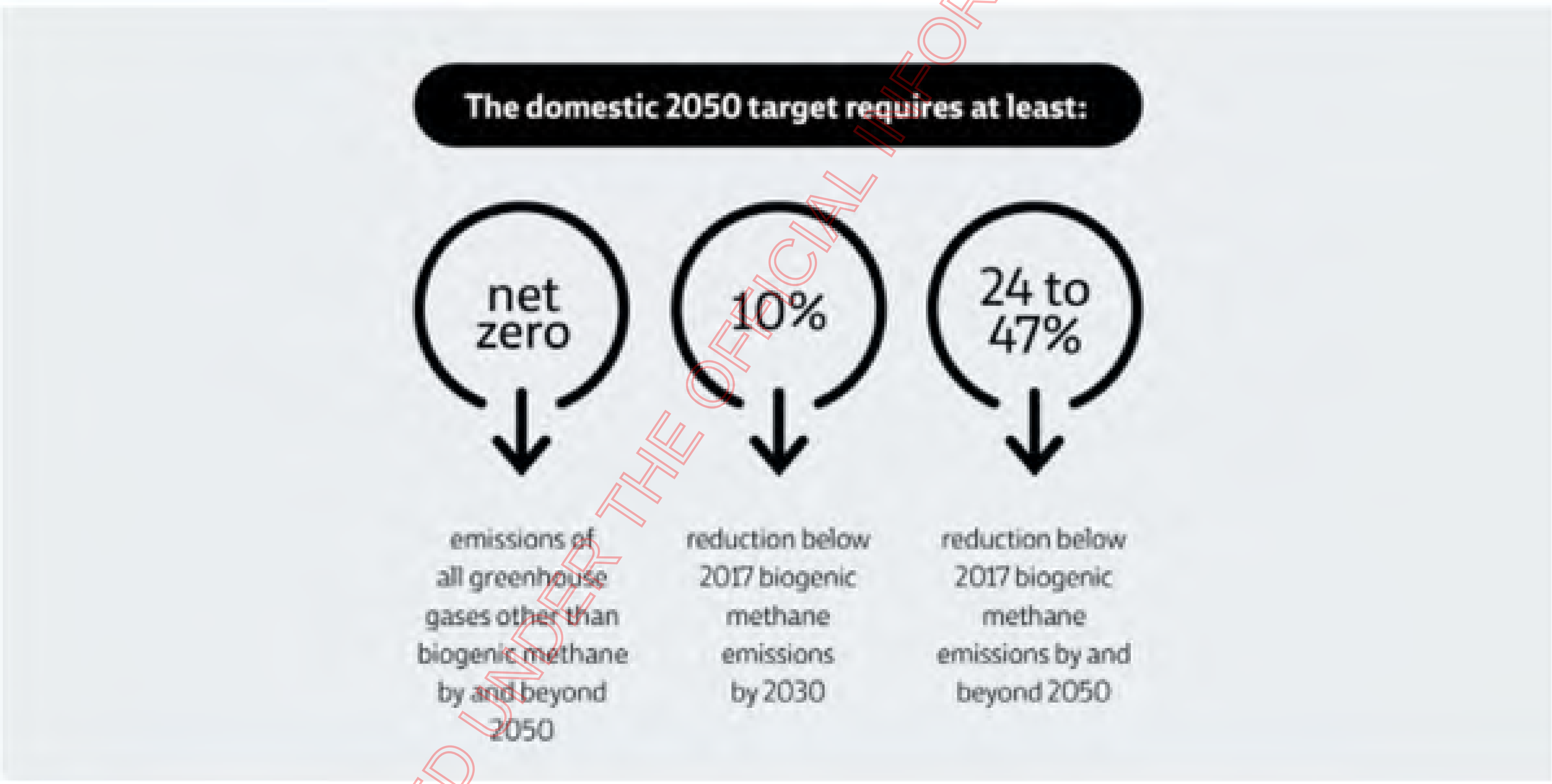
…driven in part by the "three D's":

1. **Decentralisation** – the increase in deployment and use of distributed energy resources (DERs), particularly by consumers, and the resulting shifts towards multi-directional power flows on networks, and increases in the number of consumers actively participating in energy markets
2. **Digitisation** – the use of smart, digital technology to harness, control and automate these DERs in particular, new ways for consumers to engage using technology, and increases in artificial intelligence
3. **Decarbonisation** – the global drive to reduce carbon emissions

…and our advice on responding to these trends is guided by the Energy Trilemma.



Decarbonisation and the Climate Change Response (Zero Carbon) Amendment Act sets important strategic context for the energy sector

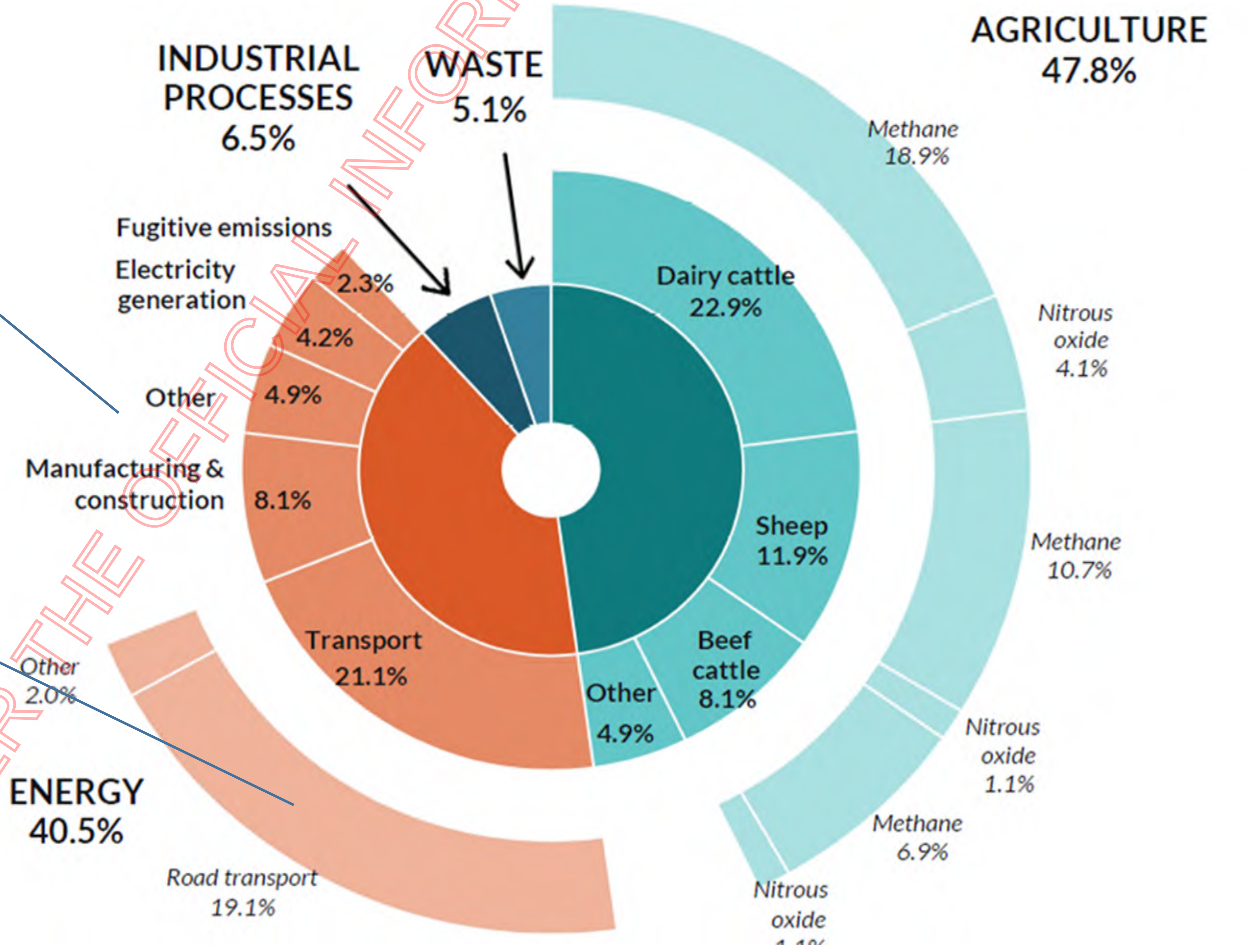


Energy sector emissions make up about 40% of NZ's gross emissions…

About half of NZ's energy emissions are from electricity, industry, residential and commercial

…and the other half are from transport

…but there are strong links between the two.



…and the Climate Change Commission has laid out it’s recommended pathway to Net Zero Emissions.

For **energy and industry,** the key recommendations for energy by the Climate Change Commission are to (in partnership with Iwi/Maori):

(rec 20) Developing an energy strategy to decarbonise the energy system and ensure the electricity sector is ready to meet future needs, including:

- Supporting development and deployment of low-emissions fuel options such as bioenergy and hydrogen
- Enabling fast paced build of new renewable generation and phasing out coal
- Ensuring the electricity system is capable and technology ready

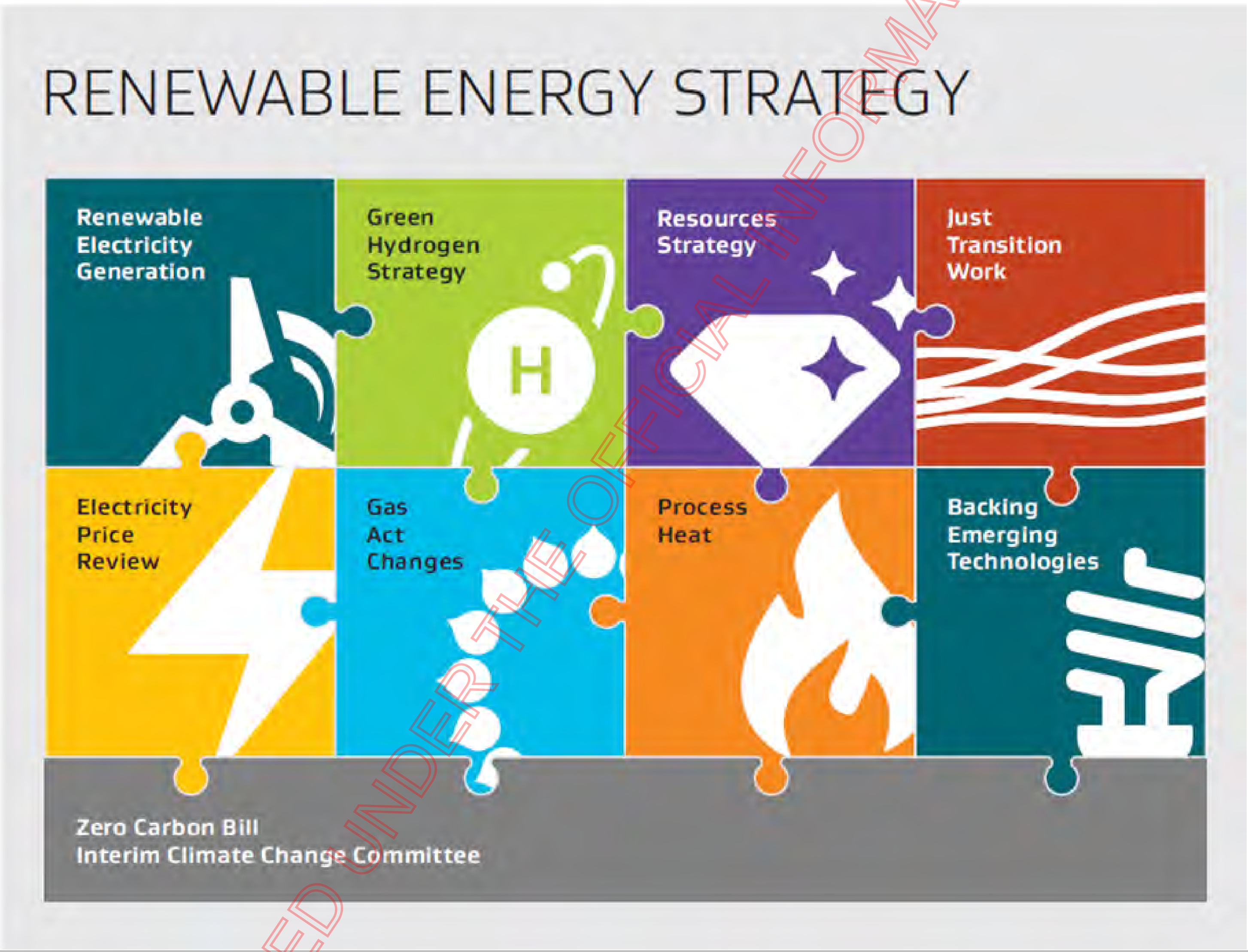
(rec 21) Reduce emissions from industry , including

- Accelerating industry switching to low-emissions fuels for process heat and uptake of energy efficiency measures
- Ensuring no new coal boilers are installed and setting a timetable for the phase out of fossil fuels used in boilers

ERM is developing the Emissions Reduction Plan (ERP) for Energy and Industry…

- By end 2021 the government must set emissions budgets for three periods from 2022 to 2035, following advice from the Climate Change Commission (CCC)
- The government must also set an emissions reduction plan (ERP) setting out policies and strategies to meet the budgets, including in the **transport, building and construction, land use, waste, and energy and industry (E&I)** sectors
- The E&I component of the ERP will set out the policy direction for reducing emissions in E&I, taking into account the CCC's recommendations

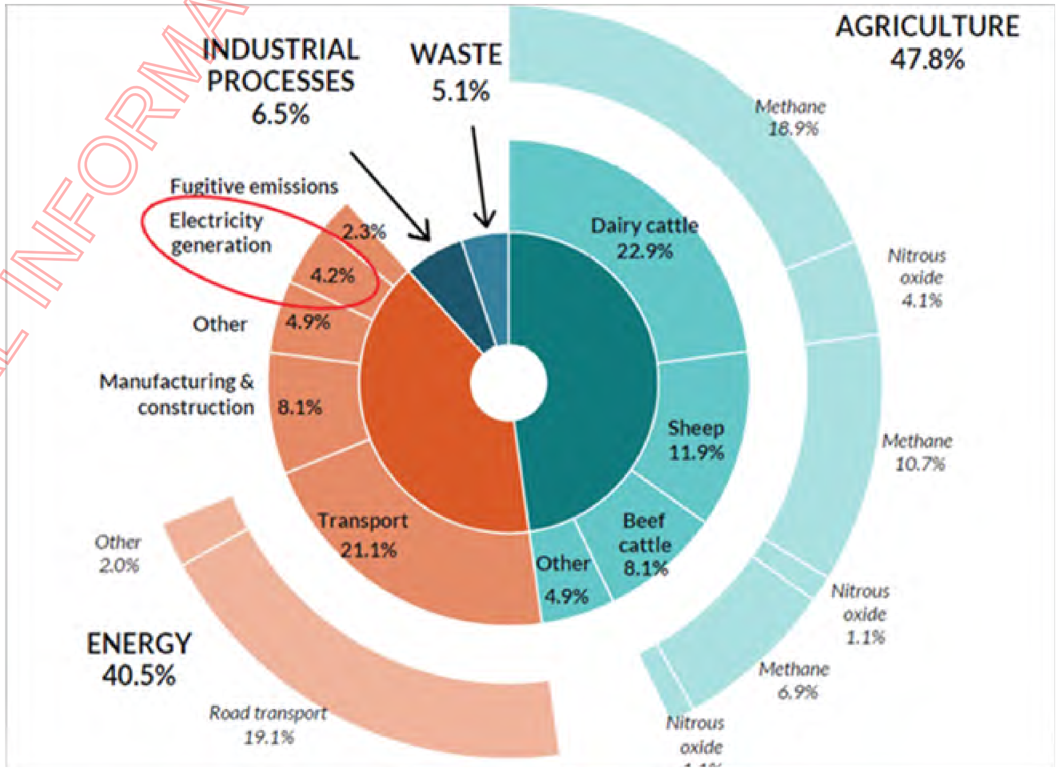
…leveraging the existing energy markets work programme.



We are accelerating renewable electricity…

Addressing barriers and opportunities relating to accelerated investment in renewable electricity:

- The **New Zealand Battery Project** seeks to find a renewable solution to New Zealand's dry year electricity problem (which is currently solved with coal)
- Examining options to implement Government manifesto commitment to ban **new baseload thermal** electricity generation.
- Reviewing **national direction for renewable electricity generation** and transmission under the RMA
- The Māori and Public Housing Renewable Energy Fund aims to improve energy affordability and reliability through the provision of renewable energy solutions, such as small-scale community solar projects on Maori and Public housing.
- Working across government to **address barriers in the electricity transmission and distribution** systems



…And the Government has a target of 100 per cent renewable electricity generation by 2030, with a review at the 2025 emissions budget…

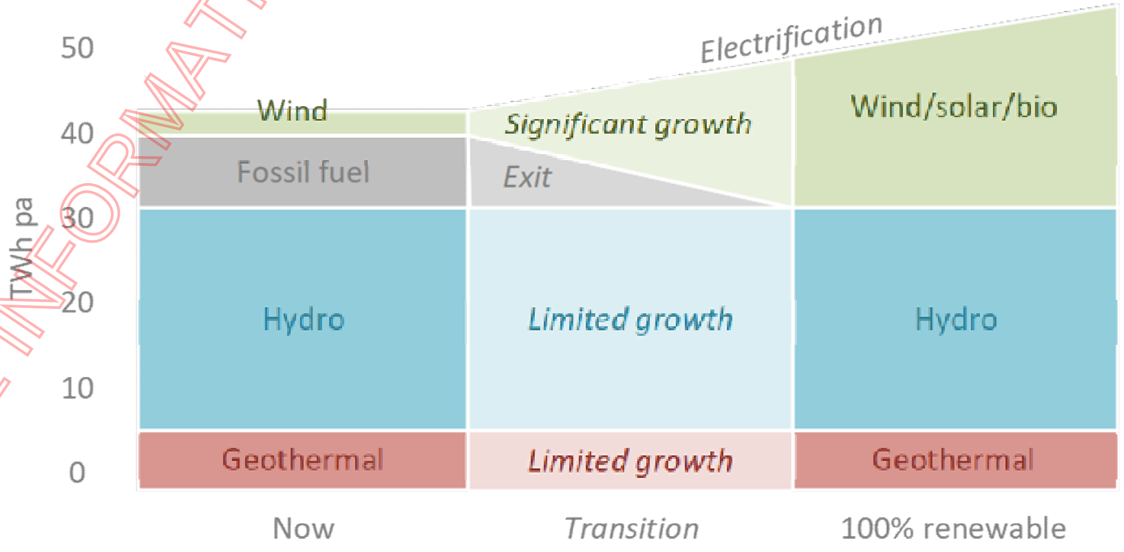
And working out how a transition to 100% renewable electricity could work…

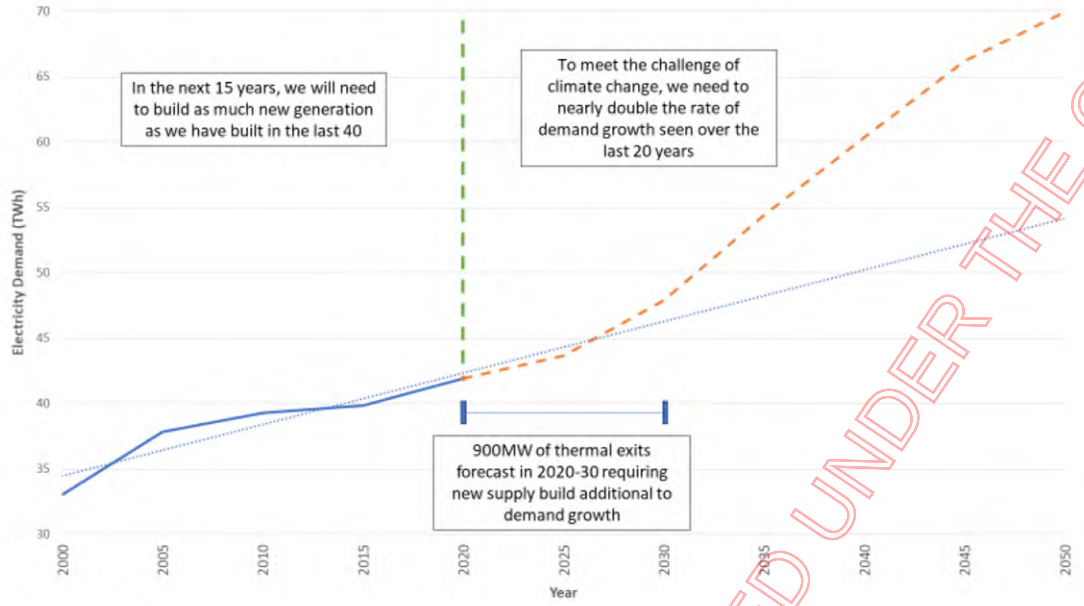
Achieving 100% renewable electricity will require:

- About 900MW existing fossil fuel-based generation retired or repurposed
- significant investment and build of new renewable generation
- enhanced transmission and distribution

While simultaneously:

- Managing security of supply and dry year risk
- Maintaining affordability and prices at levels that encourage fuel switching





- What will drive fossil fuel thermal retirement, and how will this be organised/sequenced?
- What will replace the "services" that thermal generation provides?
    - Daily/weekly balancing intermittency
    - Seasonal energy storage
    - Dry year security
- How to ensure secure, flexible fuels through the transition?
- How to maintain strong incentives to invest in new generation?
- How can the existing electricity market support the objective?

The New Zealand Battery project could address one of the main obstacles to 100% renewable electricity…

Investigating options to resolve New Zealand's 'dry year risk' problem in a highly renewable electricity system, with the aim of identifying the best option, or combination of options, to address this risk and support the move to 100% renewable electricity.

PHASE 1
Feasibility study
→ April/May 2022

A feasibility study identifying the best option or options to address dry year risk

Includes early field work (subject to procurement)

PHASE 2
Detailed business case
→ Late 2023/early 2024*

Further investigations, detailed engineering design and field work, leading to a final investment decision

PHASE 3
Implementation
Early 2024* onwards

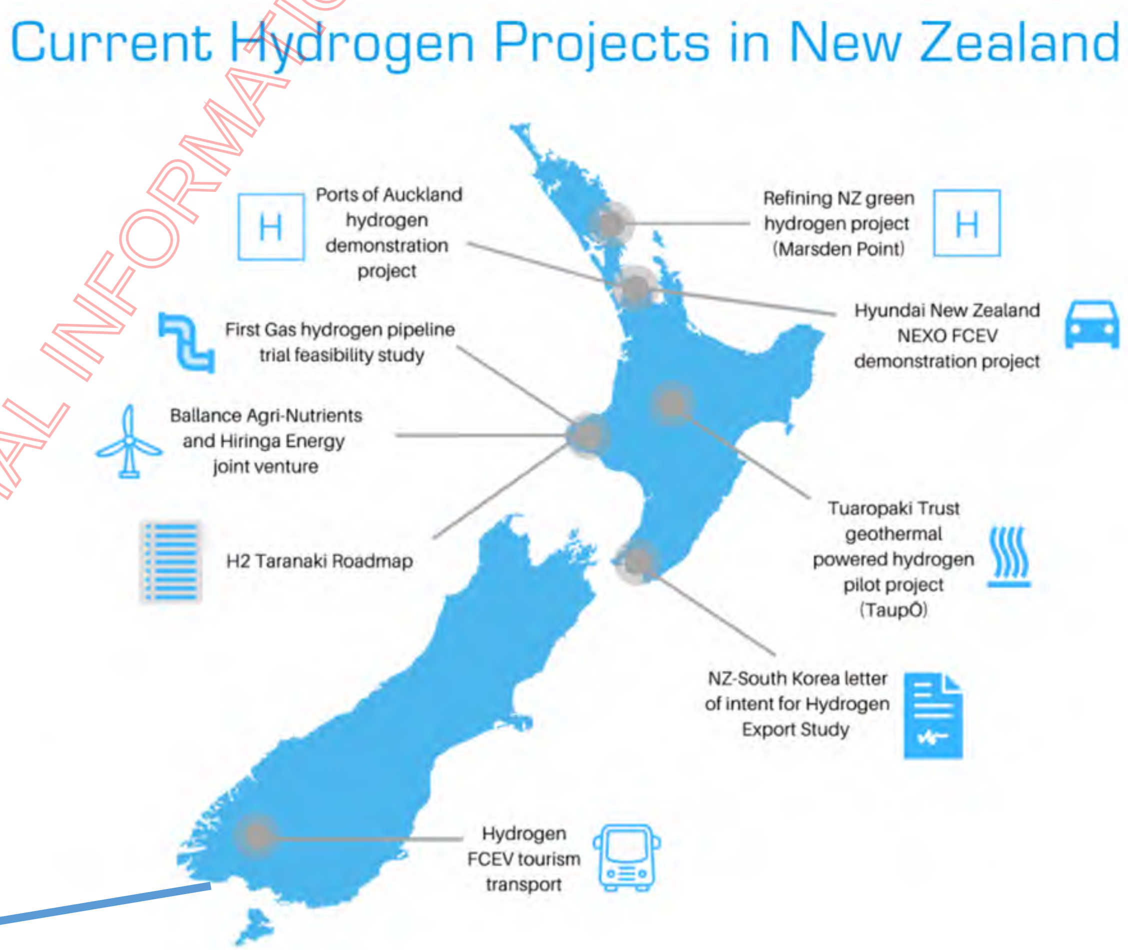
Contracting and construction

**Depending on chosen option or options*

…and Hydrogen could also play a role.

Our work programme focuses on developing the hydrogen market, including hydrogen production, transport, use in New Zealand and potential export. It concentrates on the following key objectives:

1. Removing regulatory and other barriers to hydrogen development and production
2. The first phase of a hydrogen roadmap, and
3. Liaison with local and international business, community and research interests in hydrogen.



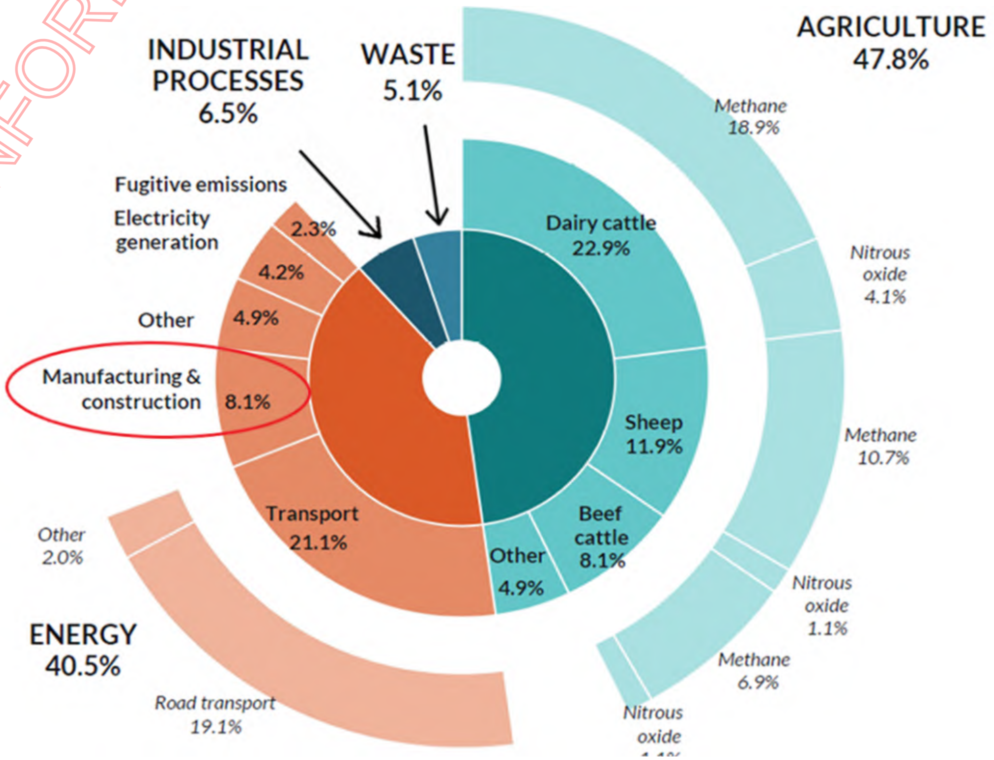
Meridian and Contact are spending up to $2m to investigate the potential of a large scale, renewable hydrogen production facility…

…and are working closely with the NZ Battery project, to understand its potential for large demand response

We are addressing industrial process heat emissions…

Our work in this area includes:

- Implementing **Government manifesto commitments to phase out fossil fuels** in low temperature process heat through national direction for greenhouse gas emissions under the Resource Management Act, to be in place by end 2021 (NB this Act is also under review).
- Investigating an **energy and emissions reporting regime** to help to understand opportunities for decarbonisation of process heat.
- Policy and working with EECA on the **Government Investment in Decarbonising Industry Fund (GIDI)** fund



…and working out how to phase out fossil natural gas from the energy system.

Our work will be informed by several pieces of work we have facilitated across industry and Government:

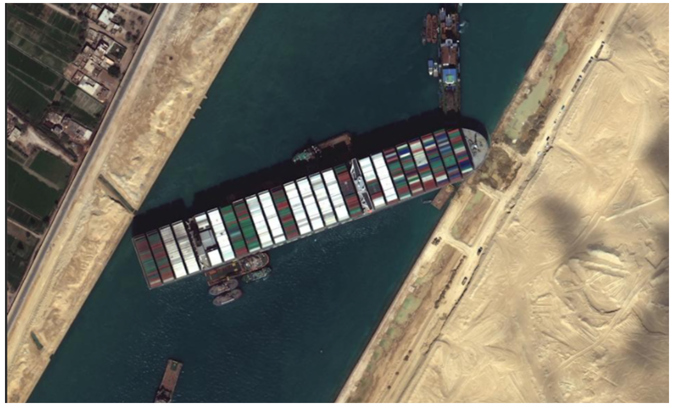
- The Gas Industry Company's gas market settings investigation to determine if current market, regulatory and commercial settings are fit-for-purpose for the transition.
- The industry-led Gas Infrastructure Future Working Group which intends to report to Government on key challenges for mass market consumers and infrastructure.
- Development of a Green Gas certification scheme to enable green gases to be used in the current gas infrastructure.
- Hydrogen feasibility work both across industry and within Government.

We are co-leading policy on a biofuels mandate…

- Public consultation on the biofuels mandate proposal likely this month.
- Between now and early 2022, more work on modelling and detailed policy design (for example, biofuels' sustainability criteria, certification and fuel specification requirements).
- Report back to Cabinet on the final policy design by 30 September.
- Subject to Cabinet approval, Bill introduction to the House in the first half of 2022, and legislation coming into effect from 1 January 2023.

…and reviewing New Zealand's fuel security settings.

- MBIE has a role in ensuring domestic fuel security, and meeting New Zealand's IEA treaty obligation on oil stockholding
- Refining NZ is actively considering the option of converting from a refinery to a fuel terminal import terminal, and is expected to make final decision on its future business model in the third quarter of 2021.
- ERM has commissioned work on the implications of Refining NZ's potential conversion for fuel security, and measures for mitigating fuel security risks
- We expect to update Government on actions in response to the Auckland Fuel Supply Disruption Inquiry and Refining NZ's final decision on its future business model, soon after RNZ's decision
- MBIE is likely to consult on enhanced fuel security options later in 2022.



We continue to implement the recommendations of the Electricity Price Review

- The aim of the recommendations is to ensure a market which is fairer, more consumer focused, more affordable and more prepared for future challenges such as greater renewable generation and new technology
- We have work underway to progress the recommendations including:
  - Taking a Bill through the House to make **changes to the Electricity Industry Act**
  - Setting up a **Consumer Advisory Council, Energy Hardship Expert Panel** and a cross-sector **Energy Hardship Reference Group**
  - **Community-level support services -** Support for Energy Education in Communities (SEEC) Programme, funding community-led pilot projects
  - Enhancing the role of the **Council of Energy Regulators**
  - Reviewing the Electricity Authority's **compliance framework**
  - Work on the phase out **low fixed charge tariff regulations**
  - Cross-agency work to develop an agreed **definition and indicators of energy hardship**.
- MBIE now has a dashboard on the EPR website that outlines progress towards key work streams its leading.
- The Electricity Authority is leading a number of other work streams.

Our priority next steps in energy are clear…

- We have begun thinking on what a **National Energy Strategy** might look like
- Consultation on **Emission Reductions Plans** is likely to begin at the end of August
- The **NZ Battery Project** will provide an interim report-back to Minister of Energy and Resources in the fourth quarter
- We will advise on the **phase out of fossil fuels** from the energy system in December
- We will advise on the issues and options for achieving the **100% renewable electricity** target in the fourth quarter
- We will advise on the outcome of our **fuel security review** with a view to consulting in 2022 on options
- We will continue our work on the performance of the **wholesale electricity market**
- We continue to lead or support work related the **industrial sector,** including the broader outcomes of Refining New Zealand's strategic review (eg Sustainable Aviation Fuels)

Contact us

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NZ Battery Project - Technical Reference Group Meeting Record

Rā:	5 August 2021
Wā:	9:30am - 3:30pm
Wāhi:	KPMG building, Wellington & Teams
TRG members:	Cristiano Marantes, George Hooper, Isla Day, Allan Miller, Amanda Larsson, Mike Howat, Hoani Langsbury, Stephen Batstone, Raymond Gunn
MBIE staff & contractors:	Adrian Macey, Adrian Tweeddale, Andrew Millar, Bridget Moon, Carl Walrond, Conrad Edwards, Jodi Percy, John Hancock, Malcolm Schenkel, Maria Hernandez-Curry, Samuel Treceno, Kimberley Carter
Apologies:	N/A

NZBP queries	Discussion points	Actions
Project news – led by Adrian Tweeddale & Andrew Millar		
NZBP team sought feedback / observations on project progress from last six weeks and plans for next six weeks	• Further economic modelling of different dry year risk management options will be required as well as a clear, aligned set of assumptions so new investigations completed by the team are comparable • Further investigation is required into renewable overbuild and shortlisted non-hydro options • There's a need to have the costs/opportunities and implications to the electricity system's stability included in economic modelling – for example the transmission upgrade required if Lake Onslow were to go ahead • Transmission implications for renewable overbuild are unknown – more investigation is required to understand net benefits	• Assumptions to be shared with TRG • TRG to continue providing feedback on Concept and Sapere reports • Update to be provided on workstream three investigations on bioenergy, hydrogen, large scale planned load reduction at next TRG
Stakeholder update – led by Maria Hernandez-Curry		
NZBP team sought feedback / observations on approach to engagement and stakeholders identified.	• TRG members agreed that it was important to continue high level of engagement with landowners and meet with community around Lake Onslow, hear concerns and help to reduce misconception • There are still some gaps on engagement for the project – for example with the investment community	• Continue developing stakeholder matrix • Investigate engagement with investment community • Lake Onslow stakeholder meetings scheduled for late-Sept
Operational Governance - led by Conrad Edwards		
NZBP team sought feedback / observations on operating models	• Need to ensure the right incentives are present so that the right thing's built at right time for the right cost and risk	• Refine and further develop operating models

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	• Need to further develop discussion on how a battery like Lake Onslow could operate in dry years with the market, including who in the market decides when the battery should store energy or generate it • Analysis will need to consider how the market would change with 100 per cent renewable energy generation, and how future technology in the energy supply chain might interact with a battery • A "green thermal" solution would be easy to integrate with current market arrangements • Effect of aggregation threshold on the market will need to be considered – once solar/wind power combines with battery • There's an option to require that generators purchase insurance cover from a battery, and they can exercise that option at their discretion • Aspects of models considered – note that the competitive slicing (sharing) models could become more sophisticated. Could consider an FTR model – allocated through auction, and owner risk model which would include a generation contract • Another option would be a co-op of generators where they purchase blocks of water to fill the dam, and during dry year could sell back to the market	• Progress the revenue and operator parts of operational governance • Conrad to conduct further discussion with TRG
Other hydro options – led by Malcolm Schenkel		
Project team sought feedback / observations on: • Input parameters for NIWA search including dam height/length, distance to source and fill time • Search approach and any alternatives / refinements • Screening criteria including input parameters and exclusions – infrastructure, length of time to fill	• TRG wanted assurance that DOC views would be included in review of conservation values vs energy storage value • Surprise that very few potential options for pumped hydro other than Lake Onslow were uncovered by NIWA. NIWA findings in line with generator discussions • Agreement that Lake Onslow fits the big, high, fillable, dammable criteria • s 9(2)(f)(iv) [redacted]	• Update on other potential sites to be investigated
Freshwater workstream at Lake Onslow – led by Carl Walrond		
s 9(2)(f)(iv) [redacted]		

s 9(2)(f)(iv) [redacted]		
Driving the energy transition – led by Andy Hume		
Project team sought feedback / observations on how the wider work programme may affect the Battery Project	• Operating model for the NZ Battery makes assumptions on how the market's working at the moment – will need to look at what market could look like in the future • Need to ensure right conditions there for new investment. Participants are claiming that NZB investigations are already impacting incentive to invest • More remote parts of grid will face challenge of getting 100 per cent renewable electricity • Transmission pricing rules create a "First mover disadvantage" - a barrier to electrification and new generation investment • NZ producing hydrogen would be non-competitive with other market sources. Currently high risk, including if production cost isn't reduced • 100 per cent renewable energy sources isn't required for climate neutrality, or to meet NDC/Paris Agreement targets	
The energy transition & NZ Battery Project – led by Bridget Moon		
Project team sought feedback / observations to the arguments presented and what it means for the solution	• Developing an effective solution requires a clear view of the problem that everyone broadly agrees with – this will eventually inform a business case • There's a wide range of elements involved in the dry year problem. This means it's also unlikely that there's a fixed solution – continued reiteration to solution/s will be required • s 9(2)(f)(iv) [redacted] • Problem as set out is one for the government to solve, rather than the market	• NZBP team to keep building and refining arguments • Soon to engage with Treasury to guide initial business case

	• s 9(2)(f)(iv) [redacted] • Discussion on whether finding a solution for the long term creates a new problem for medium term • Also dealing with a technological risk – immature markets and regulatory framework that doesn't allow for them	

Storage Options for the New Zealand Electricity Sector

Operational and Organisational Issues

Prepared for the

Ministry of Business, Innovation and Employment

by

E Grant Read

Final DRAFT

V4.4

14 June, 2022

RELEASED UNDER THE OFFICIAL INFORMATION ACT 1982

EGR Consulting Ltd

Executive Summary

1. This report has been prepared at the request of MBIE, as a contribution towards developing a comprehensive framework for understanding and assessing options for managing a large-scale storage facility, and integrating such a development into the New Zealand electricity market.
2. Much of the material presented here is new, and relates to possible future situations of which we have no direct experience, and have not yet been thoroughly researched. Accordingly, our goal has been merely to identify issues that are likely to need attention, and directions that are likely to be productive. So, all "conclusions" presented here should be regarded as tentative, and subject to further discussion, verification, and revision.
3. We focus mainly on the management and integration of pumped storage hydro because pumped storage hydro developments are being actively investigated, and because they raise more complex management issues than other options of which we are aware.
4. The report does not attempt to cover any issues relating to the organisational form, structure, ownership, or governance, of any of the hypothetical entities discussed in the context of the options explored. Nor is any consideration given to transitional or establishment issues of any kind.
5. The report does outline a wide range of structural options, though, focussing on the decision-making arrangements implicit in each, and on how a storage facility would interact spot/hedging market, and with market participants, the System Operator, and any host system manager.
6. It also provides a preliminary assessment of which of those options seems most promising for further development, while recognising that the preferred option will ultimately depend on the location, scale and nature of any development that might proceed.
7. Chapter 1 merely outlines the context of this report, the history of the theory underlying it, and the structure of the report itself.
8. Chapter 2 summarises the general principles of storage management, as developed in a much more comprehensive report recently released by MDAG, while highlighting aspects of particular relevance to the management of storage facilities, and surveying storage developments that might prove attractive in the projected environment.
9. Chapter 3 applies that theory to the management, analysis and organisation of "stand-alone" storage facilities, including, but not limited to, batteries and pumped storage.
10. Chapter 4 extends that work to provide a more detailed framework for understanding the optimal operation of pumped storage hydro facilities embedded in host system catchments that may have their own storage /generation facilities, the opportunity costing of energy stored in such facilities, and the kind of situation in which conflicts might arise, and coordinate be required. The situation is potentially complex, and highly dependent on the configuration of the host system pumped storage, and the positioning of the pumped storage facility within that system. Broadly, though:

s 9(2)(f)(iv)

- s 9(2)(f)(iv) [redacted]

11. That chapter is complemented by four Appendices containing more detailed discussion of host system conflict and coordination issues.

12. Appendix A discusses examples where coordination of host system interactions might be more, or less, complex and /or critical:

s 9(2)(f)(iv) [redacted]

13. Appendix B discusses the kind of agreement that could be used to resolve conflicts and coordinate operations, where necessary.

14. Appendix C discusses the water and/or energy trading concepts that might be employed in forming such agreements.

15. Appendix D discusses the interpretation of modelling results, and particularly optimised recommendations about buffer storage requirements, in light of the fact that optimisation models normally assume that perfect coordination can and will be achieved.

16. Chapter 5 then moves on to consider the various ways in which a pumped storage facility could be used to provide hedging to market participants, as well as hedge its own energy cost risk:

s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv) [redacted]

17. Chapter 6 then provides the core contribution of this report, which is to outline and assess a fairly wide range of alternative operational and organisational arrangements for a general large-scale pumped storage hydro facility in three broad groups:

s 9(2)(f)(iv) [redacted]

18. Finally, Chapter 7 presents our conclusions. We do not think it appropriate to make a definitive recommendation with respect to the choice between s 9(2)(f)(iv) [redacted] arrangements at this stage, and realise that that decision may depend on wider issues then those considered here, but we have summarised our views on what we believe to be the most promising s 9(2)(f)(iv) [redacted] regimes, at this stage.

s 9(2)(f)(iv) [redacted]

Contents

Storage Options for the New Zealand Electricity Sector

Operational and Organisational Issues

1. Introduction

Context

This paper has been prepared at the request of the New Zealand Ministry of Business, Innovation and Employment (MBIE), with a view to informing discussion relating to the "NZ Battery" project. The motivations of that investigation, and key options being considered, are well known, and do not need rehearsing here. At the same time the Market Development Advisory Group (MDAG), has been conducting a parallel investigation into how the New Zealand electricity market might operate in the emerging environment without any substantial addition to national storage capacity, and has recently released its issues discussion paper.[1]

Although we did not participate in that investigation, we were asked to prepare a paper that has been released along with their report, on the application and implications of storage management theory, and particularly on the opportunity costing water, or other storables, in the context of the kind of market conditions MDAG expect to have developed by 2030, and then by 2050.[2] The discussion in that paper draws, in turn, on an earlier overview of electricity market economics, prepared for a generator's consortium, and released in 2018.[3] In particular, Appendix C of that earlier report outlined the theoretical concepts underlying the discussion in our paper for MDAG, and in the current report.

History

The conclusion of our report to MDAG was that, while the balance of generating capacity in the power system will be changing, the classical theory outlined in earlier papers has not changed. Indeed, much of it is rooted in analyses of the optimal management of electricity systems, going back as far as the work of Massé in the 1940's.[4] All of that earlier work was developed in a public sector context, assuming a framework of centralised national cost-benefit optimisation. However, the central concepts emerging from that work, over many decades, focus on economic interpretation of the "shadow prices",[5] calculated by the optimisation process as its measure of the marginal value of each resource utilised in the optimal solution.[6]

1 *Price discovery under 100% renewable electricity supply: Issues discussion paper*, MDAG report, February 2022, https://www.ea.govt.nz/assets/dms-assets/29/01-100-Renewable-Electricity-Supply-MDAG-Issues-Discussion-Paper-1341719-v2.4.pdf

2 *Opportunity Costing in the NZEM: Implications of Decarbonisation*, EGR Consulting Ltd report to MDAG, January 2022, https://www.ea.govt.nz/assets/dms-assets/29/05-Water-Values-under-100-Renewable-Electricity-Dr-Grant-Read1341584-v2.1.pdf

3 *An Economic Perspective on the New Zealand Electricity Market*, Prepared by EGR Consulting Ltd for a broad generator consortium, and submitted by Meridian in response to MBIE's *Electricity Price Review: First Report*, October 2018 https://www.mbie.govt.nz/dmsdocument/4195-meridian-energy-electricity-price-review-first-report-submission

4 P Massé Les Réserves et la régulation de l'avenir dans la vie économique. Hermann & Cie. Paris, 1946.

5 Also known as "Lagrange multipliers", "dual prices", or "dual variables".

6 Here "resources" include anything for which a "constraint" is defined in the formulation of the optimisation problem, because it is recognised as being potentially in short supply. Those constraints may limit concrete observable "commodities". like "water in the reservoir", but also more abstract concepts like 'the ability to release extra water down the river at an environmentally acceptable rate".

At the time, that economic interpretation was partly a tool allowing “decomposition” of sectoral planning/operating optimisation problems that were too big to be solved by the technology available at the time, and partly a way of developing an intuitively comprehensible theoretical framework for understanding and managing these inherently complex processes. It has long been realised, though, that exactly the same mathematics, and conceptual understanding, would apply in a hypothetical perfectly competitive market context.

The major development of the last 30 years, then, has been to create actual markets based on these concepts, even when perfectly competitive assumptions can not be fully satisfied. Discussion of the strengths and potential weaknesses of that development lie outside our present scope. But the key point is that while allowances must be made for the various ways in which the New Zealand electricity market environment may differ from the perfectly competitive ideal, the same decades old theory still provides an intuitively comprehensible theoretical framework for understanding and managing storages, in the market environment as it is now, and as it will be in future.

Outline

Accordingly, the basic structure of this report is to:

- Outline, in Chapter 2, the basic theory of storage management in a national optimisation or perfectly competitive market environment, while highlighting aspects of particular relevance to the management of pumped storage hydro facilities;
- Address, in Chapter 3, the application of that theory to the management and analysis of “stand-alone” storage options that were not considered closely in our previous paper;
- Focus, in Chapter 4, specifically on the application of that theory to the management and analysis of hypothetical pumped storage hydro facilities embedded in host systems, because it seems to us that the integration of this technology into the market, and into an existing host system could pose unique and complex changes;
- Develop, in Chapter 5, a range of hedging strategies and instruments by which the pumped storage facility could meet the risk management needs of market participants and end-consumers, and of itself;
- Consider, in Chapter 6, a range of organisational options and operational regimes that have been proposed for managing pumped storage hydro, mainly to deal with the problem that s 9(2)(f)(iv) [redacted]; and finally
- Summarise our conclusions, in Chapter 7.

Scope

This report is preliminary, in the sense that it identifies quite a number of potentially important topics and issues that it does not attempt to resolve. It also focusses mainly on pumped storage hydro, because that is an important option that is reasonably well understood, having been long established elsewhere, and which clearly needs to be analysed. We believe the framework provided here can be simplified and/or extended to cover a wide range of other options though.

Much of the material presented here is new, and should be regarded as tentative, and subject to revision. No attempt has yet been made to formulate, solve or analyse formal mathematical optimisation models as a means of validating the various propositions advanced in the text, or to apply them to any specific proposal. While some of the discussion could provide a basis for developing a quantitative analytical framework for pumped storage hydro, or other similar projects, no attempt has been made to develop such a framework or perform such analyses.

The report also makes no attempt to cover any issues relating to the organisational form, structure, ownership, or governance, of any of the hypothetical entities discussed in the context of the options explored. Nor is any consideration given to transitional or establishment issues of any kind, including the development of rules, charters, or statements of corporate intent, even at a high level.

Note on terminology

All references to electricity prices in this report should be interpreted as referring to half-hourly spot prices in a perfectly competitive wholesale market, and/or to the equivalent "shadow prices" that would theoretically emerge from an economic dispatch optimisation, in a centrally planned environment. While we do discuss organisational arrangements designed to limit the exercise of market power by the manager of any new pumped storage hydro development, we do not address the implications of potential discrepancies between real market prices and the market prices that would theoretically emerge from the perfectly competitive market implicitly assumed by most discussions in this report.

Many analysts and industry discussions, including our own, refer to a "Marginal Water Value" or "Marginal Value of Water" (MWV or MVW) as if it was defined directly in $/MWh terms. For a simple hydro system, we might also call this the Marginal Value of Storage (MVS), and our report to MDAG, used that term to refer to the marginal value of water that could be stored in a reservoir, as distinct from the "Marginal Cost of Release" (MCR), which will generally equal MVS, for a simple e hydro system, but could be zero for flows that have to be spilled, even when MVS is strongly positive.

The advantage of defining these concepts in energy terms is that they can then be compared directly with electricity prices. For that reason, we will sometimes refer to the Marginal Cost of Generation (MCG), and Marginal Value of Pumping (MVP) for pumped hydro systems, even though those may not be simply set by a single marginal water/energy value, in that more complex setting. This report will also frequently refer to Marginal Value of Stored Energy (MVSE) in contexts where the term could apply in very similar ways to all storage technologies.

However, parts of this report focus more on understanding operations and valuations in river chains, and particularly in pumped storage hydro schemes. For those purposes, it will be necessary to differentiate between water value concepts more carefully than in our report to MDAG. So, we will use the term Marginal Water Value (MWV) to denote marginal water values defined in $/unit of water volume, that being the most likely marginal value to be reported by a formal mathematical optimisation detailed enough to be concerned with effects like the dependence of pumping/generation efficiency on flow rates, or head.[7] As discussed in Appendix C, though, what is really valued in these contexts is not the water, as such, but the potential energy stored by holding that water at a certain location in a catchment, from whence it will be released to generate while passing through one or more hydro power stations, before eventually reaching sea level.

Finally, in most contexts the relevant driver of managerial behaviour should be an expected value, which we will denote by EMWV/EMVSE, except when discussing values determined in a hypothetical deterministic context, or for a particular simulated scenario.

[7] The most obvious "unit of water volume" here would be a cubic meter, which corresponds to a metric tonne of water. But that would imply prices defined in $/Kilojoule, whereas the electricity sector generally prefers to define energy in kWh, or MWh. Because there are 3600 seconds in an hour, 1 kWh equals 3,600 Kilojoules, and 1 MWh equals 3,600,000 Kilojoules So that conversion factor would need to be applied, if we wanted* to compare MWV directly with electricity prices quoted in $/MWh. Or, reversing that conversion, the "water volume unit" that, when raised by 1m, would store 1 MWh of potential energy, is actually 360,000 cubic meters, with the gravitational constant g approximated to 10. But, except in Appendix A, we will generally just refer to a "unit of water volume", or "water unit", because the precise units do not really matter for the purposes of the conceptual discussions in this report.

2. Managing Storage in the Future Electricity Sector

2.1. Introduction

The MDAG report explores and simulates what might be described as a "business as usual" scenario for electricity market operation, under which:

- All conventional fossil-fuelled thermal generation would be retired;[8]
- That capacity would be replaced by a mix of new geothermal, solar and wind plant, with substantial further capacity development to cover substantial load growth, as electricity takes over from fossil fuels, across the economy; and
- That geothermal/solar/ wind capacity might be supplemented by some "green peaking thermal" capacity, perhaps fuelled by biodiesel or hydrogen; but
- Importantly, no new hydro capacity, including no pumped storage hydro, would be added; and
- The market would continue to operate as it does at present.

MDAG concluded that, while this rapid re-orientation would obviously imply major challenges for the sector, those challenges could be met by:

- Significant development of various forms of "Demand Side Management" (DSM); and
- Significant investment in battery capacity.

Still, hydro storages, and river chains, might need to operate quite differently than they have in the past, and it would be highly desirable to augment their capacity by expanding less conventional "storage" options, such as large-scale pumped storage hydro, or demand side flexibility, to assist with limiting:

- Cyclic day-night price differentials;
- Cyclic summer-winter price differentials; and
- Random price volatility, over time frames ranging from hours, to days, weeks, and years.

Our report to MDAG complemented that study, by explaining the theory of how any of these storage options should be operated, and valued, first from the perspective of national cost-benefit optimisation, which we believe to be theoretically equivalent to a perfectly competitive market, and then in a more realistic market environment. That report focussed mainly on management of conventional hydro storage, though, and only briefly touched on the optimal operation and valuation of less conventional storage options, such as demand side inventories, batteries, or pumped storage hydro.

Thus, the intent of this current report is to flesh out that discussion, particularly with respect to pumped storage hydro, with a view to developing an understanding of, and possible management regimes for the kind of large-scale developments currently being considered by MBIE. Before doing so, though, we should outline the general theory, and highlight some aspects of particular relevance to the management of less conventional large-scale storage options, including demand side flexibility and pumped storage hydro.

[8] References to "thermal", in this report should be taken as referring g to "fossil-fuelled" thermal, unless explicitly stated otherwise.

2.2. Basic concepts

Chapter 2 of our report to MDAG discusses the basic theory of storage management, as it would apply to a single stand-alone stockpile of any kind, and as it has traditionally been applied to long term reservoir management in the New Zealand electricity sector.

The core concept is that storage capacity provides a physical means of "arbitraging" across time. That is, it allows units of the stored commodity to be carried forward from periods when they have a low marginal value, because they are in relatively good supply, to periods when they have a higher marginal value, because they are in relatively poor supply. In the New Zealand electricity sector, this has traditionally meant carrying water forward from summer to winter, and from night to day.

In that context, managers are constantly deciding how much water to release now, and how much to save for future use. For that purpose, it is useful to define the Marginal Value of Stored Energy, MVSE, as the "opportunity cost" of not having a unit of "potential energy" (in the form of water stored at height), available to use at some future date as a result of releasing it now.[9] We can think of the arbitrage process as proceeding by working through the units of water currently available, and identifying the best remaining opportunity to utilise each successive unit of water stored:

- At first, units would be assigned to the future periods in which the supply/demand balance was most critical, as determined by their having the highest prices, in either a national cost-benefit optimisation or perfectly competitive market context.
- But, as more and more water is put aside for release to support generation in those periods, the prices in those periods will gradually drop, and/or generation from our reservoir will reach its upper limit.
- Either way, later increments of stored water will be progressively assigned to other periods, in which they have progressively lower marginal values.
- Eventually, we will run out of water or, more likely, reach a point at which the next unit of water we could store would actually have no higher value than the last unit of water released to support current generation.

The "incremental arbitrage" process described here is just a way of illustrating the principles involved. Real optimisation models actually employ more direct methods to determine the "marginal value" of storing water for the future, and can equate it exactly to the marginal value of releasing water.[10] The key point is, though, that any optimisation algorithm will stop when it reaches the point at which it has identified the "marginal economic opportunity" for utilisation of stored water. And the MVSE is then set by the "opportunity cost" of not taking that opportunity.

Note that, even if there were no limits on storage capacity, and the future were completely known, the arbitrage process will not completely eliminate electricity price differences between periods, because:

- prices can not be lowered any further in periods with a relative excess of demand, once the upper limit on generation capacity is reached; and
- prices can not be raised any further in periods with a relative excess of supply, once the lower limit on generation capacity (possibly zero) is reached.

Also note that the biggest challenge in all this is that the future is not known, so there are many scenarios to consider, each with its own "marginal economic opportunity" and opportunity cost, MVSE. It can be shown, though, that ignoring the possibility of risk aversion, the optimal marginal water value, on which decisions should be based, is EMVSE: That is, the expected value of all those MVSE values.

Starting from Chapter 2 of our report to MDAG, we emphasise that much of what is commonly described as electricity price "volatility" is really predictable "cyclic variation". So, before tackling the mathematical and conceptual challenges of stochastic optimisation, it is helpful to first examine reservoir management from a "deterministic" perspective, focussed on maximising the value of reservoir storage

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9 See *Note on Terminology*, in Chapter 1.

10 This assumes that the volume of water stored/released are continuous variables, with differentiable cost/benefit functions.

capacity to transfer water from low valued summer periods to high valued winter periods, and from low valued night-time periods to high-valued daytime periods.

"Deterministic cycling" in a single hydro reservoir[11]

Looking at reservoir management from a deterministic perspective, we argue that the common assertion that the marginal value of water must be zero when the reservoir is full, does not hold, if the reason the reservoir is full is because the manager (with perfect foresight) has decided it should be full so as to carry as much water as possible forward from a low value period to a higher valued one. In fact, in that idealised world:

- Stock levels should be expected to regularly cycle up, during periods of relative over-supply, and down during periods of relative under-supply, with the key cycles being daily, for small hydro reservoirs, and annual for large ones.[12]
- Since reservoir capacity is costly, we do not expect reservoirs to be built so large as to be able to fully arbitrage away all marginal value differences, in either daily or annual cycles.
- Thus, under deterministic assumptions, optimal reservoir management must involve holding the reservoir approximately full (apart from minor daily cycling) for some time at the end of each filling cycle, and approximately empty (apart from minor daily cycling) for some time, at the end of each emptying cycle.
- For an annual reservoir, we should expect to see this pattern when a deterministic analysis is performed on the assumption of expected inflows, and probably for most individual hydrological years, with the length of time optimally spent in the full and empty states depending on how different the supply/demand balance is in summer vs winter, in each scenario.
- From this perspective the marginal value of water/energy in storage (both MWV and MVSE) would be constant, at a lower level during the summer/night period, then rise over the period when the storage is full to a higher level, which is then maintained over the day/winter period, before falling again over the empty period.
- While at their storage bounds, reservoirs would effectively be operating in run-of-river mode, albeit with some daily cycling, but non-supply and spill are both very unlikely, with perfect foresight.
- And the day/night situation will be similar for most small reservoirs, on most days, although some mid-sized storages may not need to reach their storage limits on some days.

Managing stochasticity in a single hydro reservoir [13]

That perspective is clearly unrealistic, on its own, because there are many sources of true volatility in the sector, making a stochastic perspective important, too. From a "purely stochastic" perspective (i.e., assuming that flows and market requirements are purely random, with no predictable average patterns), the main function of any storage facility is to buffer the effects of random fluctuations in the supply/demand balance. From that stochastic perspective:

- Since reservoir capacity is costly, we do not expect reservoirs to be built so large as to be able to fully absorb all such fluctuations, so stock levels should be expected to reach both full and empty bounds. s 9(2)(f)(iv) [redacted]
- Storage deviations should be managed to revert, when possible, to levels far enough below the upper limit s 9(2)(f)(iv) [redacted], far enough above the lower limit to allow non-supply to be avoided when flows randomly drop off.
- The Marginal Cost of Release (MCR) will obviously be zero, when spill becomes inevitable, and that may happen even before the reservoir is full.

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[11] The summary here is taken from the Executive Summary from our report to MDAG, with only minor changes.
[12] We will acknowledge, but largely ignore, weekly cycles, because they do not add much insight.
[13] The summary here is taken from the Executive Summary from our report to MDAG, with only minor changes.

- s 9(2)(f)(iv) [redacted]
- For a small daily reservoir, though, "shortage" may just mean inability to take full advantage of a (probably moderate) unexpected intra-day price spike. So, it may well be optimal to use the water when prices are known to provide a reasonably valuable use for the water, rather than holding water back in case a higher spike occurs, but eventually only finding fewer valuable uses.

Synthesis[14]

Our report to MDAG discusses how the interplay between the deterministic and stochastic perspectives can imply a wide variety of outcomes, depending on the balance between energy capture, storage capacity, and utilisable release capacity, in different hydro systems. Thus, a wide variety of marginal water values should be expected, from different reservoirs, at the same time, and from the same reservoir at different times. In general, though, the Expected Marginal Value of Stored Energy (EMVSE) can be estimated by simulating realistic management (i.e., without perfect foresight) of a large number of hydrology sequences, and determining the (conditional) MVSE for each one, from some future "marginal economic opportunity" in that sequence.[15]

The marginal opportunities available vary greatly, depending on the reservoir, storage level, time of year or day, and scenario, but:

- There is no marginal economic opportunity available to release more water from a reservoir in periods when that reservoir should optimally be releasing at its maximum utilisable release rate, no matter how high the price may become. And there is no marginal economic opportunity available to release less in periods when that reservoir should optimally be releasing at minimum, no matter how low the price may become.[16] So, increased price volatility, implying prices further above/below the price levels at which maximum/minimum release becomes desirable in those periods, will have no impact at all on the marginal water value of that particular reservoir.
- There is no marginal economic opportunity available to store more water for release in periods beyond the next time when a reservoir is expected to be full in a particular scenario. And there is no economic opportunity available to store less water for release in periods beyond the next time when a reservoir is expected to be empty in a particular scenario, either.[17] So, we should expect to see significant cyclic variation in MVSE across seasons (for larger reservoirs), and across the day (for smaller storages).

As a result, water that can actually be held in storage might be given a high opportunity cost value (MVSE) if it seems at all likely to be required to avoid non-supply at some later date, even when excess (unstorable) water is being spilled from the same reservoir, at an implied MCR of zero.

Importantly, the need to hold storage levels away from bounds to deal with volatility reduces the effective capacity available to arbitrage between low and high valued periods. So, it actually increases the expected cyclic variation between day and night-time prices, and between summer and winter prices, thus increasing the importance of the fundamental insight derived from the deterministic analysis: Namely that the underlying MVSE must be rising while reservoirs are relatively full around autumn, and falling while reservoirs are relatively empty around spring.

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[14] The summary here is taken from the executive summary from our report to MDAG, with only minor changes.

[15] This kind of "simulation" may not be explicit, but it is implicit, in some form, in all stochastic reservoir management optimisation packages.

[16] This discussion, like that in our report to MDAG, accounts for upper/lower flow limits, but ignores the possibility that limits may be imposed on the rate of flow change. If such limits are binding, they will act like upper bounds on flows in some periods, and lower bounds on flows in other periods.

[17] This discussion, like that in our report to MDAG, accounts for upper/lower storage limits, but ignores the possibility that limits may be imposed on the rate of storage volume change. If such limits are binding, they will act like upper bounds on storage volume in some periods, and lower bounds on storage volume in other periods.

Discounting, wastage, and head effects

Finally, we should mention three effects that were not discussed in our report to MDAG, but may have an impact on optimal operation of large-scale storage developments, including pumped storage hydro.

- First, stockpiled water, or energy of any kind, is implicitly subject to an "interest charge", just like any other commodity. That may seem strange, in cases were nothing was paid to fill the stockpile, but the arbitrage process described above always involves comparing the value of an opportunity to generate now, with the value of an opportunity to generate in some future period. So, a discount rate should really be applied, just as for any other such comparison.[18] As a result, marginal water values should not actually be constant, as in the simplified discussion above, but rising at the discount rate, over free trajectory arcs.

  s 9(2)(f)(iv) [redacted]

- Second, stockpiled water, or energy, is subject to wastage, just like any other commodity. The mathematical form of that wastage will differ between technologies. Batteries will slowly lose their charge, and water will slowly seep away and/or evaporate.[20] These effects are not generally significant in a daily cycling situation, and they have often been ignored as insignificant in longer term New Zealand reservoirs, too.[21] But it should be recognised that this form of "loss" has quite a different impact from the "round-trip loss factor ratios" discussed later. [22]

  - s 9(2)(f)(iv) [redacted]

- Third, though, stockpiled water has one particular property not shared with other commodities, including "energy", namely the "head effect". The potential energy stored in water in a hydro reservoir is roughly proportional to its "head", that is the elevation of its surface above the point at which it will be discharged from any associated generation facility. So, the more we fill the lake

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[18] Mathematically, the issue is what difference adding a unit now will make to all the simulated trajectories from which EMVSE will be calculated. In some cases, the 'extra unit' may be held for a long time, and in others released fairly soon, thus letting the trajectory revert to the level it would have followed if there had been no extra unit.

When discounted back to the present, that marginal opportunity will set the current MVSE for that trajectory, and the average of all those MVSE values will form EMVSE. So, the higher the discount rate, and the further away the marginal release opportunities, the lower EMVS will be, and the less willing a rational manager will be to hold more energy in storage.

[19] The extra unit will definitely have to be shed before the next time the storage trajectory reaches the full level, or otherwise it will be spilled at that time. And the extra unit will probably be used before the next time the storage trajectory reaches the empty level. Or, otherwise, it may be used to avert shortage at that time.

[20] For hydro, wastage includes leakage, and some reservoirs become particularly leaky when certain geological levels are reached. In the limit, leakage may be great enough to match natural inflows, making it impossible to build storage up above that level.

But evaporation is an issue, too. Although less severe in New Zealand than in warmer climates, it is not zero. The form of the effect depends on the shape of the reservoir bed. If the sides of the reservoir were vertical, then adding more water will not actually change the surface area, or the evaporation rates, so the incremental wastage due to adding one unit will actually be zero. Generally, the reservoir surface area will increase as incremental water is added, though, so there is some effect. But the rate of change, and hence the EMVSE impact, will vary non-linearly, depending on the surface area of the reservoir at each contour level.

[21] With the notable exception of leakage at Waikaremoana.

[22] This is just a particular application of "Hotelling's Rule", a long established result in the economic literature. See: H. Hotelling: The Economics of Exhaustible Resources", *Journal of* Political Econo*my*, Vol 39, Issue 2, p. 137–175, 1931.

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the higher that surface level will be, and the more will be generated when each water unit is released. And that means that each unit of water stored in a reservoir contributes to increasing the productivity of other units being released, for as long as that unit is stored.[23]

- s 9(2)(f)(iv) [redacted]

2.3. Traditional non-hydro storages

Thermal fuel stockpiles/trading

Sections 2.2.4 and 2.3.1 of our report to MDAG discuss the situation of thermal generators in New Zealand, and how "storage" in the thermal system has traditionally related to hydro storage. Since thermal generation is being phased out, there is no need to go into detail. But it is important to understand, in broad terms, how that sector has traditionally contributed to supplementing hydro storage, over various timeframes, and what capabilities might therefore need to be replaced.

In the case of gas, for example, there has always been long-term storage in gas fields which could be drawn down to a greater extent in dry years, to provide inter-annual storage not available in the New Zealand hydro system. And there has always been some very short-term storage in the form of overnight "line-pack" that could be drawn upon to allow extra gas-fired generation for a limited period, each day. Contractual arrangements may have complicated and obscured those realities, but the same opportunity costing logic applies to each of those limited storage resources, as to the hydro reservoir discussed above.

The coal supply system had its own explicit stockpiles, historically including pre-stripped open-cast coal seams, to which the same opportunity costing logic applied, but it also had the ability to replenish those stocks, via a supply chain that implied quite strict limitations on inter-temporal variability, each of which implied similar, but slightly different opportunity costing issues.

But the key point is that the "storage" capacity accessible through the thermal sector always went well beyond the obvious stockpiles being held, in three respects:

- First, it has also been possible, at least in principle, to purchase fuel that would have otherwise been used by other parties in the New Zealand economy. This may not seem like it is drawing on "storage", but in fact it often is. If those other parties are producing less of some product, it will sometimes be the case that consumption of that product actually falls, in the sense that end-users consume less at that time, and never make up the difference.[24] More often, though, the producer may draw down stockpiles of the product to meet customer demand, effectively forcing their customers to draw down their own stockpiles of that product, or of some end-product they would otherwise have produced from it. Or, it may be that end-consumes are not actually reducing ultimate consumption of whatever end-products are involved, but merely deferring it, which can be seen as a form of "storage" in itself.

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[23] This effect applies irrespective of whether the water is drawn off the surface level, and thus "falls further" when released, or from a lower level where the energy is stored in the form of pressure from the weight of water above. The form of the effect depends on the shape of the reservoir bed, though. If the sides of the reservoir were vertical, then adding more water will raise head relatively quickly. Generally, though, the reservoir surface area will increase as incremental water is added, making it harder and harder to raise the surface level as the reservoir fills.

[24] This is more likely with services, like heating, than it is with commodities.

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- Second, many New Zealand fuel users are directly involved in international networks trading the products they produce. So, when they reduce production of some product, New Zealand is either exporting less, or importing more, of that product, and the slack is taken up within that international trading network. Unless worldwide consumption actually falls, the New Zealand electricity sector is ultimately drawing on “storage” somewhere in that international trading system to deal with fluctuations in its supply/demand balance
- Third, and more obviously, fuels like oil and coal are themselves internationally tradeable.[25] Thus an oil-fired generator in New Zealand does not actually need to hold a large stockpile locally, provided it can buy more from the international oil trading network, at short notice. When it does so, oil production must eventually increase somewhere, thus ultimately drawing down the planet’s underground oil stockpile, but there is also a long chain of intervening oil storages, at ports and refineries, and in transit, that will be drawn down in the meantime.

Thus, it should be recognised that when we talk about “storage” in the thermal fuel supply sector, we are not just talking about the stocks held at New Zealand power stations, but storage in the whole vast trading network supplying and consuming those fuels, outside the New Zealand electricity sector. In principle, the same opportunity costing principles apply to all those storages as to the New Zealand hydro storages, but the application of those principles is mostly invisible to the New Zealand electricity sector, which must just accept whatever price deals can be negotiated with the fuel suppliers. And, whether the storage implications are visible or not, the end effect is that “tradability” of fuels has effectively been a substitute for fuel “storage”, so far as the New Zealand electricity sector is concerned.

Demand side stockpiles/trading

While the above discussion of thermal fuel stockpiles and trading arrangements may seem increasingly irrelevant, it is important to understand that, when Section 2.3.1 of our report to MDAG talks about an increasing role for DSM, it is talking about utilising very much the same set of mechanisms, except on the demand side of the electricity sector, rather than the supply side. There, we discuss the distinctions between demand reduction; and demand deferral, and between implicit elastic demand responses to market prices, and explicitly contracted demand responses.

Overall, we conclude that there could be significant potential for demand-side response to enhance effective system storage capacity, and/or replace thermal flexibility, but also much development still to be done in that area. Options would include the aggregation of a great many small-scale (e.g., household) responses. But they could also involve a few large-scale responses, such as establishing a large-scale electrolysis plant to produce green hydrogen that could be traded internationally (e.g., as ammonia). Then, production could be reduced, with exports being reduced or imports increased, in "dry years", or perhaps when hydro storage falls to a certain guideline level, or projected electricity market prices rise high enough to make New Zealand electricity sales more profitable than supply to the electrolysis plant, over some planning horizon.[26]

Even the "reduction" options are implicitly utilising the storability and tradability of goods, feedstocks etc outside of the New Zealand electricity sector, to substitute for the storability and tradability traditionally called upon within the electricity sector, or in associated fuel sectors. In both cases, the net effect is to draw on the inherent diversity and flexibility of the international production/storage/trading system, which is vastly greater than that of the local electricity sector.

Although this report does not do so, s 9(2)(f)(iv) [redacted]

[25] In principle, gas is tradeable too, but large-scale LNG trading infrastructure was never developed in New Zealand.
[26] Shorter term flexibility could also be feasible, and highly valuable, but the details are yet to be investigated.

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s 9(2)(f)(iv) [redacted]

2.4. Multiple independent storages

Section 3.2.1 of our report to MDAG discusses the extension of the above theory to cover management of multiple storages that are "independent", in the sense that they are not hydraulically connected within the same river catchment. Irrespective of whether those storages are hydro reservoirs, or something else, and no matter who manages them:

- The EMVSE in each of them must now depend on the whole vector of storage levels across all of them.
- Thus, in principle, there are now ***n*** EMVSE surfaces, each with ***n*** dimensions, for a system with ***n*** independent storages.
- But optimal arbitrage, either via centralised optimisation or perfectly competitive market interaction, will act to equate EMVSE values, as closely as it can within the limits implied by minimum/maximum limits on utilisable release from each storage, and the limits and losses imposed by the transmission system.

Fortunately, this last bullet implies that participants need not really concern themselves about the precise level of every storage in the system, but can make reasonable decisions based on considering the storage levels in a few key (aggregate) storages. It also means that any mis-alignment in EMVSE or storage levels, whether due to managerial misjudgements, or unexpected events, will be self-correcting over time.

This kind of equilibration between EMVSE levels in storages linked by a "lossy" transmission system provides an important analogy to the kind of equilibration we should expect to see, and plan to ensure, between the upper and lower storages in a pumped storage hydro facility, linked together by a "lossy" hydraulic system.

2.5. Linked storages

Section 3.3 of our report to MDAG discusses some issues of critical importance to understanding the economics of pumped storage hydro operations. Once two or more hydro stations are linked together into some kind of river chain, their EMVSE and optimal generation patterns are no longer independent.[27] Under moderate conditions, when no release/flow/generation/storage limits constrain operations, EMVSE levels might be quite closely aligned down the chain, but of course the potential energy stored in the water is being released as it passes down the chain. So, it becomes important to distinguish between EMVSE, defined in \$/MWh terms, and the "Expected Marginal Water Value" (EMWV), in \$/ unit of water volume:

- If a unit of water in an upstream storage can be released to instantly arrive in the next downstream storage, then its EMWV must be at least as high as a unit of water in that downstream storage, at that moment, even if that release is a spill that generates nothing; and

[27] Many models and discussions treat this short run river management problem as largely deterministic, but uncertainty is still a significant issue, so we will refer to EMWV/EMVSE, rather than MWV/MVSE.

- The optimal release/generation pattern for the intervening power station will be driven by the difference between the EMWV in the upstream storage, and the EMWV in the downstream storage.[28]

As discussed in that section, the picture can be significantly complicated by issues like flow limits, and delays, either of which can make it impossible to instantly transfer a marginal unit of water from an upstream to a downstream reservoir, thus making it possible for water that is already downstream to actually be more valuable than water still trapped upstream, at particular times. Luckily the interaction between the upper and lower reservoir in a pumped storage facility is typically more direct, but flow limits still apply, and the interactions between the pumped storage facility and the host system within which it is embedded must account for all the flow/storage limits and delay times applying to that system. The most fundamental difference, though, is that the "upper" reservoir is not actually "upstream" from the "lower" reservoir, or vice versa, in a system where water can circulate.

2.6. Sectoral overview

Although they were prepared independently, the general picture emerging from our conceptual report to MDAG aligns strongly with MDAG's own quantitative modelling work. Clearly:

- Managing "cyclic variation" in the supply/demand balance, over days, weeks, and seasons, has always been, and will always be, a critical issue in the New Zealand power system; and
- So has managing random fluctuations (mainly) caused by the impact of weather on demand and on the availability of energy on the supply side.[29]

Historically, three main types of "storage" have worked together in a loosely coordinated way, to manage both cyclic variability and random volatility:

- Conventional hydro system storage, as discussed above;
- Demand-side storage, such as the storage of energy in domestic hot water cylinders; and
- Thermal fuel storage, both explicit and implicit in the international trading system.

The emerging challenge is that:

s 9(2)(f)(iv)

[redacted]

MDAG argues that batteries will become an increasingly economic option for managing the day/night cycle, and intra-day volatility, but they will not be able to deal with longer term supply/demand balance issues, in the foreseeable future. So, the implications are that:

s 9(2)(f)(iv)

[redacted]

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28 The pattern of MVSE values down the chain is trickier. If some station is so overloaded that incremental water must be spilled past it, the EMWV in its storage will equal than in the storage below, and those values will be monotonically non-increasing down the chain. But spilling the water reduces its potential energy without decreasing its value, so its EMVSE actually rises.

29 Traditionally this has just been the availability water to "fuel" hydro that generation, but increasingly also wind, and now solar.

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

So, while MDAG did not study large-scale storage options, it did highlight their potential value, in four particular roles:

- Replacing the "storage" traditionally available from the domestic/international thermal fuel production/trading system, in dealing with wet/dry year fluctuations over multi-year timeframes, which has always been a problem in the New Zealand power system and will remain so, for as long as the sector relies heavily on conventional hydro;
- Assisting conventional long-term (traditionally annual) hydro storages in dealing with the inter-seasonal supply/demand balance cycle, which is projected to imply a much stronger annual price cycle than in the past;
- Assisting batteries and conventional short-term hydro storages in dealing with intra-day supply/demand balance cycles and increased short-term volatility due to reliance on weather dependent renewables; and
- Assisting conventional mid/long-term hydro storage in dealing with extended dunkelflaute situations.

While MDAG concluded that the market could continue to produce acceptable, albeit more volatile, outcomes without significant storage augmentation, it clearly also recognised the potential contribution from two main longer-term "storage" options:

- Large-scale pumped storage hydro, or some similar technology that would allow energy to be stored within the electricity sector and/or "fuel supply" infrastructure, for eventual conversion into electricity, when required; or
- Large-scale demand side flexibility, e.g. from an export-oriented hydrogen plant, able to dial down its electricity consumption when the supply/demand balance becomes critical, in which case the "storage" being utilised is the ability of the international trading/storage system for the export commodity to take up the slack.

Accordingly, the current report is intended to complement our report to MDAG, by focussing on developing a conceptual framework for the analysis, operation, and organisation of such options, in a realistic New Zealand market context.

2.7. Non-traditional storage options

2.7.1. Introduction

Pumped storage hydro is obviously an important option, and a particular focus of current investigations, but it is far from the only option under consideration. The ultimate goal of this investigation is to develop a general framework for understanding how each of the options likely to be considered might be operated, organised, and integrated into both spot and hedge markets. It should be recognised, though, that each option has its own technical characteristics, likely operating mode, and organisational options and challenges. Thus, our discussion can not be entirely generic. Broadly speaking we see four types of options, and will discuss each separately below.

2.7.2. Passive supply side storage options

These options may be thought of as "incidentally embedded" in the supply side of the electricity sector, in the sense that there is some store of energy, in a tank or reservoir, closely linked to a generator. But, while it may have been supplied from a wider distribution network the fuel (or water), once delivered, is stored for the use of that particular power station, and will be managed for that purpose alone. This category would include traditional hydro reservoirs and fuel stockpiles, but also some potential green alternatives.[31]

The management of traditional hydro is well understood, and has already been discussed extensively in our report to MDAG. So, we see no need to discuss its operation any further in this report, and note that it already has established organisational structures, and is reasonably well integrated into both spot and hedge markets. We only note that the storage aspects of traditional hydro systems will become increasingly important in future years, and suggest that, if a market were to be developed for some form of storage-based hedges, as discussed in Chapter 5, serious consideration should be given to designing that market in a way that would allow traditional hydro to participate.

The management of traditional thermal will become increasingly irrelevant, but MDAG has identified a potential role for "green thermal", perhaps fuelled by hydrogen, or biofuels. The fuel supply chain would obviously be different, for each technology, but the overall structure of the biofuel supply chain does not seem very different from that for existing thermal capacity. We expect there would be stockpile of some kind, stored for station use, and a limited rate at which that stockpile could be replenished from local sources, and/or the ability to import. This seems very similar to the situation currently applying to coal, and we expect it would be managed in a very similar way to that discussed in Section 2.3.

Hydrogen could present some different issues, though, if it was locally produced by electrolysis. Obviously, it would not make sense to use electricity to produce hydrogen at times when prices were high enough to justify producing electricity from hydrogen. But one could imagine a closed cycle, in which hydrogen was produced at times when electricity prices are low, and then used to fuel generation when electricity prices are high, thus forming a kind of "battery", which could be analysed and managed as such under the "stand-alone" category below.

Alternatively, we could imagine hydrogen powered generation occurring in the context of a much wider trading network, in which hydrogen night be exported at some times, and imported at others. If there was no local hydrogen powered generation, this would be an example of "embedded" demand-side response, as discussed below. Local hydrogen powered generation enables a net switch from absorbing electricity to "charge" the hydrogen storage system, to "discharging" the hydrogen storage system to produce electricity. That would create a situation more akin to that of embedded pumped storage hydro, as discussed in Chapter 4, below. There may not be any physical linkage between the hydrogen-

[31] Gas is an exception, in that it is supplied by a network, within which interactions quite similar to those discussed later for pumped storage could arise. But there seems little point discussing the intricacies of those arrangements, given that gas is supposed to be eventually retired, as a fuel, in New Zealand.

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producing facility and the hydrogen-powered generation, either in the electricity network, or the hydrogen trading network. But the traded price of hydrogen should optimally be driving the behaviour of both facilities, in a similar way to host system EMWVs, impacting both operational and hedging strategies.

Geothermal may also be seen as a special case. Although generally thought of as "renewable", most geothermal developments have significant incidental carbon emissions, to the extent that, unless a suitable carbon capture technology can be developed, future geothermal development seems likely to significantly curtailed by rising carbon prices. We understand, though, that there has been discussion of the possibility that geothermal plant could be developed, but only used in standby/backup role.

At one level, if we believe the carbon price will be set at an appropriate level, that that seems like a decision that could be left to the market, with potential investors making their own decisions as to whether it is worthwhile investing in plant that will only run when market prices are high enough to cover the carbon price, plus variable O&M. But there could be policy reasons for treating this kind of development as providing a form of storage capacity, perhaps operating under a stricter carbon limit than that implied by the carbon price.

Given the longevity of carbon in the atmosphere, it makes little difference when, in its lifetime, such plant may operate, so it probably makes most sense to think of it as having a lifetime carbon budget. In that case, it is the carbon budget, not the geothermal resource, that constitutes the "storage" to be managed. The facility manager should logically determine an opportunity cost to ration its stock of carbon release opportunities over its lifetime, and then add that opportunity cost to the carbon price when determining operational strategy. But note that discounting would play a very significant role over this kind of planning horizon, and the opportunity cost should not be constant, but rising at the discount rate, as in Hotelling's rule, thus implying an increasingly restrained operational policy, as time progresses.[32] [33]

2.7.3. Stand-alone active storage options

The facilities we have in mind here are dedicated to storing electricity, in the sense that (unlike with traditional hydro or thermal) electricity is taken out of the electricity system to build up some store of potential energy, so that it can be later released back into the electricity system. In principle, this could be achieved using a very wide range of technologies to store the potential energy, including compressed air, and flywheels, but the two most relevant options in the current context would be batteries and pumped storage hydro.

Batteries are an inherently "stand-alone" technology. While some batteries might be associated with particular (typically intermittent) generators, their internal operation is in no way connected with the generation facility they may be associated with. The same could be true of a pumped storage hydro development that drew water from a source not otherwise associated with electricity generating infrastructure, and released to that source, or possibly to another similarly un-associated water body.

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[32] In other words, it should behave rather like the "Depletion Related Opportunity Cost" calculated for gas-field depletion. As in that case, though, that may mean that current opportunity costs are set by working back from some assumed future value, to a possibly very low current value. And that would imply that the geothermal plant might expect to operate reasonably freely in its early years, adding only a small increment on to the carbon price, but become increasingly restrained as time progresses, and its "stock" of allowable carbon discharge is depleted. In fact, under various simplifying assumptions, Hotelling's rule also implies that the usage rate should be decreasing at the discount rate, if the plant had an infinite life. We have not researched the issue to determine how that broad outline might be modified by the particular characteristics and maintenance cost structure of geothermal developments, or by factors such as the carbon price probably also rising over time, and dry year response requirements possibly falling over time.

[33] The economic and scientific logic discussed here actually applies to all existing thermal and geothermal plant, with a critical issue then being the technical and economic life of that plant over an extended period of rising maintenance costs and decreasing utilisation. In all cases, the prospect of technical failure and/or obsolescence, not to mention annual maintenance costs, must increase the incentives implied by Hotelling's rule to utilise available resources earlier, rather than later. And that will be particularly the case if doing so allows stocks to be built up in other, more durable, storage developments.

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While the discussion of stand-alone storages in Chapter 3 focuses on batteries and pumped storage hydro, we believe it will largely apply to any other stand-alone technologies. The main difference is that some technologies are essentially self-contained black boxes (like batteries), while others store potential energy by drawing in some medium, such as water or air, from the environment, and holding it under pressure, or at elevation.

The organisational challenges may differ significantly, though, depending on the extent that the technology might be dispersed across multiple small-scale sites, vs focussed in one large-scale development. While our discussion in Chapter 6 is focussed on pumped storage hydro, we believe that it would largely also apply to other large-scale stand-alone developments, without the complexities potentially arising from "host system interactions". Dispersed smaller scale developments might benefit from centralised development of a market, for the kind of hedge products discussed in Chapter 5, but should not need the same kind of attention as large scale developments, for which market power is a significant issue.

2.7.4. Active storage options embedded in supply-side systems

The most obvious example here would be pumped storage hydro. Such developments might be retrospectively embedded in existing "host" hydro systems, but they could also be designed as part of an integrated catchment development that also included conventional hydro. The fundamental difference is, though that these are facilities specifically designed to provide "active" storage. That is, water would be actively pumped up to a dedicated "upper reservoir", at some cost, rather than just being passively "held" in some structure that essentially just delays its ultimate passage to the sea. We have devoted a whole chapter to the discussion of such developments, because we think the mix of (large-scale) pumped storage and conventional hydro in the same catchment poses unique operational and organisational challenges beyond those faced in the current market, or by the other options considered here.

2.7.5. Embedded demand side storage options.

A variety of demand-side "storage" options were briefly discussed by Section 4.3.3 of our report to MDAG, which suggested that they could play a significant role, with possibly greater potential than pumped storage hydro. There is a great diversity of possible developments, though:

- At one end of the spectrum, large-scale export industries could be deliberately developed in such a way as to ensure flexible demand reduction in response to short and/or long-term fluctuations in the electricity supply/demand balance. Production of hydrogen by electrolysis, or even development of more flexible smelting activities, would provide prime examples.
- At the other end of the spectrum, encouragement, and perhaps co-ordinated management, of distributed small-scale flexibility, including EV/solar battery charging, and even traditional hot water heating loads, could also make a significant contribution to the DSM component which MDAG considered to be critical to managing supply/demand balance, in the absence of traditional thermal capacity.

We describe all of these options as providing "embedded storage", because what is actually being stored is a product, such as hydrogen, or heated water, and the storage facility is embedded in some demand-side system somewhere on the planet, and not in the New Zealand electricity system, or necessarily even in New Zealand. We see this as being somewhat similar to the way pumped storage hydro is embedded in a host hydro system, in that:

- The medium of potential energy storage has its own value, as a product or feedstock in some process other than the energy storage process itself; so
- The effective cost of charging the storage will include the cost of taking that medium away from the production/storage process in which it would otherwise have been involved, at some time; and
- The effective value from discharging the storage will include the value of returning that medium to the production/storage process from which it was withdrawn at some earlier stage.

As a result, optimal charge/discharge decisions should not just be driven by electricity prices, but also by the fluctuating valuation of the storage medium in other markets. And that also means that the hedging these options can provide to electricity market participants might be affected by factors other than the electricity price at that moment.

Unlike pumped storage hydro, though, the other markets whose price movements may play an important role typically have no connection with the New Zealand electricity market.[34] The delay and cost involved in switching from charging to discharging, and the organisational issues will also differ widely between options. Thus, a detailed discussion can not be generic, and seems inappropriate, at this stage.

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[34] Hydrogen being a possible exception, in that it might be both produced and consumed within the New Zealand electricity sector, at different times. And it might be both exported and imported at different times, too.

3. Optimal Stand-Alone Storage Operation

3.1. Introduction

This chapter discusses the idealised operation of a large stand-alone storage facility on the assumption that this could be achieved through centralised optimisation, or in a perfectly competitive market. While that assumption is obviously unrealistic it enables us to establish a basic theoretical reference point, to which later discussions can refer. Also, while this discussion focuses, at times, on the specifics of pumped storage hydro, the principles are broadly applicable to any "stand-alone" storage facility: that is, to storage facilities that are either fully "closed" or fully "open", in the senses discussed below.

The most obvious "closed system" would be a battery, and we discuss the optimal operation of batteries before moving on to consider pumped storage facilities that might either be fully closed or fully open, but have no interaction with any "host" hydro system associated with either the lower or upper reservoir. Studying these stand-alone systems allows us to understand the properties, and optimal management, of some of the simpler options under consideration. But it also provides a basis for understanding the much more complex case of storage facilities "embedded" in other systems, including the embedded pumped storage facilities discussed in Chapter 4 below.

3.1.1. Closed systems

It has often been said that pumped storage is just like a big battery, but that is an over-simplification for most real systems. It would be true, though, if the pumped storage facility was a stand-alone closed loop system, in which the same water was constantly re-cycled. That would be possible, if the combined rate of inflow to upper/lower storages at least matched the combined rate of leakage or evaporation.[35]

In addition to the obvious limits implied by the MW capacity of the pumps/generators, the effective cycling/storage capacity of the system would be set by the minimum of the upper and lower reservoir capacities. Even if the upper/lower reservoir could contain more than the other reservoir, the extra could never be run up/down into that other reservoir. The pumped storage hydro facility could operate "just like a battery" within those capacity limits, though. Conversely, the principles discussed here apply equally to any battery, or other "closed" storage system, which contains its own storage medium, rather than relying on potentially constrained supplies from some other system.

3.1.2. Open systems

Pumped storage hydro could also operate "just like a big battery", if the water was drawn from, and discharged to, the ocean, or some body of water large enough as to not be materially affected by the pumped storage hydro operation. In that case, its operation will not be limited by interactions with any other system, and its effective storage capacity is just the energy storage capacity of the upper reservoir of the pumped storage facility. And the same will be true of any other facility, like compressed air storage, drawing its storage medium from an essentially unlimited source.

[35] If water loss occurs from the upper storage, it may be seen as equivalent to the gradual "leakage" of energy from a battery, over time. This loss of water in storage is quite different from the "round-trip" loss of electro-mechanical energy due to inefficiencies in the pumping process, as discussed elsewhere. Such leakage does not fundamentally change the principles discussed here, but we will discuss it, along with "discounting", in Section 3.3.4 below.

3.2. Optimal battery operation

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[redacted]

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s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

3.3. Deterministic cycling of stand-alone pumped storage

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[redacted]

s 9(2)(f)(iv)

s 9(2)(f)(iv)

[redacted]

3.3.1. Seasonal cycling

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[redacted]

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s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

3.3.2. Daily/mixed cycling[59]

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[redacted]

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s 9(2)(f)(iv)

[redacted]

3.3.3. Additional storage capacity

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[redacted]

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[redacted]

3.3.4. Discounting, wastage, and head effects

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[redacted]

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s 9(2)(f)(iv)

[redacted]

3.4. Stochastic management of stand-alone pumped storage

s 9(2)(f)(iv)

[redacted]

3.4.1. Real-time stochasticity

s 9(2)(f)(iv)

[redacted]

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s 9(2)(f)(iv)

3.4.2. Daily/weekly/monthly stochasticity

s 9(2)(f)(iv)

[69] Opportunity costing concepts are relevant, though, inasmuch as the prices set for ancillary services in a co-optimised market always include the opportunity cost of displacing generation. And that opportunity cost, itself, reflects the difference between the electricity price in that market trading interval, and the offer which, under perfectly competitive assumptions would be determined by the EMVS.

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3.4.3. Inter-annual stochasticity

s 9(2)(f)(iv)

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3.5. Achieving balance with other storages

3.5.1. Storage balancing in a multi-reservoir environment

s 9(2)(f)(iv)

s 9(2)(f)(iv)

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s 9(2)(f)(iv)

3.5.2. Capacity balancing in a multi-reservoir environment

s 9(2)(f)(iv)

s 9(2)(f)(iv)

4. Embedded Pumped Storage Operation

4.1. Introduction

Chapter 3 discussed the idealised operation of a large pumped-storage hydro facility as if it could be optimised and/or operated in a perfectly competitive manner, without considering any direct interaction with a host hydro system. Here we retain the assumption of operation in an optimised/perfectly competitive environment, but generalise the discussion to cover more realistic configurations in which the pumped storage hydro facility is embedded in a host catchment that is being managed to support its own conventional hydro scheme, potentially both upstream and downstream of the pumped storage facility's intake/discharge point.

Unlike batteries, pumped storage hydro is a very site-specific technology. So, we first describe the kind of pumped storage hydro facility we have in mind, and to which this theoretical discussion might ultimately be applied. But we then proceed to work through a series of simpler configurations to build up a picture of the various interactions involved, with a view to identifying the kinds of situations in which a co-operative working agreement might become important, and those in which it may not be necessary at all.[82] Finally, we briefly discuss the forms such an agreement might take, if it did prove to be necessary or desirable, and expand on that discussion in Appendix B.

4.2. Reference system

Rather than tackling analysis of any particular real system, it seems more helpful to develop some insights into how pumped hydro systems should operate, in general, and to identify areas and issues that should be examined more carefully when analysing any particular development proposal. s 9(2)(f)([redacted]

[82] Appendix A takes a rather different tack, working through some highly stylised numerical examples, in order to get a feel for the relative importance of various capacity dimensions and siting considerations that may materially impact on the assessment and operation of potential developments, and perhaps limit the choice of operational and organisational regimes that might be appropriate, in such cases.

[83] The opposite situation, in which water is run down to a dedicated reservoir, and then pumped up again, is technically possible, but seems unlikely in New Zealand.

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

4.3. Host system status quo

s 9(2)(f)(iv)

[redacted]

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s 9(2)(f)(iv)

[redacted]

4.4. Run-of-river host system

4.4.1. Introduction

s 9(2)(f)(iv)

[redacted]

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4.4.2. Undeveloped host system

s 9(2)(f)(iv)

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4.4.3. Accounting for upstream generation capacity

s 9(2)(f)(iv)

[redacted]

4.4.4. Accounting for downstream generation capacity

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

4.5. Accounting for downstream storage

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

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s 9(2)(f)(iv)

[redacted]

4.6. Accounting for upstream storage

4.6.1. Introduction

s 9(2)(f)(iv)

[redacted]

4.6.2. Conflicting objectives

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

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s 9(2)(f)(iv)

[redacted]

4.7. Adding buffer storage

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[redacted]

4.7.1. Basic operational limits

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[redacted]

4.7.2. Mixed mode cycling

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

4.8. Managing host system interactions

s 9(2)(f)(iv)

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s 9(2)(f)(iv)

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5. Hedge Market Interactions

5.1. Introduction

As will be seen, some of the organisational options discussed in Chapter 6 rely heavily on contracts that can be interpreted as "hedges", albeit perhaps of unconventional form. It should be stressed that, while these contracts may be described as "financial instruments", they are not necessarily designed to be traded at all frequently, or easily. The more complex "natural" forms discussed below are much more in the mould of a traditional lease: Simpler and more flexible than outright ownership, but giving the long-term holder benefits similar to outright ownership, and hence exposed to some of the complexities normally associated with ownership.

On the other hand, the art of mainstream hedge market design rests heavily on finding a hedge product form that a wide range of parties feel they can value, and hence are prepared to trade. And there are already several broad forms of hedge available in the New Zealand market:

- Strips of energy "futures", representing energy to be delivered to a specific location, at specified times of day (in broad base/peak blocks) in specified months, perhaps months or years ahead;
- Options on those energy hedges, and "swaptions", under which the holder may call on specified capacity, at any time over the contract period; and
- Locational swaps, known as "Financial Transmission rights" (FTRs) allowing the hedging of inter-nodal price differences, potentially also at specified times of day, in specified months, perhaps also months or years ahead.

So, the issue arises as to whether the manager of a pumped storage hydro facility should merely provide "natural form" contracts, or (also) interact with those established markets, and/or perhaps with some market trading a new class of product. Accordingly, we will start by discussing the "natural form" of contracts that could be supported by storage facilities, including batteries and pumped storage, then move on to discuss prospects for providing hedges that traders, and some market participants, might find more attractive, for various reasons.

5.2. Natural hedging for generators, loads, and traders

Our own thinking, over the years, has tended to focus on the fact that all hedges are still forms of contract. We think it important not to entirely lose sight of the fact that the original purpose of contracts was to induce parties to fulfil promises to deliver goods or services of value, on the one hand, and to pay for them on the other. Thus, whatever deals may be done by third parties in trading rooms, perhaps unconscious of the implicit physical realities, there must ultimately be parties able to (at least approximately) back these contracts with physical production, and parties ready to pay for physical delivery.

As a result, we have tended to favour "hedge products" that reflect, as closely as possible, the properties of the physical capacity ultimately underpinning the value of those products:

- For geothermal plant, that would be a base-load "strip" of energy futures, as might be traded in the current hedge market, and the same would be true of the "minimum running" component of hydro generation.
- Less predictable run-of-river hydro and wind generators might also back similar base-load products, if there is not much pattern to their expected output capabilities, albeit at some risk to themselves if unable to match the volumes sold, when conditions go against them on the hour.
- Solar plant seems unlikely to back that kind of product, though, because it knows it simply can not generate over half the 24-hour cycle (on average). Thus, it would presumably prefer to offer day-time hedges. It would also have to sculpt its monthly offerings over the year, offering more in summer than in winter.

None of those capacity types would seem like natural backers of call options, though, because their output is basically independent of market price, and not controllable to match option calls.[107] Thermal plant presents a range of more interesting cases. In theory, the natural form of contracting would reflect the cost and capability structure of thermal plant, which can be characterised as a fixed annual sum being paid to provide the physical option of running the plant to generate whenever electricity prices exceed its "Short Run Marginal Cost" (SRMC), including fuel and variable O&M.[108] In other words, it would ideally want to (only) offer call options to the market. In reality, though:

- A base-load thermal generator may be quite confident in offering base-load hedges, even years ahead, because it believes that it will (nearly) always be operating in that mode, since prices will seldom fall below its SRMC.
- A "shoulder" generator may think similarly, because it also considers its future generation schedule to be fairly certain, but restrict itself to only offering, say, day-time hedges in winter months.
- A "peak support" generator may be much less certain, particularly in the inherently volatile hydro-dominated NZEM, and would more naturally offer call options, or some combination of call options with sculpted energy hedges covering the generation levels it is fairly certain it will be called for.
- But true "extreme peaking" capacity, which may only be called on for a few hours in a typical year, and perhaps for a more extended period every decade or so, really can not offer anything but call options, because it has little idea as to when it will be generating.

The broad picture, then, is that thermal generators might effectively be selling across some combination of three different modes:

- Strips of energy futures matching generation levels they are fairly certain of achieving; plus
- "Natural Form" call options covering (ideally) their remaining available capacity; plus (or potentially minus)
- Supplementary spot trading, when high/low prices make it more economic to generate above/below contracted levels.

The above discussion omits an important factor, though, which is that the "natural form" of the contracts consumers ideally wish to buy is typically quite different from the natural form of contracts generators ideally wish to sell:

- Most small consumers will simply want to buy from a single retailer, on a fixed price /variable volume basis;
- Larger consumers may be willing and able to buy more on a spot basis but, if they think they know exactly what their load profile will be, they will also want to buy conventional hedge strips to approximately match that profile; while
- Traditionally, some very large consumers might consider investing in their own power stations, to provide a "physical hedge option".[109]

Such physical investments would, by definition, provide hedging in the "natural form" applicable to the technology employed. So, large consumers contemplating such investments should be trading that option off against the option of sticking with their core business, while buying hedges off the market. If hedge contracts were available in the natural form corresponding to that technology, that would effectively give them access to a "slice" of that type of capacity developed by some other party in the market, but probably at a lower cost, due to economies of scale and scope.

That mode of thinking might be expected to spread, in the scenarios discussed by MDAG. Businesses and households contemplating rooftop solar investments, and trying to match their load patterns to

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107 Ignoring the possibility that market prices may fall below production-dependent O&M costs.

108 Although, as discussed in Section 2.3, much of the fuel cost may also be locked in, thus lowering the true SRMC to a level at which the thermal generator is effectively committed, in advance, to generate according to some profile, almost irrespective of market price, and may hence issue energy hedges accordingly.

109 Many smaller entities have also made investments in backup capacity in the form of Diesel generators, although the motivations for that investment often relate more to dealing with localised transmission/distribution outages than with energy market pricing peaks.

output and/or buy batteries to facilitate that match, should logically consider buying virtual battery capacity instead.[110] And, if DSM is going to play as large a role as MDAG considers it may need to, consumers should not actually "know" their consumption levels far in advance, because they should be planning to respond flexibly to future market signals. So, they should be looking for flexible electricity supply arrangements, rather than sculpted strips of futures. They might achieve that by buying capped hedges, or by selling their own call options, reflecting their willingness to reduce demand, at prices above specified levels.

Still, the reality is that most consumers will not understand, or want to purchase, a whole portfolio of hedges, each in the natural form representing the technological capabilities of the ultimate underlying technology. So, the role of the retailer is to re-package what the generation sector can naturally offer into forms acceptable to the consumer.

The hedge market plays an important role in that re-packaging by allowing generators who wish to act as retailers to purchase hedge products to complement their own capacity, and stand-alone retailers to purchase a virtual portfolio of capacity to back their retail commitments. In the process, though, a third factor emerges to determine the shape of available hedging products: Namely the hedge form considered most natural by traders, who often come to the sector with experience of other markets, in which the underling natural forms of contracting may be quite different from those natural to the electricity sector.

Traders prefer, and indeed require, simplified products that may not match the technical characteristics of the underlying technology terribly well at all. And that tends to force market participants into dynamically adjusting market positions to reflect their ever-changing physical situation, rather than relying on the automatic adjustment implicit in more "natural" contract forms, such as call options.

5.3. Natural hedging for hydro systems

The above discussion directly applies to hydro plant that has no associated storage, and hence can only adopt a run-of-river operating mode. Such plant could naturally support base-load hedges, up to a generation level corresponding to its minimum flow level. Beyond that, it would face increasing risk if it were to offer energy hedges, or if it were to enter the retail market, because it would be facing the risk of having to buy power in from the spot market in order to meet its retail commitments. So, if it wanted to make commitments beyond that point, it would be looking to purchase hedges itself, to cover its own risk exposure.

A hydro generator with physical storage options available can provide much of its own hedging, by storing water arriving in periods when its commitments (and/or electricity prices) are low, so as to be able to generate in periods in which its commitments (and/or electricity prices) are higher. But its physical self-hedging capability will be limited, and it may well still seek supplementary hedging from the market. And/or it could use its physical hedging capacity to back hedges that would enable other market participants to cover some of their own risks. So, we turn to discuss the natural form of hedges backed by hydro generators with storage.

[110] Assuming the metering and network cost recovery arrangements could be worked out to create a level playing field, and that such hedge products were available, and comprehensible.

s 9(2)(f)(iv)

Barroso et. al. discuss international examples involving "virtual model" representations of physical systems used as a basis for contracting in the hydro sector.[111] In particular, Hunt and Read proposed a "virtual reservoir" to allow competing parties to govern operational strategy for the Tasmanian hydro system by multiple, while retaining integrated management of the physical system.[112] s 9(2)(f)(But the point, here, is that Hunt and Read proposed to express those "virtual reservoir" contracts in the form of "financial options" that would approximately reproduce the "physical hedging" made possible by the storage, in its "natural form".

The natural form of physical hedging provided by pumped storage hydro will be discussed further below, but the natural position of a traditional hydro plant that has associated storage is that:

- Storage levels are built up by uncertain inflows received into the reservoir;
- The reservoir manager assesses an EMVSE for stored water, using some form of opportunity costing methodology, as discussed in Chapter 3, and thus determines how much of that water should (in that manager's opinion) be optimally released for immediate use, and how much stored for future use;
- The manager makes market offers intended to produce something close to that "called for" release;
- The manager then implements the release determined by the market;
- Storage levels adjust to reflect the net impact of inflow minus release; and
- The process continues, with the manager being responsible to ensure that physical efficiency is maximised, and physical limits respected, while managing a continuously changing stream of inflows, and market conditions.

Accordingly, we suggested, in the Tasmanian proposal referred to above, that the "natural form" of a financial contract for hydro reservoir storage would be to:

- Form a mathematical representation of the system, with all of its various reservoir/tributary inflow streams, storage capacities, release/generation capacities, flow limits, conversion efficiencies, etc, such as would be employed by a (probably simplified) formal mathematical optimisation model of the system; then
- Sell/lease "slices" of that "virtual reservoir/system model" as hedges to be "managed" by the lessees, as they see fit; where
- Lessees "manage" their slices, not by exercising "dispatch rights", but by calling the corresponding MW under the virtual reservoir hedge contract, on the understanding that their share of the virtual storage capacity will:
    - Fall to reflect the volume released to support the dispatched generation, but also
    - Rise to reflect their share of incoming inflows.

Such "options" may seem complex, to those familiar with trading standardised options on generic trading platforms, but the intent is not to create a tradable product. It puts each option owner in exactly the position they would be in, if they owned a scaled down version of the system themselves, and used established techniques to manage it, but without any responsibilities for physical maintenance, dispatch, environmental compliance etc. Conversely, the physical system manager would be responsible for all those things. They would also interact with the spot market to determine physical generation schedules,

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111 L.A. Barroso, S. Granville, P.R. Jackson, M.V. Pereira & E.G. Read: *Overview of Virtual Models for Reservoir Management in Competitive Markets* Proceedings 4th IEEE/Cigré International Workshop on Hydro Scheduling in Competitive Markets. Bergen, Norway, 2012

112 D. Hunt, E.G. Read, P.R. Jackson, L. Barroso and S. Granville: *Tasmanian Market Reform: Commentary on Panel's Preferred Options* Concept Consulting Report to Aurora Energy, Tasmania, Australia, 2012.
Summarised in Section III B of Barrosso et al, and also:
P.R. Jackson and E.G. Read: Financial Reservoir Models Supporting Competition in Integrated Hydro Systems *ORSNZ 2014*.

but they would do so with strong incentives to approximately match the aggregate "calls" from the various lessees which they must ultimately honour, in a financial sense.

Returning to the original discussion, then:

- A hydro generator could issue "slice" contracts in a form that directly provided the hedging capability of the underlying hydro system in its natural form to slice holders;
- Those slice holders could be end consumers who would call on their slices as required; or
- They could be other generators who would use the slices to complement their own physical capacity, in order to support their own retail/wholesale market offerings; and/or
- They could be intermediaries offering more conventional hedges to current markets.

But the key point is that it would be the slice holders, not the facility owner, who would be in a position to offer conventional hedges to the market, just like any market participant owning similar physical capacity under the status quo.

5.4. Hedging for batteries and storage facilities

5.4.1. Hedging in the new environment

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5.4.2. Active trading in conventional hedge markets

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5.4.3. Collars

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5.4.4. Financial storage rights

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5.4.6. Tank options

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6. Organisational Arrangements

6.1. Introduction

The primary issues determining whether any particular storage development should proceed include its technical feasibility, the national and/or commercial costs and benefits it might deliver, its environmental impact, its ownership structure and the risks faced by its owners. All of those issues would need to be carefully assessed, both qualitatively and quantitatively, but that kind of assessment lies outside our present scope. Our focus is on how decisions might be made with respect to operational strategy, once a facility was built; how it might interact with markets; and what the combined effect might be on market outcomes, both short and long-term.

While much of the discussion in this chapter may apply to other storage options, it is also true that operational and organisational issues may differ widely. Some options may be large-scale developments, while others could be distributed throughout the network, some embedded and some stand-alone, etc. So, in the interests of clarity and concreteness, this discussion focusses on large-scale pumped storage hydro, and does not consider possible generalisations to cover other technologies.

Accordingly, this chapter provides a preliminary high-level overview of several organisational structures and/or arrangements that could be made to allow a large-scale pumped storage hydro development to achieve something like its full potential, in national cost-benefit terms. None of these proposals is perfect, so we list their pros and cons, and make some tentative suggestions about ways in which the negative factors might be mitigated. We do not attempt to discuss any details of the kind of institutional arrangements that might be required to make any of these proposals work, or of any other transitional arrangements that might be required.

This chapter is structured to lay out the spectrum of options available to deal with one key issue: Namely the potential of various organisational arrangements to limit the negative effects of market dominance and distortion of investment incentives. For this purpose, the options are dealt with in three broad groups:

- "Unified" regimes under which a single organisation is made responsible for operational decision-making, so the focus is on devising arrangements to limit and mitigate the market dominance of that single organisation; versus
- "Diversified" regimes under which a single organisation still operates the facility, but operational decision-making is driven by the competing demands of a number of parties, none of which is deemed to dominate the market, in its own right; and
- "Hybrid" regimes, which combine elements of both.

Not surprisingly, the general thrust of the suggested mitigations and resolutions is towards a hybrid regime that combines organisational and contractual mechanisms in such a way as to gain some of the benefits of diversified regimes, while retaining the benefits of a unified regime, as much as possible.

First, though, Section 6.2 identifies several other "key issues" that will eventually need to be addressed in the context of each organisational regime. While the main description and discussion of each regime largely ignores those issues, the section on each broad group of options includes a sub-section briefly outlining the way in which those key issues could be handled, under regimes of that type.

6.2. Key issues

6.2.1. Market impacts and economic efficiency

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6.2.2. Hedge market interactions

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6.2.3. Host system interactions

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6.2.4. Real-time issues

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6.3. Organisational arrangements for s 9(2)(f)(iv) [redacted]

6.3.1. Introduction

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6.4. Organisational arrangements for s 9(2)(f)(iv) [redacted]

6.4.1. Introduction

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6.5.1. Introduction

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7. Conclusions

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8. APPENDIX A: Illustrative Host System Interaction Examples

8.1. Introduction

Chapter 4 focuses on the issue of dealing with host system interactions, because we believe it may be a critical factor limiting the economic value of some pumped storage hydro proposals and, crucially for this report, the kinds of operational and organisational arrangements that need to be, or can be, considered in those cases. Since we understand that a variety of proposals may be considered by MBIE, we will not focus on any particular proposal, but briefly discuss a few simplified examples to illustrate the range of situations that could be encountered.

Our goal is not to provide a basis for calculations, but to illustrate the key considerations involved, as simply as possible. We will discuss s 9(2)(f)(iv) [redacted]

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8.2. Developments implying strong interactions

8.2.1. Introduction

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8.3. Developments requiring weaker interactions

8.3.1. Introduction

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9. Appendix B: Managing Host System Interactions

9.1. Introduction

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9.2. Organisational integration

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9.3. Water management agreements

In many jurisdictions parties interacting in a catchment are required to enter into a comprehensive Water Management Agreement (WMA). However, we are aware that two situations already exist, within the New Zealand hydro system, where an upstream and downstream party are supposed to operate independently, in the same catchment, without any real WMA.[186]

In principle, such arrangements must increase the risk of the downstream party, and can not produce "optimal" coordination. We understand, though, that the inefficiencies implied by those particular arrangements may have been deemed acceptable on the basis that the upstream party must eventually release whatever water they hold, and that the timing of that release should not matter too much, provided the downstream operator receives that water directly into a large enough long-term storage. It was also believed that the incentives of the two parties would roughly align, inasmuch as both would want to hold water back when prices are low, and maximise release when prices are high, thus establishing more-or-less compatible flows down the entire river chain. s 9(2)(f)(iv) [redacted]

s 9(2)(f)(iv)

[redacted]

[186] I.e., the Rangipo scheme, above Lake Taupo in the Waikato catchment, and the Tekapo scheme, above Lake Pukaki in the Waitaki catchment. In the latter case, we understand that there may be an agreement for the upstream party to cooperate in maintaining minimum flows, in extreme situations, but are not aware of any WMA operating when flows are at normal levels.

9.4. Water/energy trading

s 9(2)(f)(iv)

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9.5. Contractual mechanisms

Section 6.3 discusses several kinds of contractual mechanism that could be used to diversify decision-making with respect to pumping/generation strategy, and very similar mechanisms could be proposed to manage interactions between the pumped storage facility and the host system.

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9.6. Energy swaps

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[188] See Section III-C in Barroso et al, above, or:
E.G. Read *Energy Storage Management for Upstream/Downstream Reservoir Operators* Presented to EPOC Winter Worksop, Auckland, New Zealand, 2010.

s [redacted]

s 9(2)(f)(iv)

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10. Appendix C: Energy Trading vs Water Trading

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11. Appendix D: Coordination Agreements and Optimisation

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NZ Battery Project

Technical Reference Group Meeting 1

11 May 2021 – KPMG, Wellington

Today's programme

Time	Session	Key content
8.45am	**Introductions**	
9.15am	Project problem definition and background information	*Background to the project – ICCC advice, links to wider government policy around energy decarbonisation and security*
10.15am	Terms of Reference and project admin	*What the group is – and isn't – and how it's going to work.*
10.45am	Morning tea	
11.15am	Project Process – Phase 1 timeline	*Project planning and inception approach, work plan for the first 18 months of the project*
12.00pm	Long-list of options	*Framework including every practical technology that could provide dry year security in a 100% renewable New Zealand electricity system*
12.45pm	Lunch	
1.30pm	Evaluating and short-listing options	*Evaluation criteria against which technical options for the NZ Battery must be assessed, first cut screening of all potential technologies against those criteria and next steps for better understanding short-listed technologies*
2.30pm	Market modelling draft results and conclusions - Size of the problem	*Results of early modelling work on the amount of energy that the NZ Battery will need to store and how quickly it will need to be able to release it.*
3.30pm	Afternoon tea	
4.00pm	Market modelling draft results and conclusions - Market interaction	*Results of early modelling work on how the NZ Battery could interact with the existing wholesale spot market and scenarios on how market outcomes would differ, assumptions and related implications for further analysis.*
4.45pm	Questions and answers, any other business	*Feedback on the day and thoughts about future sessions.* *Confirm date of next meeting*

Member and team introductions

- Dr Allan Miller
- Amanda Larsson
- Dr Cristiano Marantes
- Dr George Hooper
- Hoani Langsbury
- Isla Day
- Mike Howat
- Dr Stephen Batstone
- Dr Adrian Macey
- Adrian Tweeddale
- Andrew Millar
- Bridget Moon
- Carl Walrond
- Conrad Edwards
- Jodi Percy
- Malcolm Schenkel
- Dr Samuel Treceno

Project problem definition and background information

Time	Session	Key content
8.45am	Introductions	
9.15am	**Project problem definition and background information**	***Background to the project – ICCC advice, links to wider government policy around energy decarbonisation and security***
10.15am	Terms of Reference and project admin	*What the group is – and isn't – and how it's going to work.*
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4.45pm	Questions and Answers, any other business	*Feedback on the day and thoughts about future sessions.* *Confirm date of next meeting*

Project background and problem definition

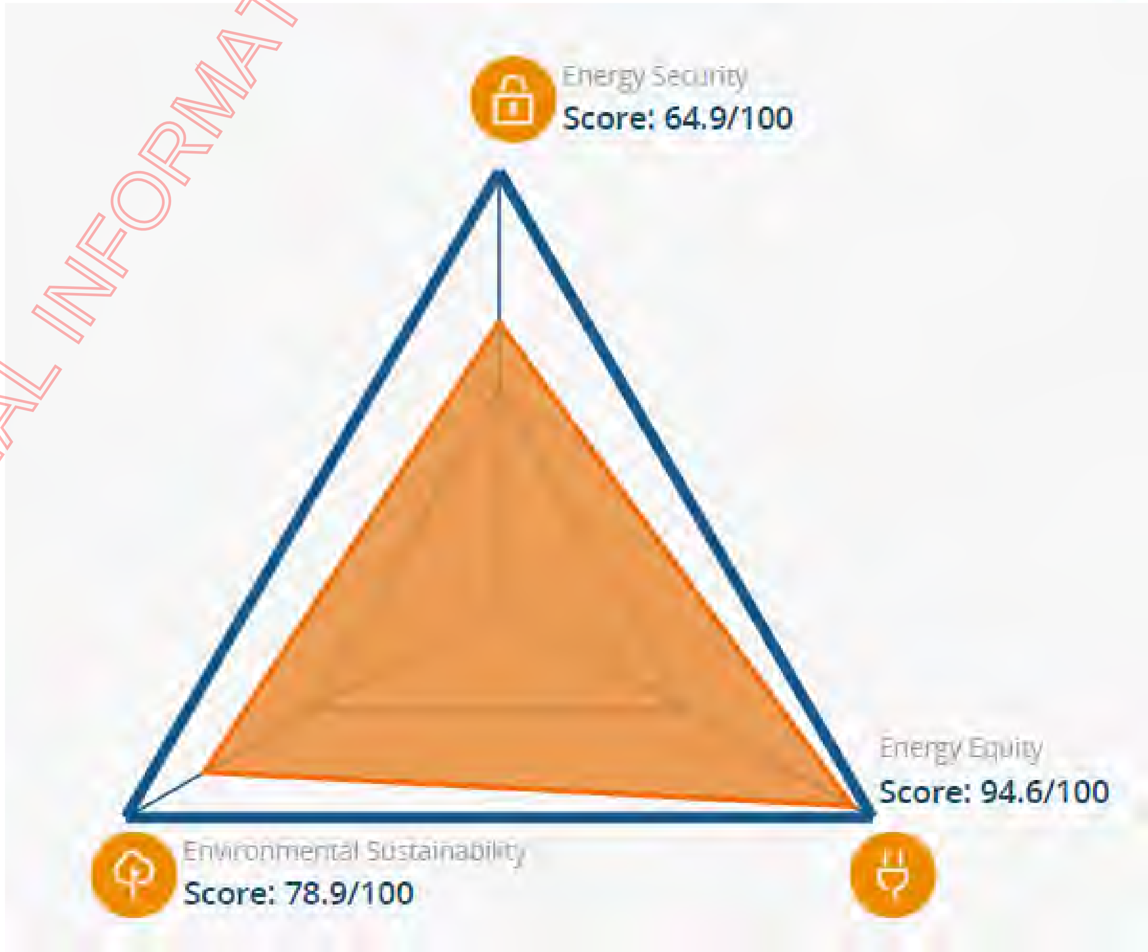
MAHI TAHI
BETTER TOGETHER

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

New Zealand's electricity market design

- Since 1996 New Zealand has had a liberalised electricity market.
- Long run average spot prices have been higher than the cost of new generation
- Costs of renewable generation have fallen faster than fossil-fuelled plant since 1996
- Cheapest new generation has generally been renewable since 2010
- So NZ's electricity industry has become more renewable since the opening of the market
- So government policies of efficiency and competition within the electricity market have balanced:
    - energy security,
    - energy sustainability,
    - and energy equity

Have achieved this without subsidising investment.

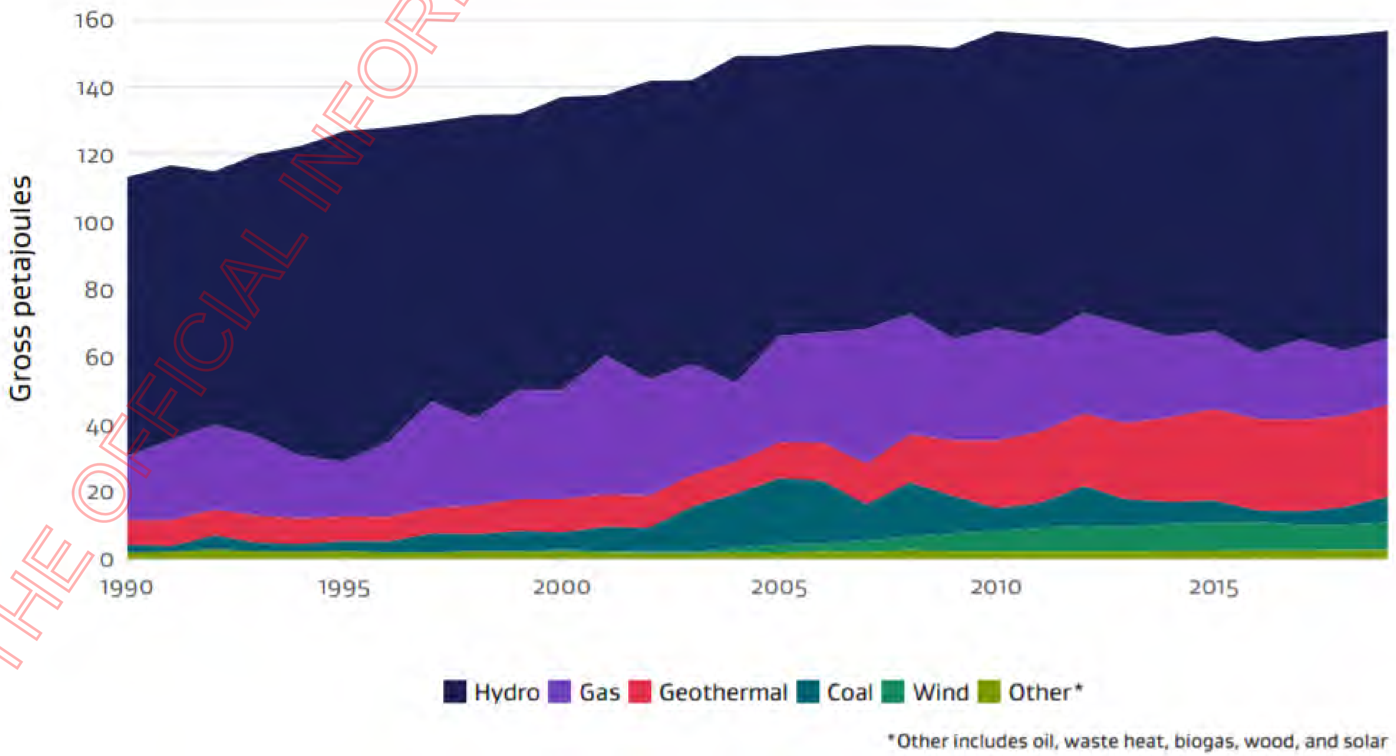


Main players

- MBIE’s role is energy policy advice – system-wide view
- Electricity Authority’s role is to regulate the electricity market
- Climate Change Commission's role is set emission reduction budgets – secretariat based on Interim Climate Change Commission
- Transpower’s role includes system operation and management of short-term supply security
- Generators are profit maximisers
  - Own different generation assets – seek to match up their supply with demand - buy from spot market or hedge shortfalls
  - Hedge contracts exist to cover dry year risk (e.g. big hydro generators contract to keep Huntly power station as back up)
- Current market with carbon prices at current level unlikely to provide sufficient return on investment for 100% renewable dry year solution by private sector

New Zealand's electricity generation mix

- New Zealand's electricity sector in 2019 was 82.4 per cent renewable, the fourth highest in the OECD
- 60% of our generation is hydro - mainly a blessing but occasionally a curse
- Most NZ hydro is run of the river 'use it or lose it' (unlike Norway)
- We have only a limited amount of storage in our existing hydro lakes (around 4 TWh)
- Fossil fuel generation – particularly natural gas and coal – provides cover for renewable sources



MBIE, *Energy in New Zealand 2020*

Electricity and climate change

- Greenhouse gas emissions from fossil fuel generation currently make up approximately 5 per cent of New Zealand's total emissions
- ICCC modelling predicts that New Zealand will continue to phase out fossil fuel generation, reaching between 82% to 97% renewable electricity generation by 2035
- CCC draft advice is that:
  - coal use for electricity cease by 2024
  - natural gas for electricity generation should have reduced by a third by 2035
  - with an ongoing role out to 2050
- But CCC notes that **eventually all fossil fuel generation would need to be eliminated and the dry year issue addressed** to contribute to efforts to limit the global average temperature increase to 1.5°C

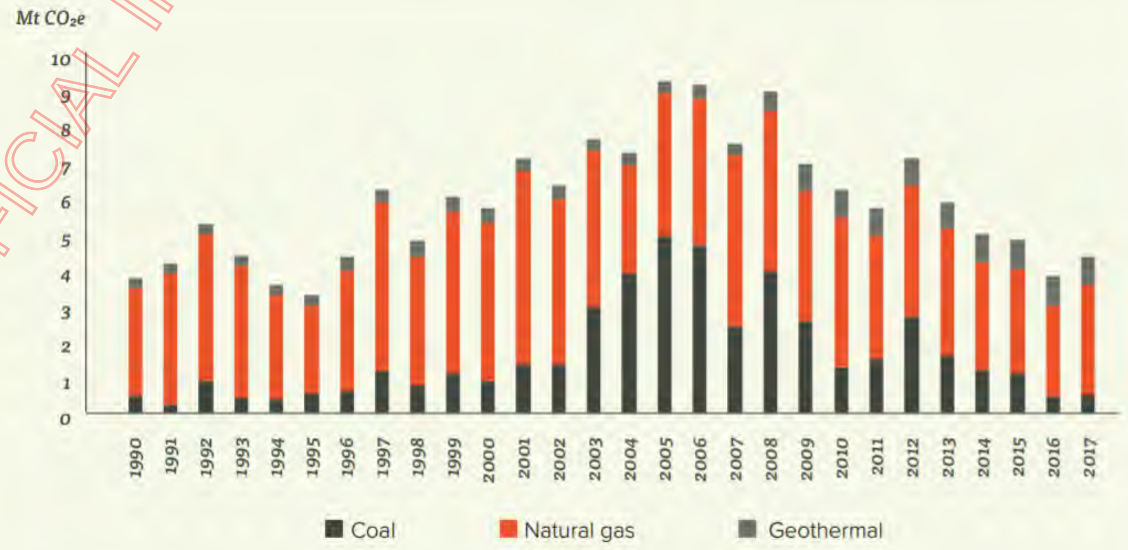
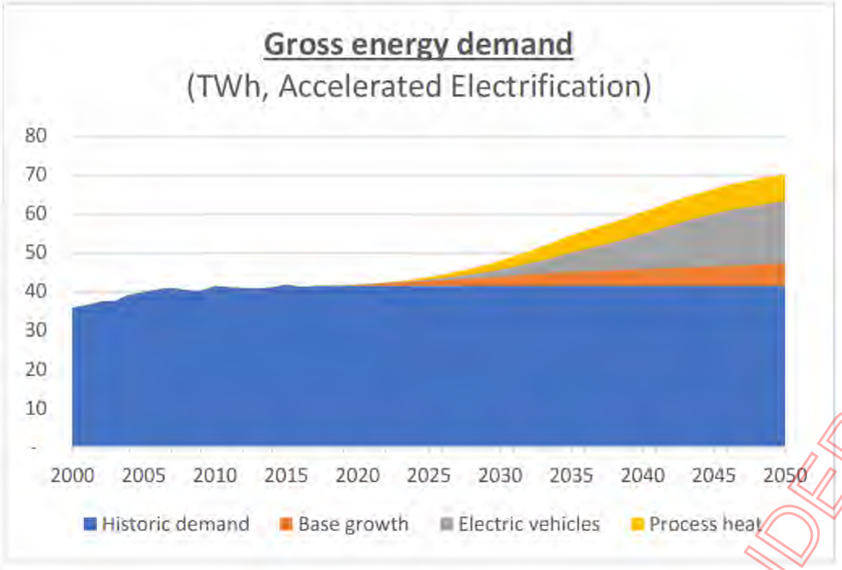
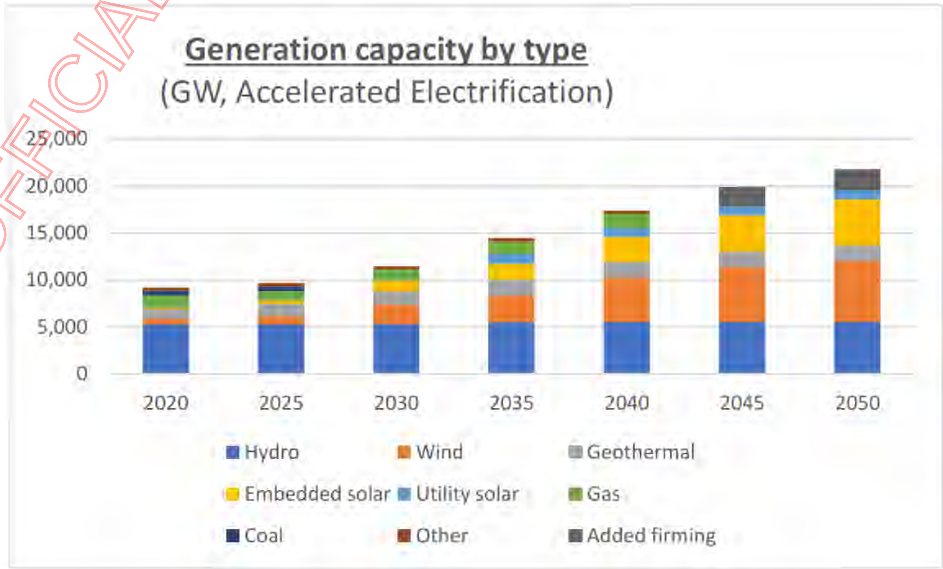


Figure 2.6: *Electricity emissions, 1990-2017*
Source: MfE (2019a)

Decarbonisation through electrification

- ICCC advice was that the biggest potential impact of the electricity industry on emissions to 2035 is through the accelerated electrification of fossil-fuel-powered activities, particularly industrial heat and passenger transport
- This could double NZ's electricity demand by 2050. This will require more renewable generation to be built over the next 30 years and substantial expansion of transmission and distribution
- Will also increase the amount of 'intermittent' solar and wind on the system

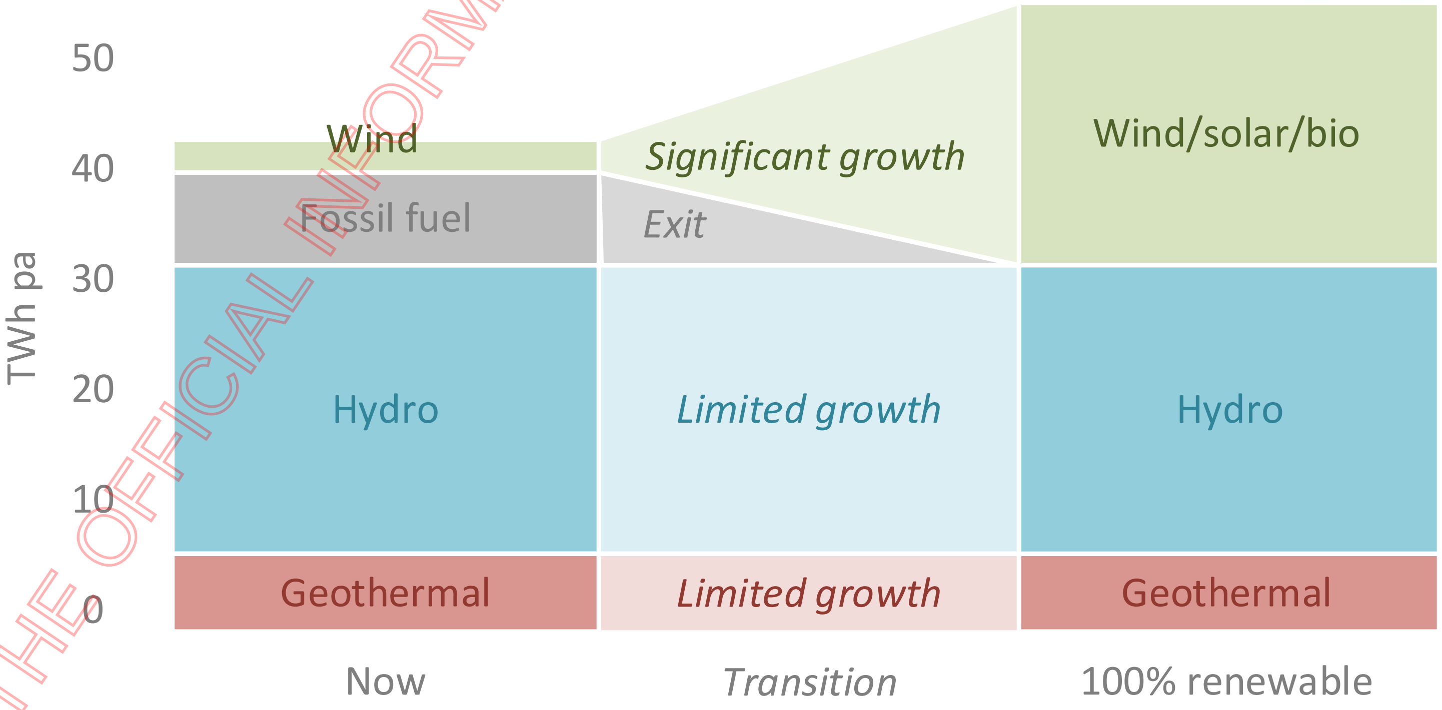




Graphs sourced from *Whakamana i Te Mauri Hiko*, Transpower, 2020

An electricity transition

- The transition to 100 per cent renewable electricity generation will be challenging.
- It will require New Zealand to:
  - increase the investment and build of new renewable generation
  - shift industrial and transport energy use to electricity
  - retire or repurposing existing fossil fuel-based generation
  - manage security of supply and dry year risk
- This could mean that the future electricity system could look different to the one that we have today

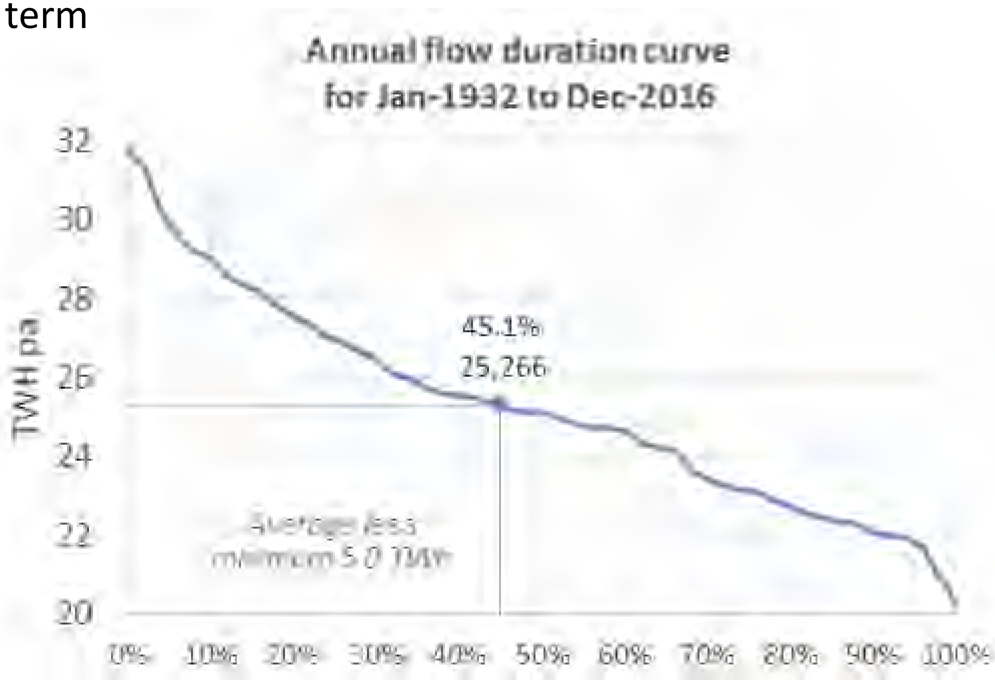


Managing dry year risk with 100 per cent renewable electricity

- New Zealand has experienced several 'dry years' in the past. Official conservation campaigns occurred in 1992, 2001, 2003 and 2008. There have also been constrained periods since 2008, mostly recently in 2018 and 2021.
- These are periods of limited rainfall or snowmelt
- ICCC explored options to manage dry year risk in the context of 100% renewable electricity
- The ICCC analysed the relative marginal emissions abatement costs of a range of renewable generation and storage options
- It found that pumped hydro storage had the lowest marginal emissions abatement cost at $250 tonnes of carbon dioxide equivalent
- While the ICCC found that no single solution stood out as a replacement for natural gas, it recommended investigating the potential for pumped hydro storage further

Dry year risk will remain and probably grow

- Our hydro inflows have historically varied by about 5 TWh between average and driest years
- This compares with about 40+ TWh annual generation
- We expect this hydro inflow variability to increase with climate change
- We expect variability of total energy inflow to increase with more intermittent wind and solar
  - Most of this increase in variability from intermittency will be short term
  - Some will be long term
- Dry year → Prolonged dry, calm, cloudy periods
- Basic assumption of NZ Battery Project:
  - The Project does not needs to find a solution to meeting the expected increase in demand due to electrification (i.e. generators will add the TWh necessary to continue to meet demand in average inflow years)
  - The Project needs to find a solution to managing the security of supply risk resulting from the uncertainty and variability of prolonged dry, calm, cloudy periods



Project focus, and some terminology

Hours | Days | Weeks | Months | Seasons | Years

Energy balance variability	Intermittency of demand, wind, solar and run-of river hydro dominates		Intermittency of storable hydro inflows (rainfall and snowmelt) dominate
Keeping the lights on	Security (capacity)		Security of supply (energy)
NZ Battery focus?	Short-term Meeting winter peaks, firming wind and solar A possible 'value add' for an NZ Battery solution		Long-term Dry years ⇨ prolonged dry, calm, cloudy periods The focus for NZ Battery
Types of 'demand response'	Short-term load shifting to avoid high price or obtain payment	Reduce output or suspend operations to avoid sustained high prices	Contracted and compensated load reduction Call for savings Rolling outages

Decarbonising electricity by 2030

- The Government has committed to a goal of 100 per cent renewable electricity by 2030
- This is part of the effort to meet New Zealand's climate change objectives and move to a low emissions future
- The NZ Battery Project is one of a number of initiatives aimed at reducing emissions and increasing renewable energy
- That means that while the NZ Battery Project is an important part of the transition, it is not the only part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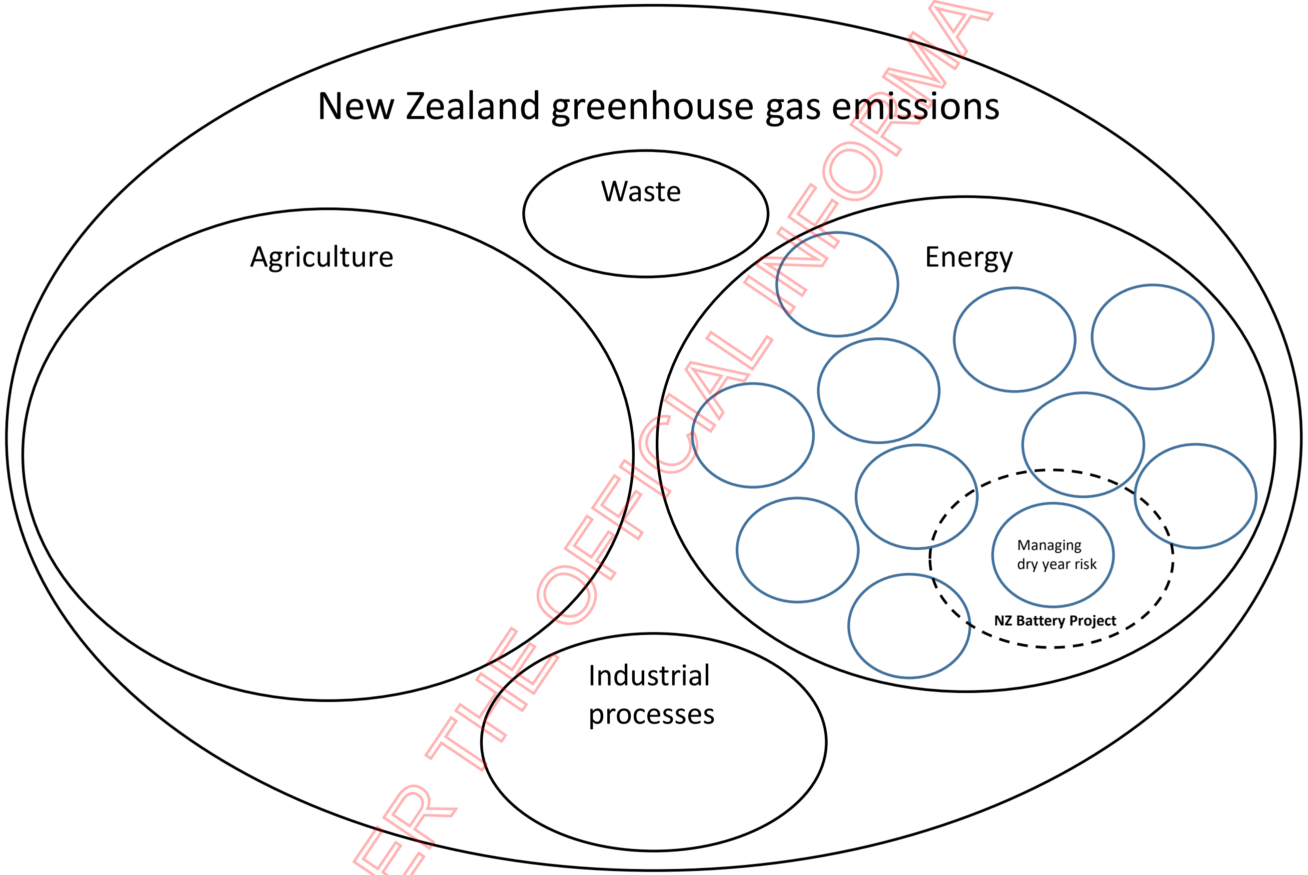
POLITICS / ELECTION 2020

Labour promises 100% renewable electricity generation by 2030

5:27 pm on 10 September 2020 Share this

The Labour Party is promising to bring forward its goal of 100 percent renewable electricity generation by five years to 2030.

NZ Battery Project – part of a wider climate change response



Key questions for the NZ Battery Project

How can New Zealand best manage dry year risk in a 100 per cent renewable electricity system?

How would a dry year solution support achieving a 100 per cent renewable electricity system by 2030?

Objectives of the NZ Battery Project

Purpose and objective of the NZ Battery Project

The Government has initiated the NZ Battery Project to:

Find the best option, or combination of options, to manage dry year risk in New Zealand and support the move to 100% renewable electricity.

Provide comprehensive advice on the technical, environmental, social and commercial feasibility of a range of dry year risk options. These include pumped hydro at Lake Onslow, pumped hydro elsewhere, and other potential energy generation and storage projects.

Timeline

PHASE 1
Feasibility study
→ April/May 2022

A feasibility study identifying the best option or options to address dry year risk

Includes early field work (subject to procurement)

PHASE 2
Detailed business case
→ Late 2023/early 2024*

Further investigations, detailed engineering design and field work, leading to a final investment decision

PHASE 3
Implementation
Early 2024* onwards

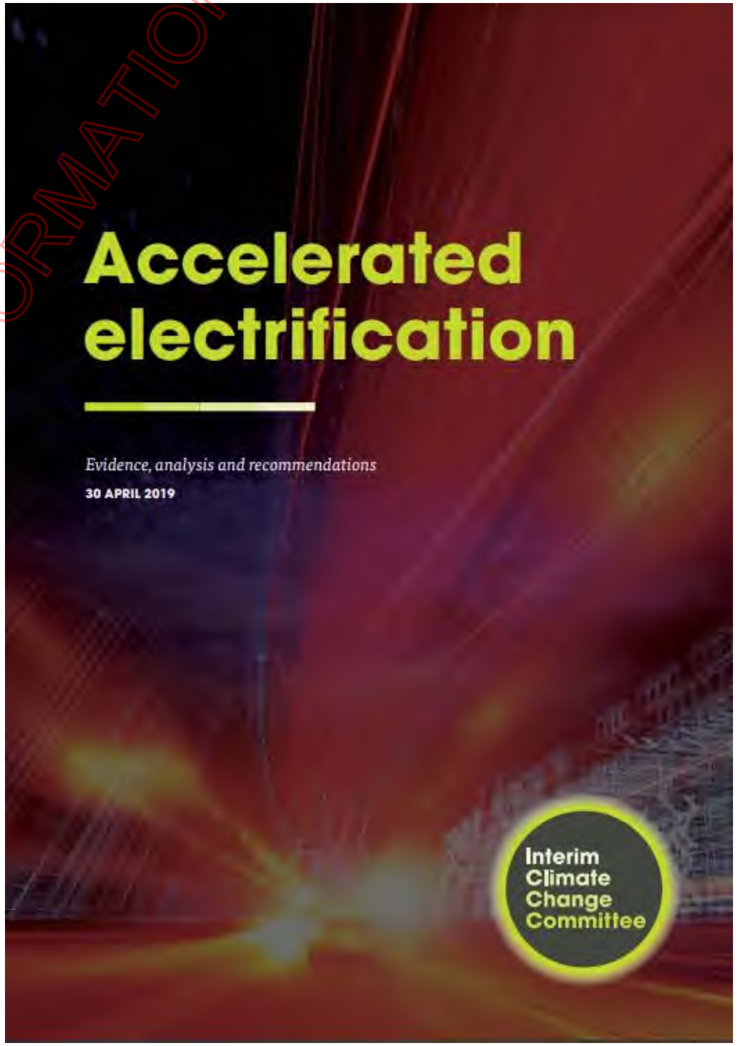
Contracting and construction

**Depending on chosen option or options*

= Key Cabinet decision point

NZ Battery Project establishment

- ICCC report April 2019
- NZ Battery first announced late July 2020
- Cabinet paper September 2020 – criteria agreed
- Project team established December 2020
- Andrew Millar arrived January 2021
- February – MOU signed DOC for Lake Onslow
- Further procurement from February onwards
- March visited landowners and Te Rūnanga ō Ōtakou
- April 2021 – TRG established
- We sit within ERM, BRM – MBIE energy policy
- Energy Project and Programmes is a new part of ERM



Phase 1 – Feasibility Study

MAHI TAHI
BETTER TOGETHER

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Timeline

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= Key Cabinet decision point

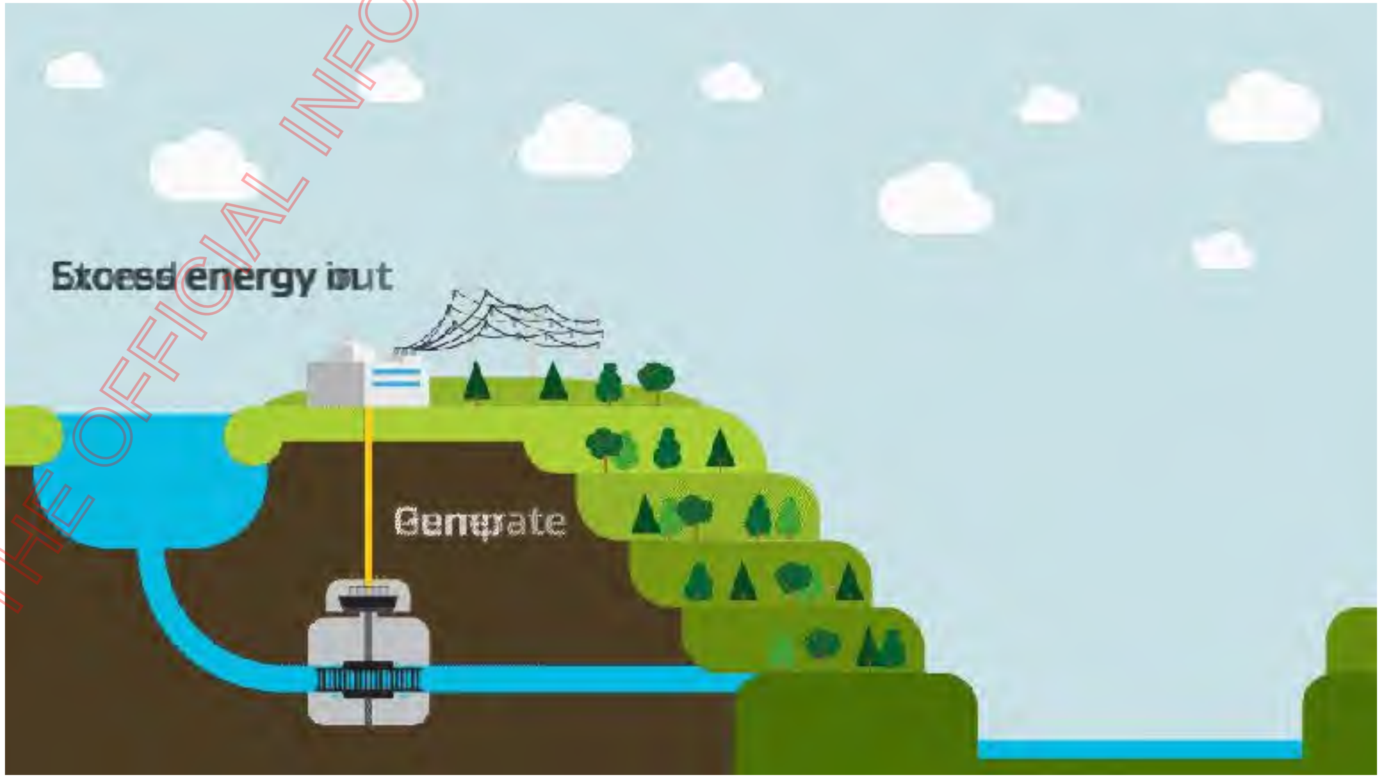
Feasibility study - objectives

- The purpose of the Phase 1 feasibility study is to identify whether there is a preferred renewable energy generation or storage option (or combination of options) for New Zealand to address ‘dry year risk’
- The feasibility study will also make a recommendation whether a preferred option (or options) should proceed to a more detailed business case in Phase 2
- The Phase 2 business case will build on the findings of the feasibility study

Phase 1 Feasibility study

The Phase 1 feasibility study will:

- outline the extent of dry year risk in the context of 100% renewable electricity
- describe the range of viable options to address dry year risk (including pumped hydro at Lake Onslow, pumped hydro elsewhere and other technologies)
- assess and compare the feasibility of these options
- explore how these options may impact on the electricity system
- recommend which option or options should proceed to a more detailed business case



How are we thinking about comparing options?

Cabinet requires that any proposal or group of proposals will be assessed against its ability to:

- provide at least [5,000 GWh]* of energy storage or equivalent energy supply flexibility
- provide significant levels of employment as part of post COVID-19 recovery
- 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
- be practical and feasible
- take into account wider social, cultural and environmental factors

** magnitude to be investigated as part of the project*

Security of supply

Social, cultural, environmental

Renewable

Job creating

Affordable

Practical

Terms of reference and project admin

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NZ Battery Project

Technical Reference Group Terms of Reference

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
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TRG purpose

- The purpose of the NZ Battery Project Technical Reference Group is to provide technical expertise and sector knowledge relating to the quantitative analysis MBIE is undertaking, including modelling, and to advise on other relevant social, cultural or environmental issues that may be bought to the Group and lie within its expertise.
- The Group is advisory – its main role is to provide specialist input and insight to the project team as they work through options and develop recommendations. Project governance and assurance will be carried out by different groups following the TRG's input.
- TRG members are expected to review and test the assumptions that underlie MBIE's quantitative analysis. It is worth noting that consensus is not an objective of the TRG.
- Members are required to act in good faith, confidentially, independently and with integrity.

Confidentiality and independence

- The intent in creating a Technical Reference Group is that members use their collective knowledge and experience when considering the matters before them.
- This means members must keep in mind that:
  - They have been appointed for their knowledge and experience as well as their ability to participate constructively in group meetings.
  - They have been appointed to act in their personal capacity (not as representatives of organisations) and must provide independent advice as a group, even though they need not be independent persons individually.
  - This means members are expected to act in the best interests of all stakeholders of the NZ Battery Project, irrespective of whether this aligns with the interests of any organisation he or she may be associated with.
  - The group is expected to reconcile divergent views and interests, both in the group and among wider stakeholders in a manner that achieves wider stakeholder 'buy in'. This requires a serious commitment by all members to understand alternative views and find workable solutions to what is a highly technical problem.
- Members are required to act independently and with integrity. All group proceedings are confidential to MBIE. All information will remain subject to the Official Information Act 1982. Any public statements will be made by MBIE.

Conflicts of interest

- Given the expertise for which members have been appointed to the group, conflicts of interest may arise from time to time.
- If a member becomes aware of a situation where they have or may be perceived to have a conflict of interest with a matter the group is considering they should disclose this to the Facilitator and the MBIE Secretariat.
- If the matter meets the conflict of interest disclosure rules in sections 62 to 72 of the Crown Entities Act 2004, the Secretariat will facilitate the member making a formal disclosure and management plan for managing the conflict.

Administration for the TRG

- Please can you send all your travel requests related to the TRG through to Linda Avlonitis Linda.Avlonitis2@mbie.govt.nz
- Ensure you keep the taxi chits for future travel purposes.
- All invoices should be emailed to mbie.invoices@mbie.govt.nz with a copy to Linda.Avlonitis2@mbie.govt.nz
- Please can you include all the information below on the invoice:
  - addressed to 'Ministry of Business, Innovation and Employment' (not MBIE)
  - include the name of the MBIE contact person (Andrew Millar)
  - include your organisation's name and GST number (if applicable)
  - include the words 'tax invoice'
  - include an invoice number
  - include Our Ref: **TRG Meeting 11 May**
  - include a breakdown of the fund(s) being charged and a brief description of the activity
- Note: If you are not set up as a supplier in the system, please can you supply proof of the bank account on your invoice and send this to Linda so she can get you set up in the system first. The proof can be a copy bank statement or letter.

How the group's going to run

- Primary objective is to help the MBIE project team in their work
  - Attempt to minimise readings between meetings
  - Will be opportunities for deep-dive sessions for members with a keen interest in specific topics and studies

- Useful experience from IGPS Climate Change roundtable process
  - Secetariat's written summaries
  - s 9(2)(g)(i)

s 9(2)(g)(i)

Morning tea break

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Project Process – Timeline of Phase 1

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Project Process – Timeline of Phase 1

Phase 1 key workstreams – work underway

Lake Onslow pumped hydro

Is a pumped hydro scheme at Lake Onslow technically, economically, commercially, and environmentally feasible?

Can any adverse impacts or risks be effectively managed or mitigated?

Other pumped hydro

Are there viable locations for pumped hydro outside of Lake Onslow?

What about our existing hydro lakes?

Other comparators

What is the range of other options?

Which options have the potential to effectively manage or mitigate dry year risk?

Which options are the most feasible?

Market interactions and implications

What impact will an NZ Battery have on the current electricity market?

What ownership and operational model should the NZ battery have?

Phase 1 key workstreams – work underway

Lake Onslow Pumped Hydro

Environmental assessment: desktop work **underway**, fieldwork **planned**

Hydrological and ecological modelling: **underway**

Engineering and geotechnical investigation: desktop and field work **planned**

Environmental assessment (**DOC**)

Lake ecology assessment (**NIWA /Cawthron/Otago Uni**)

Hydrology (**NIWA**)

Transmission implications (**Transpower**)

Engineering and geotechnical study

Phase 1 key workstreams – work underway

Other Pumped Hydro

Identify other pumped hydro options: **underway**

Assessment and evaluation of other pumped hydro options: **planned**

GIS scan large-scale pumped hydro sites (**NIWA**)

Phase 1 key workstreams – work underway

Other Comparators

Long-listing of comparator technologies: **underway**

Short listing: **planned**

Detailed studies of viable alternatives: **planned**

Identifying further information required and commissioning necessary investigations

After long list evaluation, detailed work on shortlisted options will be commissioned

Phase 1 key workstreams – work underway

Market interactions and implications

Determining the size of the dry year problem: **underway**

Potential electricity market impacts of pumped hydro at Lake Onslow: **underway**

Potential electricity market impacts of other technologies: **planned**

Ownership and operation: **planned**

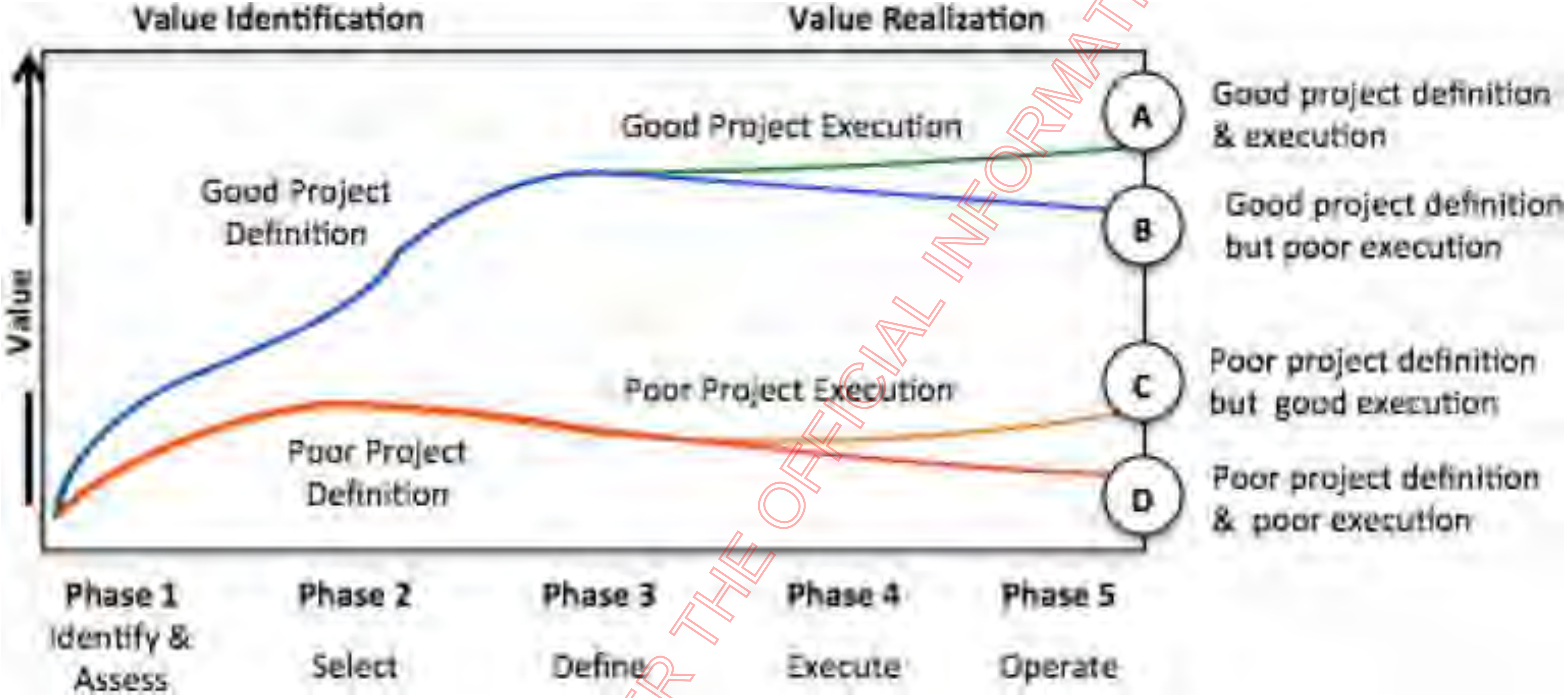
Size of the NZ Battery solution analysis (**Concept**)

Lake Onslow pumped hydro market interactions (**Sapere**)

Successful projects – Sydney Opera House?

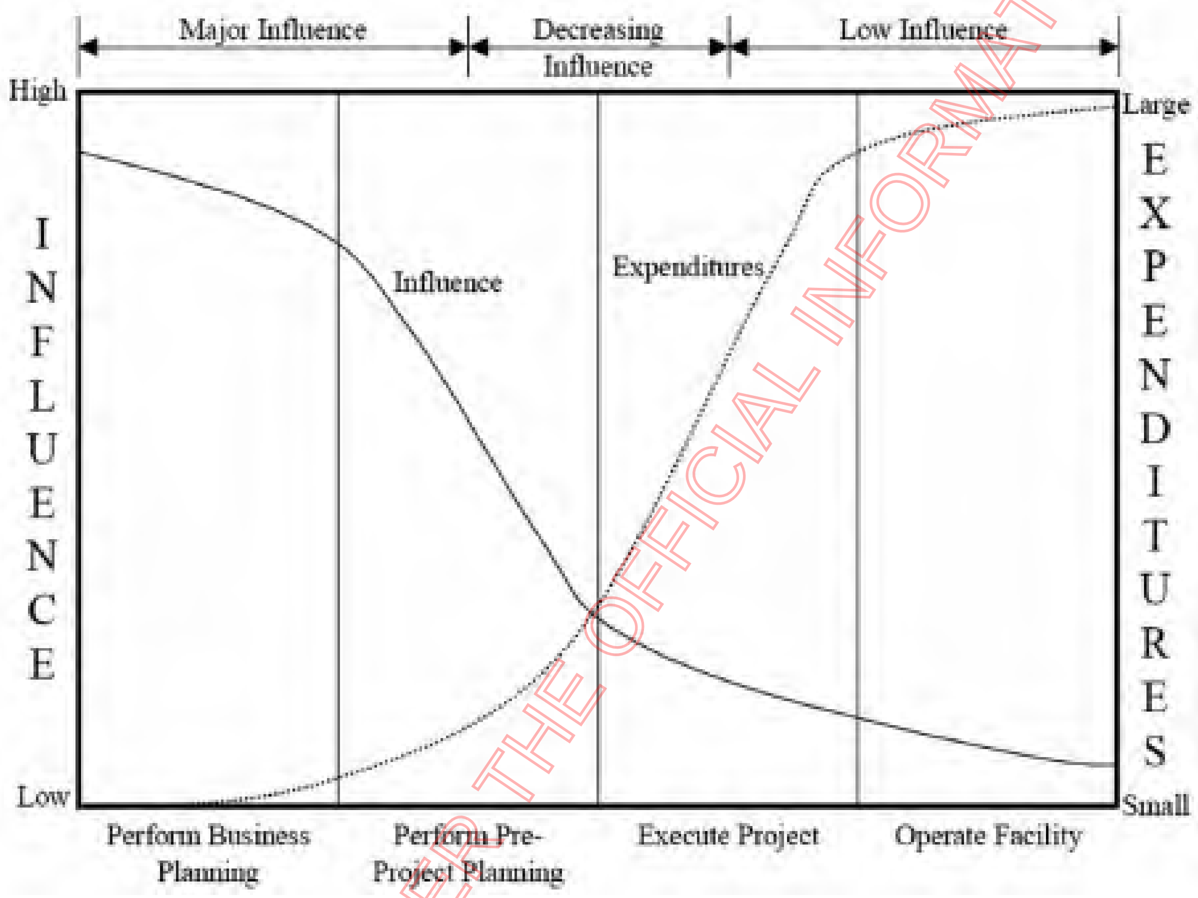
- Original estimate in 1957 was $7 million
- Original completion date was 26 January 1963
- Actual cost to completion $102 million
- Actual completion date 20 October 1973
- 10 years late, 14 times over budget
- Architect resigned in 1966 and his name was not mentioned at the public opening ceremony, nor was he invited
- Many changes to the original design took place at the request of the customer (Australian government)
- Considerable pressures from Australian government to make changes in layout and finishes, start construction with incomplete designs, reduce front end design, etc.

Value is created at the start of projects and realised at the end



Impact on value with early decisions (Parth, F. R., 2015).

Hence the importance of opportunity framing



Influence and Expenditures Curve for Project Life Cycles (Gibson et al. 1995)

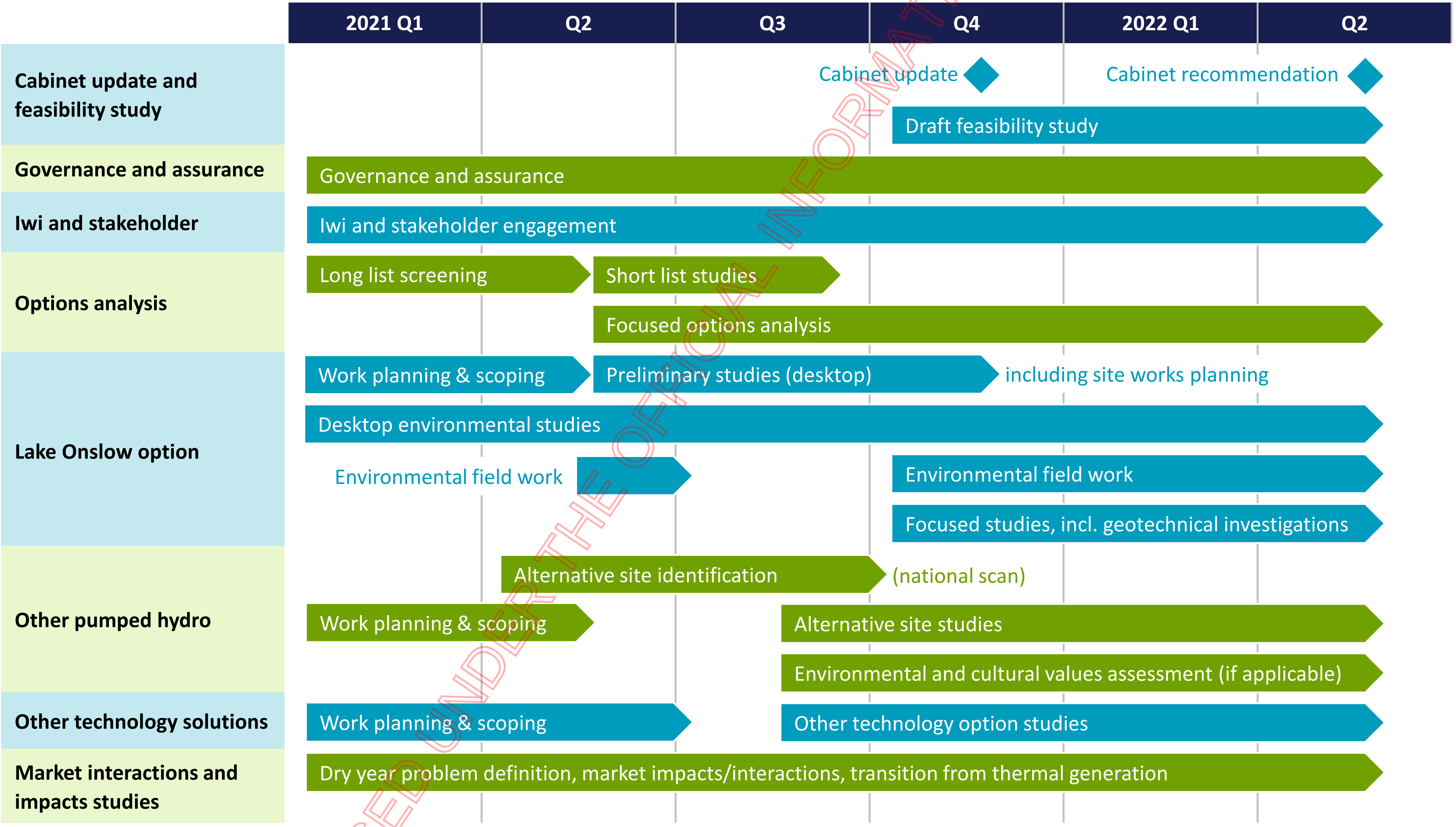
NZ Battery Project - Opportunity Statement

Providing a solution to New Zealand's dry year problem, enabling reliable, affordable and 100% renewable electricity generation from 2030

Value drivers

1. Optimum storage and generation solution
2. Partner and stakeholder buy in
3. Schedule (enabling 2030 timeline)
4. Capital cost of solution
5. Certainty and confidence of electricity industry

New Zealand Battery Project indicative timeline: Phase 1



Long-list of options

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NZ Battery Analysis

Long-list of options evaluation

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NZ Battery's long-list of options

NZ Battery is considering all options to meet the need for low energy period security of supply in a 100% renewable electricity system from 2030

Onslow pumped hydro energy storage is one option

Best solution may be a combination of smaller options

SQ Status quo NZEM & SOS & ETS

Reduce electricity demand

- D1 **Energy efficiency**
- D2 **Demand response**
- D3 **Large-scale load reduction (ad hoc)**
- D4 **Large-scale load reduction (planned)**

Electrical plant can reduce load

Increase hydro storage

- S1 **Increase hydro storage**
- S2 **Relax hydro constraints**
- S3 **Improve hydro management**

Develop electrically-charged storage

- E1 **Onslow pumped hydro scheme**
- E2 **Other pumped hydro storage**
- E3 **Other gravitat-ional storage**
- E4 **Compressed air storage**
- E5 **Liquid air storage**
- E6 **Flow battery storage**
- E7 **Electric battery storage**
- E8 **Flywheel storage**

Draft for TRG comment / discussion?

Green energy vector

(e.g. Hydrogen H_2)

- H1 **H_2 production with subsurface storage**
- H2 **H_2 production with carrier storage**

Bioenergy

- B1 **Biomass production and storage**
- B2 **Biogas production and storage**
- B3 **Liquid biofuel production and storage**

Import renewable energy

- A1 **Connect to Australia's electricity grid**
- H3 **H_2 import with buffer storage**
- B4 **Bioenergy import with buffer storage**

Build or modify electricity generation

- G1 **Baseload or inflexible generation**
- G2 **Intermittent renewable generation**
- G3 **Fossil fuel generation without CCS**
- G4 **Fossil fuel generation with CCS**
- G5 **Flexible geothermal generation**
- Flexible H2-fuelled generation
- Flexible bio-fuelled generation

Lunch break

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Evaluating and Short listing options

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NZ Battery Analysis

Evaluating and short-listing options

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Long-list of options evaluation criteria

Cabinet requires that any proposal or group of proposals will be assessed against its ability to:

- provide at least [5,000 GWh]* of energy storage or equivalent energy supply flexibility
- provide significant levels of employment as part of post COVID-19 recovery
- 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
- be practical and feasible
- take into account wider social, cultural and environmental factors

** magnitude to be investigated as part of the project*

For the purposes of filtering the long-listed options to a short list, we have interpreted these requirements into a set of evaluation criteria:

- Security of supply
- Social, cultural, environmental
- Renewable
- Job creating
- Affordable
- Practical

These are explained on the next slide

We expect to refine these criteria when we need to select a preferred option from the short list

Evaluation criteria: Long list to short list

Security of supply

The ideal solution is large and reliable enough to guarantee economic security of supply in prolonged in dry, calm, cloudy periods:

- solution could be one large or multiple smaller schemes
- capacity, efficiency, storage duration, resilience and location are all important

Renewable

Meets climate change objectives

The ideal solution helps New Zealand reach its climate change targets:

- 100% renewable electricity generation by 2030
- net-zero carbon emissions by 2050

Minimises emissions

The ideal solution:

- uses 100% renewable, sustainable energy
- minimises CO_2e emissions (including embedded emissions) in construction and operation
- supports or contributes to decarbonisation
- does not shift emissions outside NZ

Social, cultural, environmental

Treaty Partners

The ideal solution furthers the aspirations of the Crown's Treaty Partners

Community

The ideal solution serves the social needs of the local community over the short, medium and long-term

Environmental

The ideal solution avoids, remedies, mitigates or offsets localised environmental effects

Affordable

Reduces prices

The ideal solution reduces wholesale electricity prices, consistent with declining costs of new renewable generation

Retain options for the future

The ideal solution enables the approach to evolve, creating option value and a least regrets pathway

Maximises value

The ideal solution maximises cost-benefit across a range of dimensions:

- capex and opex
- transmission implications
- generation over-build implications
- maximises use of existing assets
- adds value across our economy

Private investment

The ideal solution provides incentives for private investment in:

- inter-seasonal and inter-year storage
- renewable electricity generation

Job creating

The ideal solution:

- provides significant employment for New Zealanders, in its construction then ongoing operation
- provides significant direct and indirect regional employment
- uses existing labour force and develops technical skills

Practical

Policy alignment

The ideal solution will be consistent with NZ's:

- international climate and conservation obligations
- energy, resource management, conservation and climate policy objectives

Dependable technology

The ideal solution uses technology that is:

- proven and commercialised at the required scale
- given the timeframe expected of its deployment

Constructible and operable

The ideal solution can be commissioned and operated with manageable time and costs risks including:

- ability to mitigate risks early
- efficiency and speed of construction
- ability to be implemented in a stage-wise process
- any benefits of modularity, portability and scalability
- a simple value and supply chain

Resilient

The ideal solution will be resilient in operation to the risks of:

- climate change
- natural disasters
- single points of failure
- the existence, liquidity and price of international markets

Safe

The ideal solution will be zero harm

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

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NZ Battery Analysis – Problem 1

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NZ Battery analysis

Preliminary results for Problem 1: Size of NZ Battery

Background and context

- Concept Consulting/John Culy Consulting commissioned to look at the 'size' of the dry year problem in late 2020 by MBIE
- Final draft report last week – hot off the press
- Experienced electricity economics consultancies – the other is Sapere....
- Modelling – all models 'wrong' but some are useful
- Very powerful forecasting tools for considering scenarios – likely outcomes of pulling different levers
- We must always keep in mind their assumptions
- Need more time to understand results... welcome feedback from TRG members who want to study them...

Background and context

- The dry year problem is **no magic number** e.g. '5 TWh'
- Electricity systems built with an over/under investment tradeoff...must always balance supply and demand
- Build too much = you 'spill' too much = wind blows but wind isn't dispatched = water goes down spillways... sunny day but solar isn't needed at that locality... and that investment costs $$$$
- If you don’t build enough at times your supply runs low = you run the risk of having to shed load too often....
- Economically – want to optimise generation use = you want 'most plant running most of the time'
- So... model **won't spit out magic number** – instead it will say if you build this size plant in this location ... then by this date the economic benefits to the system = $$$$

Problem 1: What is the size of NZ Battery solution?

What is the size of the NZ Battery required to solve the dry year problem in a 100% renewable future and enable decarbonisation via accelerated electrification?

- A range of NZ Battery solutions are analysed by varying the:
    - size of the energy storage – the 'tank' in TWh
    - size of the pump/generate capacity – the 'tap' in MW
    - location – South Island, North Island or a combination of both
- Rather than determining the preferred solution:
    - For each solution an economic analysis was performed to estimate the 'gross benefits'

Modelling approach & key assumptions

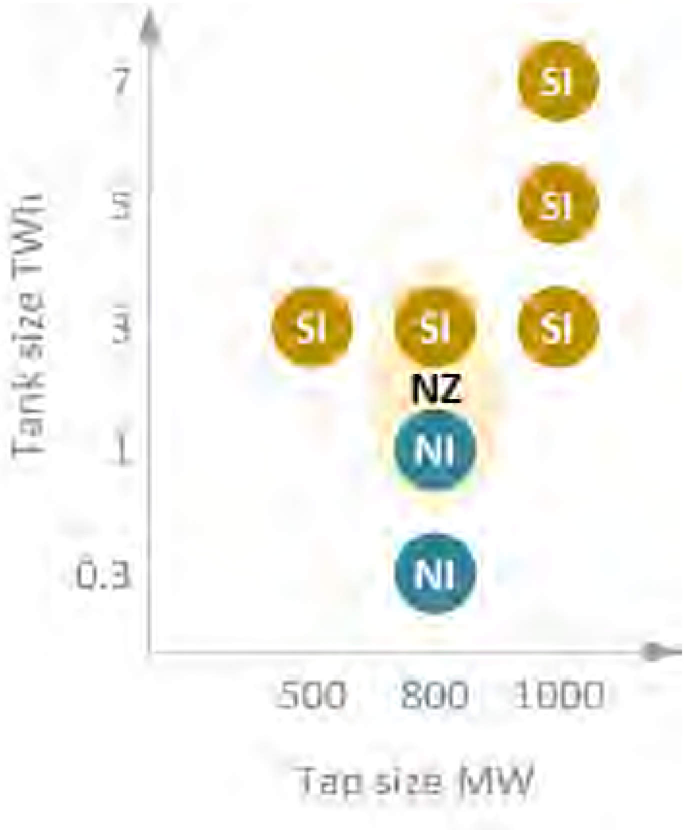
- Value of adding a NZ Battery is estimated on a 'gross benefits'

- 'Gross benefits' = the change in total 'system cost' enabled by each option
- 'System costs' = include capital costs for new generation, fuel and carbon costs, shortage costs

- Two scenarios considered:
  - 100% renewable generation – no thermal generation at all, limited new geothermal, unlimited short-term batteries (hours of operation), and unlimited wind and solar available
  - Green thermal – all baseload and co-gen fossil-fired generation retired or re-purposed, some thermal plants (as well as the geothermal) remaining, fuelled from renewable sources e.g. biomass, biogas, green hydrogen…

Modelling approach & key assumptions

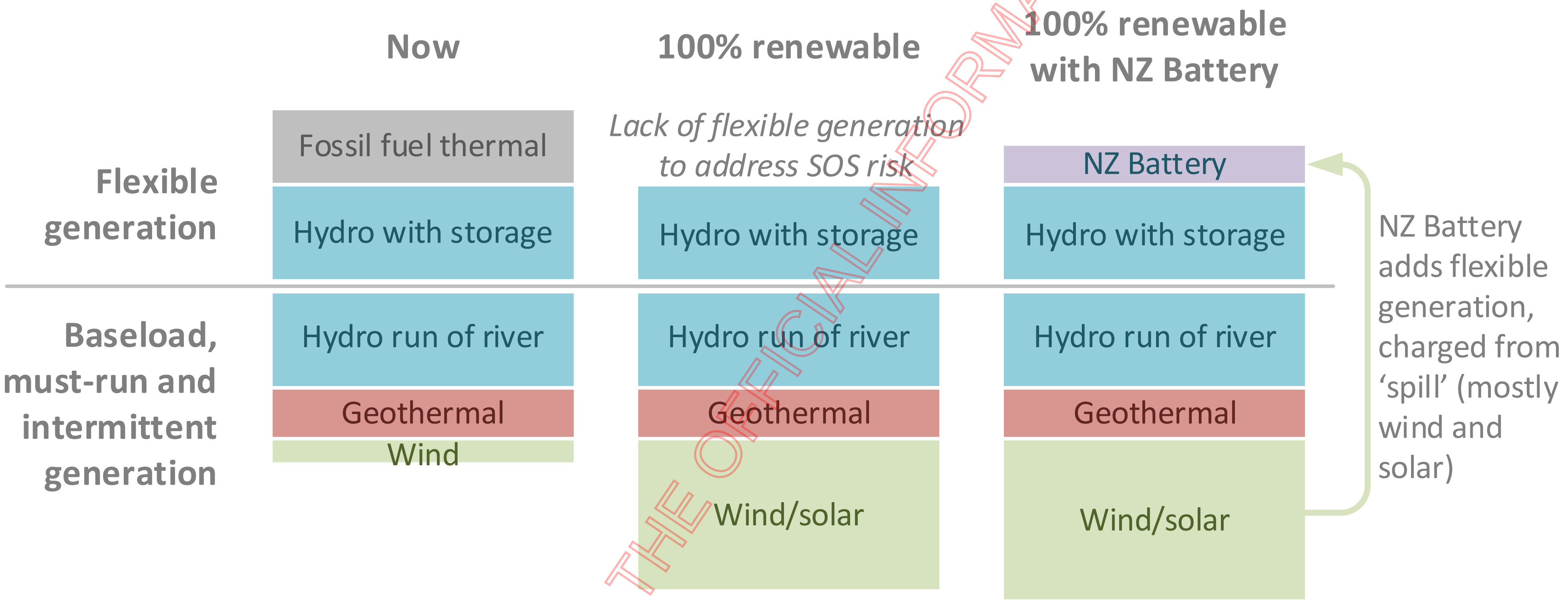
- Simulates operation of the electricity market
- Simplified representation of the electricity system, generation in each island connected by the HVDC link, includes major hydro storage reservoirs
- Uses 80+ weather years – consisting of historical range of hydro inflows and wind flows
- Three years simulated for the post-2030 era:
    - **2035** – de-carbonisation of electricity system in progress, NZ Battery operational
    - **2050** – de-carbonisation of NZ economy achieved
    - **2065** – the long term, given potential long lifetime of NZ Battery
- Eight alternative NZ Battery options considered:
    - 5 South Island, 2 North Island, 1 combination



Key findings – NZ Battery:

1. **Replaces and adds *flexibility***
   - Replaces the flexibility currently provided by coal and gas
   - Saves significant amounts of spill, even with thermals present
2. **Adds *value* in many ways**
   - All options and combinations add significant value
   - Also valuable with green thermals, but less so
   - Adds value across the sector
   - Adds more value over time (bigger the better – up to a point)
3. ***Location* is important**
   - North and South Island battery is valuable
   - There is value in a North Island battery
   - HVDC limits a South Island battery size

1. Replaces *flexibility* – displaces coal & gas



With more wind and solar, security of supply (SOS) risk evolves from dry years to prolonged dry, calm, cloudy periods

1. Adds *flexibility* – reduces spill in a 100% renewable world

- Overbuilding solar and wind to get you through a dry year is wasteful..
- Not only means you spill = let water go down spillways or don't run your wind farms even when windy....
- It also isn't enough to get you through a dry year...

Adding a 5TWh 'big tank' /1.0GW 'big tap' South Island battery reduces both spill and shortage

- Because the NZ Battery:
  - moves energy within and between years;
    - Between year for dry years (e.g. from 2020 to 2021)
    - between seasons (from summer to winter)
  - provides peaking capacity (ramps up with demand)

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2. Adds more value if bigger, especially over time

- In three ways:
  - reduces 'spill' by capturing and storing more of it....
  - reduces need for overbuild
  - covers dry year shortage *and* firms increased intermittency from the coming build of much more wind and solar

- But, this is before factoring in the NZ Battery costs:
  - value in increasing SI battery size beyond 5 TWh storage tails off....
  - larger sizes may only be economic if there are marked economies of scale in construction

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Key findings – NZ Battery:

1. Replaces and adds flexibility

- Replaces the flexibility currently provided by thermals
- Saves significant amounts of spill, even with thermals present

2. Adds value in many ways

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- Adds more value over time (bigger the better – up to a point)

3. Location is important

- North and South Island battery is valuable
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Afternoon tea break

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9.15	Project problem definition and background information	*Background to the project – ICCC advice, links to wider government policy around energy decarbonisation and security*
10.15	Terms of Reference and project admin	*What the group is – and isn't - and how it's going to work.*
10.45	Morning tea	
11.15	Project Process – Timeline of Phase 1	*Project planning and inception approach, work plan for the first 18 months of the project*
12.00	Long-list of options	*Framework including every practical technology which could provide dry year security in a 100% renewable New Zealand electricity system*
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4.00	Market modelling draft results and conclusions - Market interaction	*Results of early modelling work on how the NZ Battery could interact with the existing wholesale spot market and scenarios on how market outcomes would differ, assumptions and related implications for further analysis.*
4.45	Questions and Answers, any other business	*Feedback on the day and thoughts about future sessions.* *Confirm date of next meeting*

NZ Battery Analysis – Problem 2

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8.45	Introductions	
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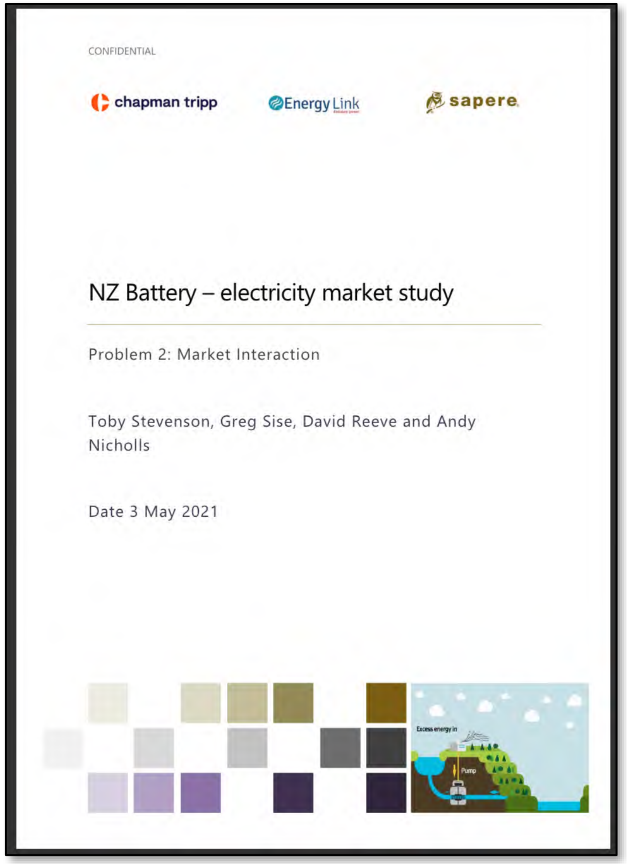
NZ Battery analysis

Preliminary results for Problem 2: Market Interaction

Our tentative takeaways from the early “market interaction” market modelling work

- It is <u>possible</u> to run a large single-site NZ Battery like Onslow in the NZ Electricity market in a way that maintains incentives for new investment in renewable generation
    - Simple cost recovery and offer strategy results in market prices that are higher than the long-run costs of wind and solar between 2030 and 2050
- Market modelling results are very sensitive to the assumptions we make about how the NZ Battery’s capital cost is recovered and the rules that it follows to offer into the market
- The wholesale spot price of electricity will be more volatile when fossil-fuelled generation is decommissioned than it is today which will make average prices for wind and solar lower than the market average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NZ Battery – electricity market study

Problem 2: Market Interaction

Toby Stevenson, Greg Sise, David Reeve and Andy Nicholls

Date 3 May 2021

Problem 2: NZ Battery Market Interaction

- How will a NZ Battery solution interact with the current electricity market in a 100% renewable generation world?
  - The New Zealand electricity market can be described as a security constrained energy only market.
  - The modelling carried out here simulates one potential NZ Battery solution (Onslow) in the NZ electricity market

- Simulating the NZ Battery solution interactions within the market allow an assessment of;
  - Price discovery.
  - Solution of dry year problem without fossil fuelled thermal generation.
  - Viability of investment in new renewable generation options required to replace retiring thermal generators and meet increased demand arising from accelerating electrification.
  - Ability to ensure a continuing secure electricity supply – ability of generation to meet demand in real time – minute by minute.

Modelling approach and key assumptions

- Market model
  - Simulates operation of the New Zealand electricity market
  - Has a comprehensive representation of New Zealand electricity system, including hydro, geothermal, wind and solar operating modes, and a detailed transmission grid
  - Simulations use 89 weather years – consisting of historical range of hydro inflows and wind flows
- Two future years modelled
  - **2030** – 100% renewable generation – all fossil fuelled thermals retired & replaced by new generation consisting of either intermittent wind & solar or inflexible geothermal.
  - **2050** – decarbonisation by 2050 leads to increased electricity demand – accelerated electrification requiring more renewable generation.
- New entry revenue adequate with operation of NZ Battery?
  - New generation options and NZ Battery assumed to put offers into electricity market based on short run costs and opportunity value – does this result in clearing prices sufficient to justify investment?

Key findings

- The modelled NZ Battery (South Island, 5 TWh, 1000 MW) can:
  - provide **security of supply** in a 100% renewable electricity system
  - contribute substantially to preserving **security**
  - provide standby reserve capacity
  - reduce prices and price volatility
  - achieve positive net revenue on average

- Other observations include:
  - many permutations of NZ Battery arrangements possible
  - North Island solutions add value

Security of supply

- Long-term
- dry years ⇨ prolonged dry, calm, cloudy periods
- the focus for NZ Battery

Security

- short-term
- meeting winter peaks, firming wind and solar
- a possible 'value add' for an NZ Battery solution

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NZ Battery can provide standby reserve capacity

- The fossil-fuelled thermal fleet currently adds to security in the form of actual generation, but also in the form of 'standby reserves'
- These are plant that are offered but not dispatched, and so available as short-notice backup in case of another generation plant outage
- The current market structure may not deliver sufficient spare capacity to ensure there is always enough standby reserve capacity, so an NZ Battery could provide significant value here too

NZ Battery can reduce prices and price volatility

- With 100 per cent renewables and no Onslow, average prices could be similar to now but volatility likely to be much higher
    - more periods of low prices e.g. when price set by wind offering at short run cost
    - less frequent periods of high prices, set by scarcity values
- Adding Onslow reduces prices and price volatility
- However, by 2050 in the North Island, price pressure and volatility is evident where meeting peak demand presents significant challenges
- These observations based on the modelling assumption of operating Onslow:
    - s 9(2)(f)(iv) [redacted]
    - [redacted]
- There are other operating modes, leaving considerable room for choices to be made about how Onslow could set prices

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North island solutions add value

- In 2030, the HVDC link daily average transfers are well within the transfer capacity in either direction, Northwards and Southwards.
  - However there are times when daily maximum HVDC transfer Northwards is at capacity (1400MW), and …
  - Southward daily maximum transfers can be at capacity (950MW).
- In 2050 HVDC transfers increase but daily average transfers remain within limits.
  - Again though, maximum daily transfers are at capacity more often in winter,
  - and, Southwards maximum transfers are also more likely to be at capacity.
- This has a modest affect on NZ Battery's ability to provide dry year security of supply.
- But, it compromises the NZ Battery's ability to provide security and standby reserve to the North Island
- South flows is also often constrained, reducing NZ Battery's ability to use all available NI intermittent 'spill'
- Constraints on the HVDC also cause persistent price separation between the islands, separating of the national market into South and North Island markets
- The value of these imbalances indicate the value of expanding the HVDC link or significant amounts of storage in the North Island

Key findings (repeat)

- The modelled NZ Battery (South Island, 5 TWh, 1000 MW) can:
  - provide security of supply in a 100% renewable electricity system
  - contribute substantially to preserving security
  - provide standby reserve capacity
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Feedback on the day, Q&A and any other business

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Next steps and future meeting dates

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MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Future meetings

Late June - Half day

- Q&A Pre-reading work
- Stakeholder & iwi update
- Project work plan & process update
- Onslow work plan
- Onslow environmental scope
- NIWA draft results
- Other pumped hydro sites and plan
- Other tech plan
- Market impact results and plan

Mid August - Half day

- Q&A Pre-reading work
- Stakeholder & iwi update
- Project work plan & process update
- Options analysis update
- Onslow early results
- Other pumped hydro early results
- Other tech early results
- Draft battery operating model and cost recovery constraints, options and recommendations
- Plan for transition from thermal

Future meetings contd.

Late September - Half day

- Q&A pre-reading work
- Stakeholder & iwi update
- Project work plan & process update
- Options assessment
- Updates on workstreams

Early November - Half day

- Q&A pre-reading work
- Stakeholder & iwi update
- Project work plan & process update
- New generation investment and transition from thermal results

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NZ Battery Project

Technical Reference Group Meeting 2

24 June 2021 – KPMG, Wellington

MAHI TAHI
BETTER TOGETHER

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Today's programme

No	Time	Item	Lead
1.	**9.15am**	Arrival Tea/ Coffee and morning tea	
2.	9.30am – 9.40am	Welcome and introductions	Adrian Macey
3.	9.40am – 10.30am	NZ Battery Project news • Overall update • Last 6 weeks • Next 6 weeks	Adrian Tweeddale
4.	**10.30am – 10.45am**	**Coffee/ Tea break**	
5.	10.45am – 11.30am	Non-Hydro approaches • Bubble diagram • Bio-fuels • Hydrogen	Bridget Moon
6.	11.30am – 12.00pm	NIWA update GIS Scan – reporting on other potential pumped hydro locations	Malcolm and Carl
7.	**12.00pm – 12.30pm**	**Lunch**	
8.	12.30pm – 1.00pm	Stakeholder update	Maria and Carl
9.	1.00pm – 2.15pm	NZ Battery Operational Governance Primer • Ownership • Reserve energy case study	Conrad and Bridget
10.	**2.15pm – 2.30pm**	**Coffee / Tea break**	
11.	2.30pm - 3.30pm	DOC update • Why are they involved? • Project Impact • What is covered in the report and what is not included • Land Ownership • Outline of the conservation values at site together with analysis on what the losses and gains in those values might be.	s 9(2)(a) [redacted]
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NZ Battery Project News

For this session:

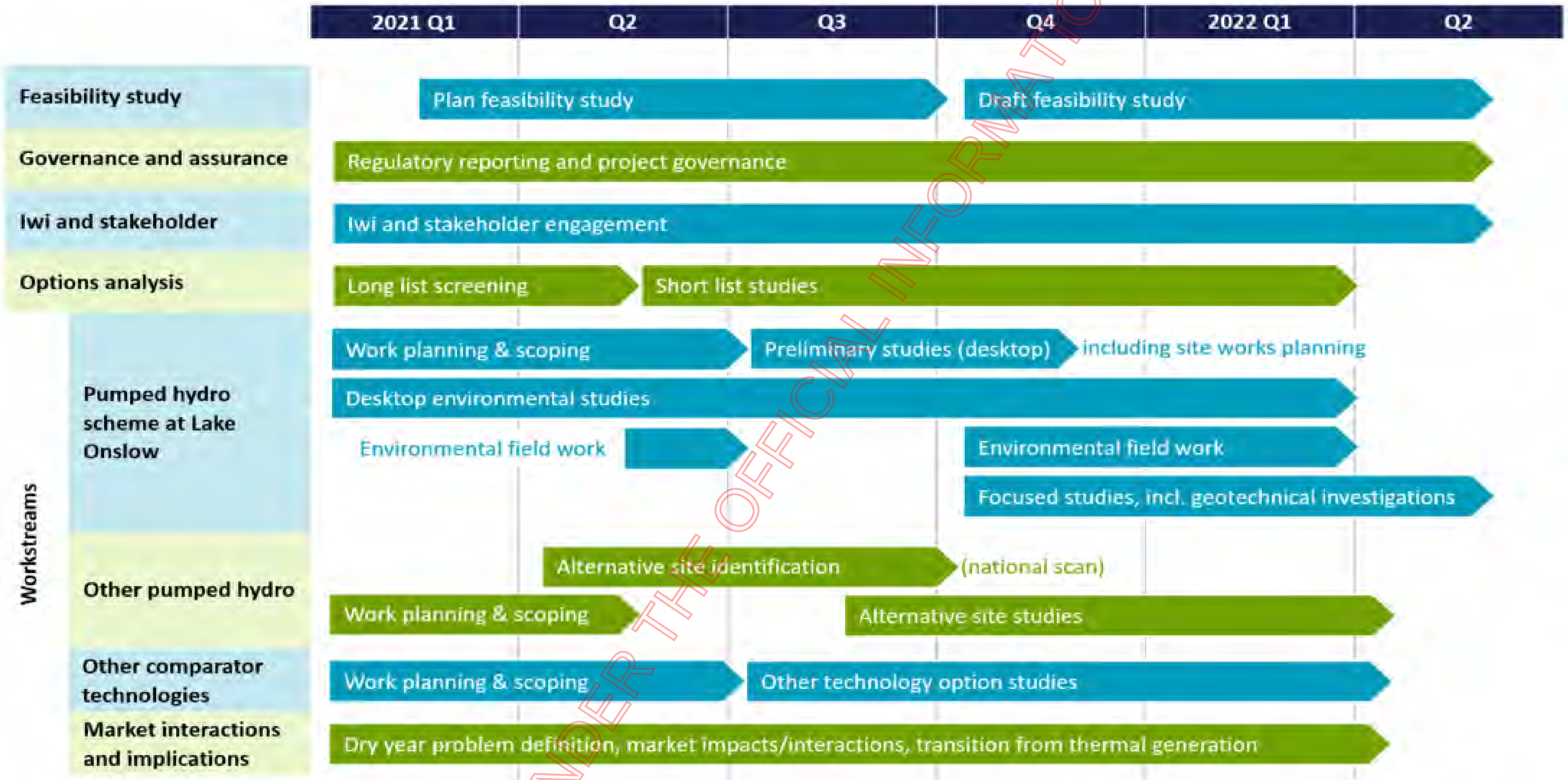
Purpose of this session

- Give you an overall project status update and cover off the current workstreams underway
- What have we completed over the past 6 weeks
- What is coming up over the next 6 weeks

What we want from you

- This is for your information but please provide feedback or observations

NZ Battery Project indicative timeline for Phase 1



Last 6 weeks milestones

- Project update briefing received by Minister Woods in June.
- Released the tender documents for the Lake Onslow engineering, geotechnical and environmental investigation.
- Received final reports from **Sapere Consulting** on the potential electricity market implications of a pumped hydro scheme at Lake Onslow, and from **Concept Consulting** on the ‘size’ of the dry year problem.
- A local central Otago provider flew LiDAR remote sensing over the lake Onslow area.
- Early fieldwork for environmental assessment and the lake ecology assessment.
- Secured agreement from a landowner for the installation of a meteorological station.
- Stakeholder engagement with landowners and industry participants.

Phase 1 key workstreams – work underway

Lake Onslow pumped hydro

Is a pumped hydro scheme at Lake Onslow technically, economically, commercially, and environmentally feasible?

Can any adverse impacts or risks be effectively managed or mitigated?

Other pumped hydro

Are there viable locations for pumped hydro outside of Lake Onslow?

What about our existing hydro lakes?

Other comparators

What is the range of other options?

Which options have the potential to effectively manage or mitigate dry year risk?

Which options are the most feasible?

Market interactions and implications

What impact will an NZ Battery have on the current electricity market?

What operational governance model should the NZ battery have?

Phase 1 key workstreams – work underway

Lake Onslow Pumped Hydro

Environmental assessment: desktop work **underway**, fieldwork **planned**

Hydrological and ecological modelling: **underway**

Engineering, geotechnical and environmental investigation: desktop and field work: **Underway**

Environmental assessment (**DOC**)

Lake ecology assessment (**NIWA /Cawthron/Otago Uni**))

Hydrology (**NIWA**)

Transmission implications (**Transpower**)

Engineering, Environmental and geotechnical study (RFP tender has been released, closes July)

Phase 1 key workstreams – work underway

Other Pumped Hydro

Identify other pumped hydro options: **underway**

Assessment and evaluation of other pumped hydro options: **planned**

GIS scan large-scale pumped hydro sites (**NIWA**)

Direct industry engagement

Phase 1 key workstreams – work underway

Other Comparators

Long-listing of comparator technologies: **underway**

Short listing: **planned**

Detailed studies of viable alternatives: **planned**

Testing initial screening, identifying further information required and commissioning necessary investigations

After long list evaluation, detailed work on shortlisted options will be commissioned

Phase 1 key workstreams – work underway

Market interactions and implications

Determining the size of the dry year problem: **underway**

Potential electricity market impacts of pumped hydro at Lake Onslow: **underway**

Potential electricity market impacts of other technologies: **Scoping**

Operational governance: **Scoping**

Size of the NZ Battery solution analysis (**Concept**)

Lake Onslow pumped hydro market interactions (**Sapere**)

Next 6 weeks milestones

- We will be supporting the tender process for the Lake Onslow engineering and geotechnical investigation. Tender responses close in early July, to be followed by tender evaluations.
- NIWA are applying for resource consent for installation of a meteorological station and a lake monitoring buoy at Lake Onslow but this will be weather dependent.
- We are planning for the next officials visit to central Otago to meet with landowners, Ngāi Tahu, and the Central Otago District Council, among others. This trip to planned for early August.
- Tender work pack for alternative technologies screening and development
- Develop screening model (next step in Concept Consulting work stream)
- Refine our list of alternative pumped hydro and existing hydro sites for further assessment.

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Non-Hydro approaches

For this session:

Purpose of this session

- To get feedback on our long-list priorities and approach to resolving unknowns

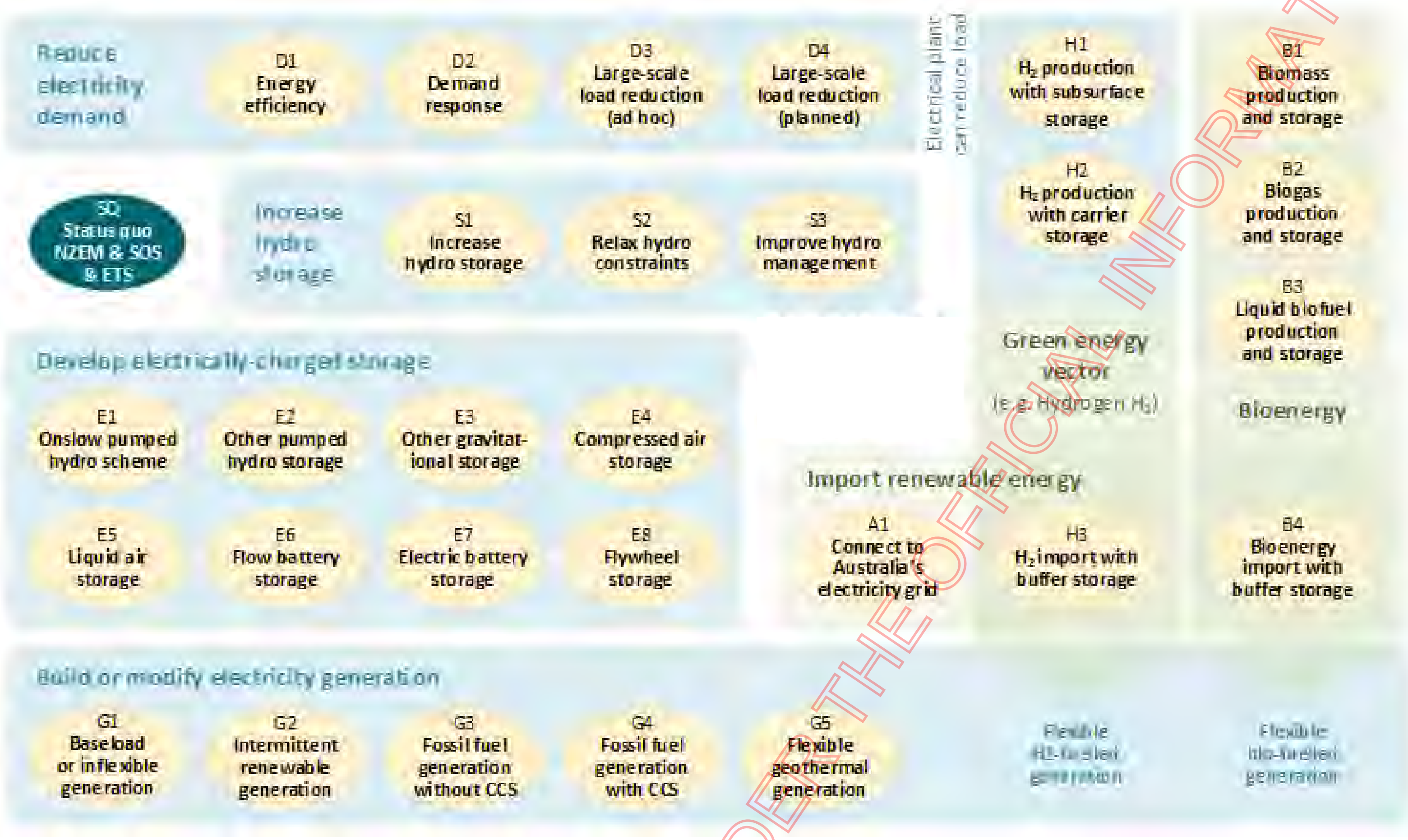
What we want from you

- This is an opportunity to challenge which approaches we're spending our time and effort investigating
- We also want your views as to whether we've identified the right information to assess options

Next steps from here

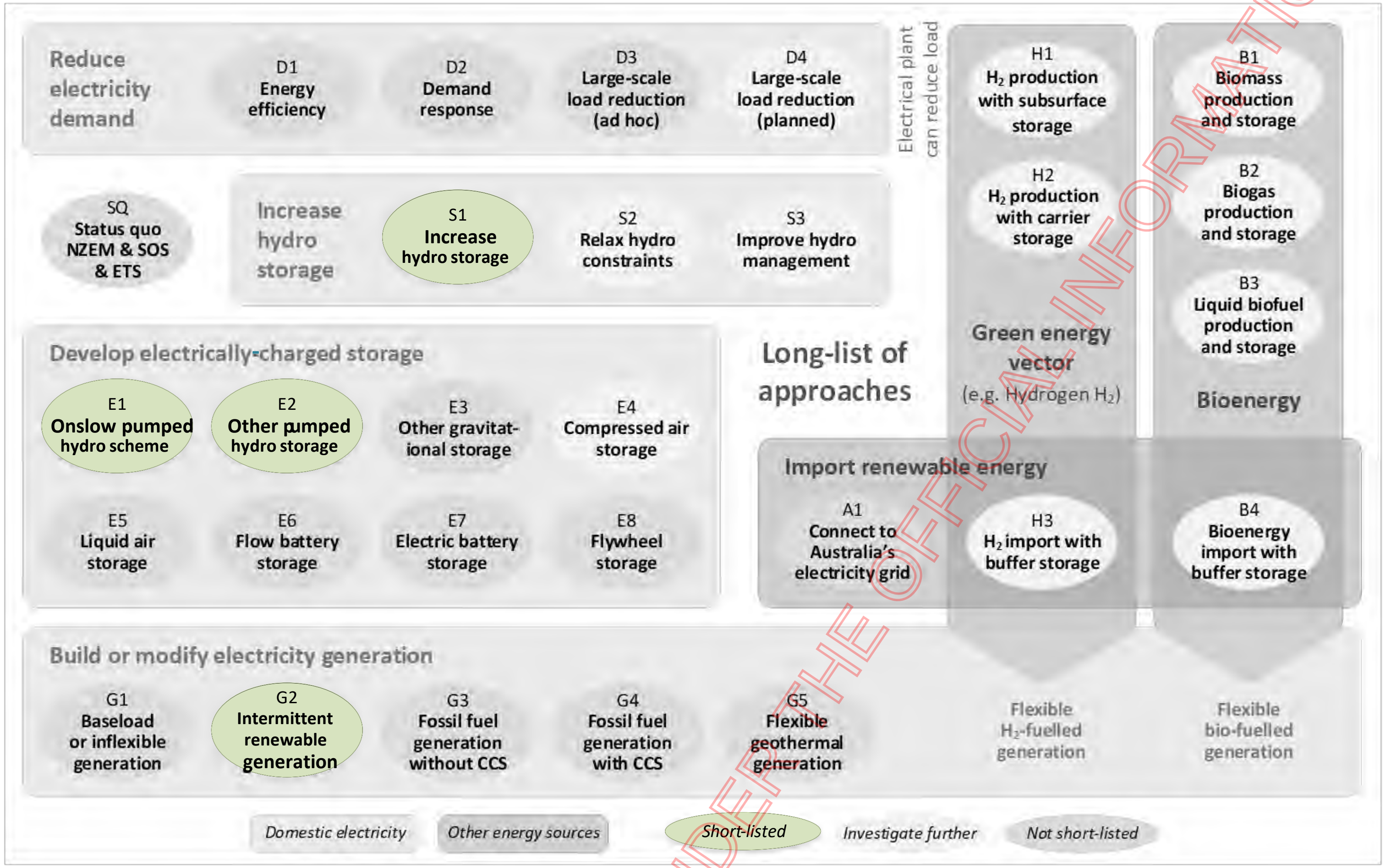
- We intend to go out to tender for a party to develop concept designs for feasible biomass and hydrogen options

Last meeting we presented our long list of approaches



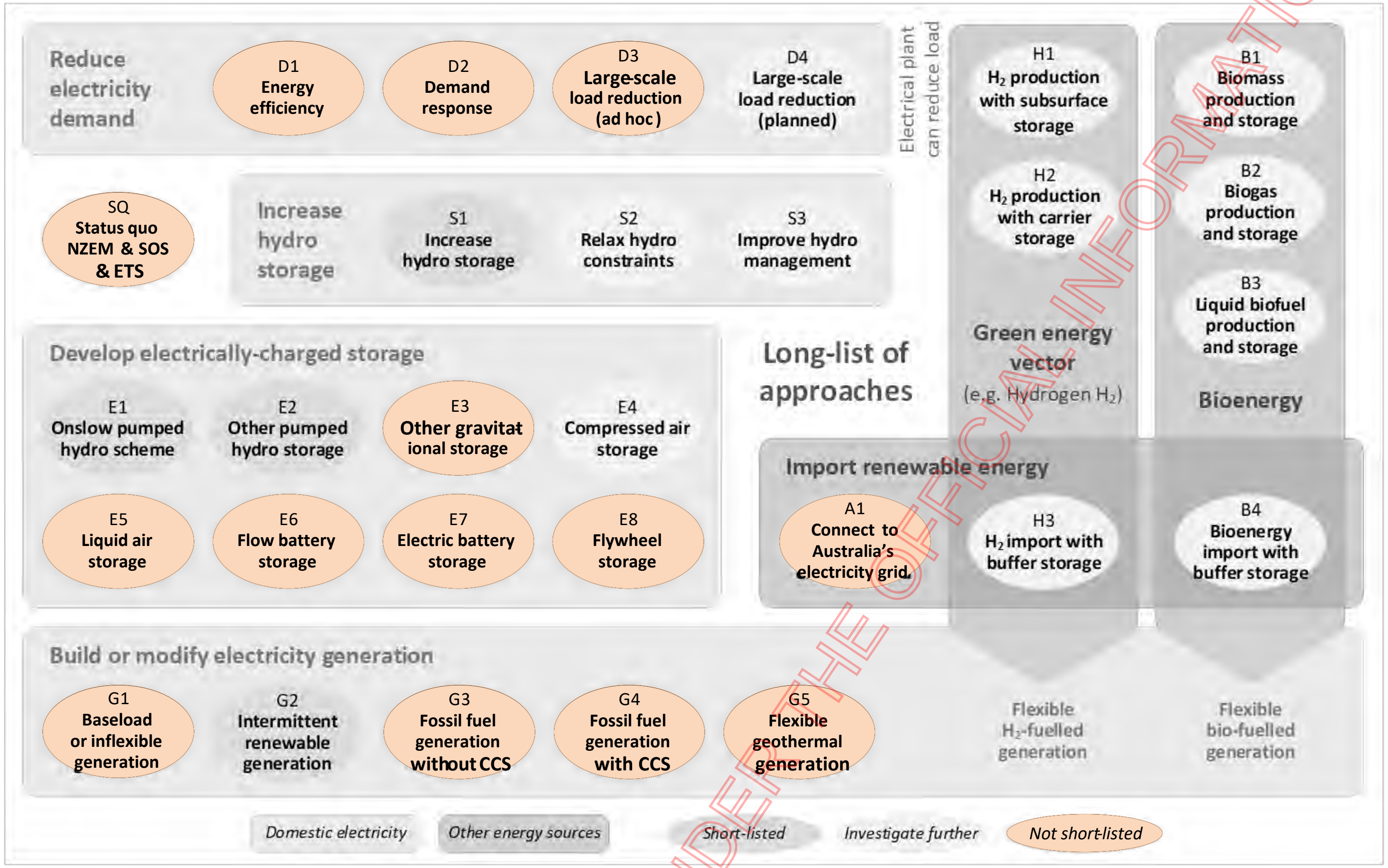
- Security of supply
- Renewable
- Social cultural environmental
- Job creating
- Affordable
- Practical

We short-listed a few approaches



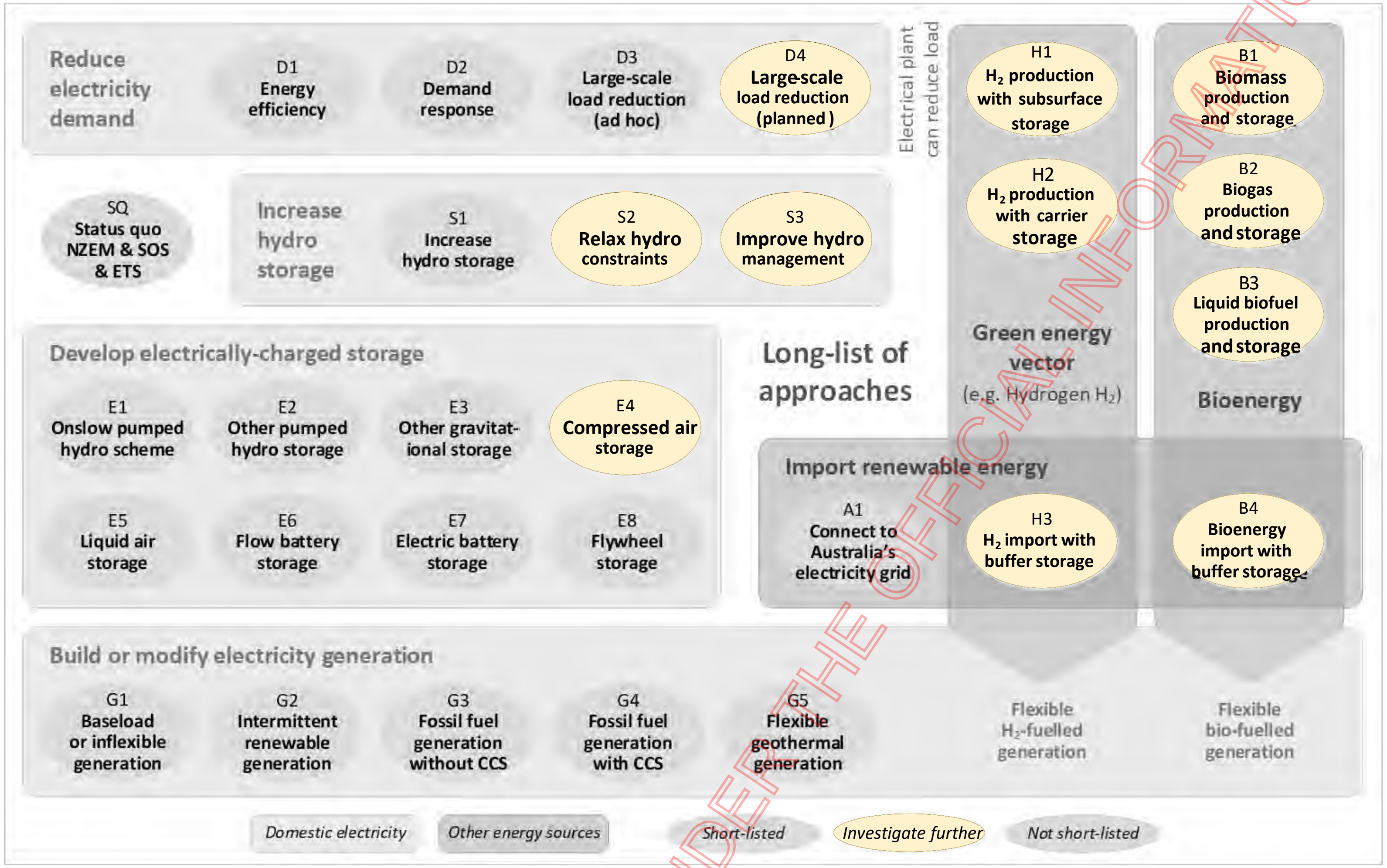
- We expect feasible hydro-based options - working to identify those under our other work streams
- An over-build of intermittent renewable generation assumed part of the solution

We ruled out several approaches



- Ruled out options that aren't renewable
- Some options, while valuable, won't provide a significant dry-year solution
- Electrical options work for short-term storage, but not long-term
- Connecting to Australia and flexing baseload plant is prohibitively expensive challenging to install

We need to further investigate some approaches to make a call



- Planned large-scale load reduction relies on an economic and reliable customer
- Our other workstreams will consider the potential contribution from varying hydro constraints / management
- Hydrogen and biomass are our main unknowns…

Results of our initial screening

Reduce electricity demand

- D1 Energy efficiency
- D2 Demand response
- D3 Large-scale load reduction (ad hoc)
- D4 Large-scale load reduction (planned)

Electrical plant can reduce load

- SQ Status quo NZEM & SOS & ETS

Increase hydro storage

- S1 Increase hydro storage
- S2 Relax hydro constraints
- S3 Improve hydro management

Develop electrically-charged storage

- E1 Onslow pumped hydro scheme
- E2 Other pumped hydro storage
- E3 Other gravitat-ional storage
- E4 Compressed air storage
- E5 Liquid air storage
- E6 Flow battery storage
- E7 Electric battery storage
- E8 Flywheel storage

Long-list of approaches

Green energy vector (e.g. Hydrogen H_2)

- H1 H_2 production with subsurface storage
- H2 H_2 production with carrier storage

Bioenergy

- B1 Biomass production and storage
- B2 Biogas production and storage
- B3 Liquid biofuel production and storage

Import renewable energy

- A1 Connect to Australia's electricity grid
- H3 H_2 import with buffer storage
- B4 Bioenergy import with buffer storage

Build or modify electricity generation

- G1 Baseload or inflexible generation
- G2 Intermittent renewable generation
- G3 Fossil fuel generation without CCS
- G4 Fossil fuel generation with CCS
- G5 Flexible geothermal generation
- Flexible H_2-fuelled generation
- Flexible bio-fuelled generation

Domestic electricity | *Other energy sources* | *Short-listed* | *Investigate further* | *Not short-listed*

Do you agree with the options we have screened in/out?

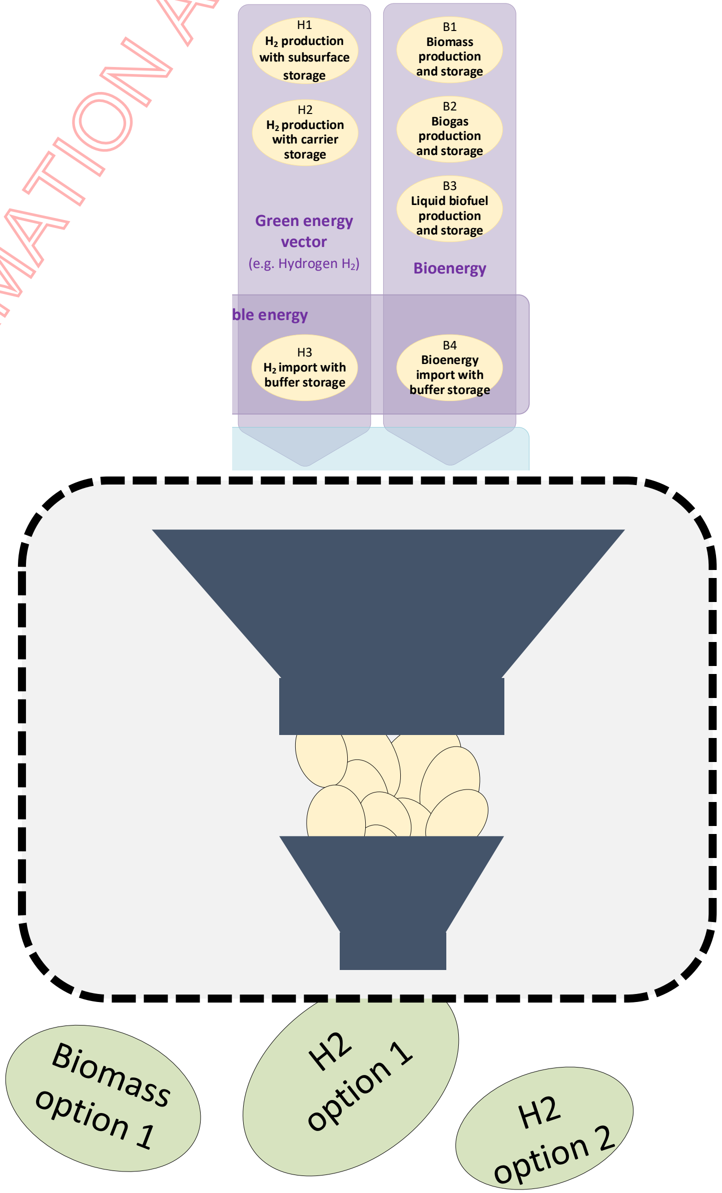
Do you agree with the options that we intend to investigate further?

We will be utilising external expertise to develop the options

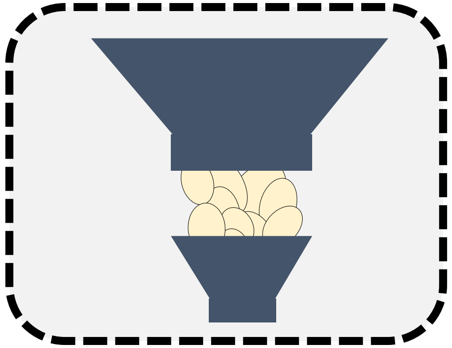
- Hydrogen and biomass approaches both cover a spectrum of options
- Lots of developments in both areas
- We’re focussed on options specifically for dry-year security
- Likely that some options should rightfully be short-listed (partial or full solutions)
- Screening the broad range of options and developing concepts will involve deep technology insights and expertise, which we will gain from external parties

Our plan for filling in the information gaps

- Want concept designs at a level of detail sufficient for Phase 1
  - ⇉ Potential to move to Phase 2 detailed design
- Able to compare against our alternatives (incl. Lake Onslow)
- Potential for "best" solution to be varied mix of smaller solutions



Have we identified the information we need to assess options?



Options	Approach	Fuel production / source Fuel transport Fuel storage Electricity generation
	Infrastructure required	Distinguish new and existing
	Site	Site requirements for production / transport / storage / generation Optimal site(s) in NZ Alternative sites
	Scale	Efficient scale Economies of scale & linearity of costs with scale
	Flexibility	Ability to vary output (years) Constraints on flexibility
	Alternatives	Key alterative design options Trade-offs considered
Costs	For fuel / transport / storage / generation • Capex -> feed into LCOS • Opex -> feed into LCOS Size / scale limits and breakpoints	

Markets and risk assessment	Timeframes	Now -> 2030 -> 2040 -> 2050 -> beyond
	Technology	Maturity of technology Rate of cost decline Redundancy risks / competitive tech
	Markets	Maturity of markets (domestic / international) Competing uses Supply / demand balance incl seasonality 'Green' (req'd) vs 'blue' vs 'brown'
	Technical issues	Engineering challenges Storage risks Safety assurance
	Environmental issues	Impacts on water (use, discharge) Impacts on air (emissions incl. greenhouse, pollutants) Impacts on land (use, discharge)
	Social issues	Construction workforce Operational workforce
Next steps	Key uncertainties remaining Further work recommended	

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Why do this?

- Looking to spend a lot of $$ on feasibility of Lake Onslow option
- How we know it's the only option?
- How do we know it's the best option?
- What are the other feasible options?
- Where are they?
- How big are they?
- What trade-offs would they involve?
- What would they cost?

Outcomes?

- may find nothing = but at least you know you looked
- may find something equivalent or better or smaller but in North Island
- may find nothing of value for dry year solution but potentially of value for firming intermittent renewables?

How are potential pumped hydro locations identified?

1. Looking at maps/historic:

- Onslow/Manorburn 2005 (Waikato Uni) (big tank, big tap)
- s 9(2)(f)(iv) [redacted]

2. GIS algorithms digital elevation models and building dams:

- ANU 2017 (scanned the world 60 °N, 50 °S) (small tap, tank)
- Canterbury Uni 2019 (testing an algorithm)
- NZ Battery 2021 (NIWA) (big tank, big tap)

1. Looking at maps – Waikato Uni

Figure 1 – The Onslow-Manorburn depression, showing maximum pumped storage reservoir development to 800 metre elevation in both Upper Manorburn and Lake Onslow basins.

Roxburgh dam becomes part of the potential energy, although at the expense of some operational flexibility of the station. On the

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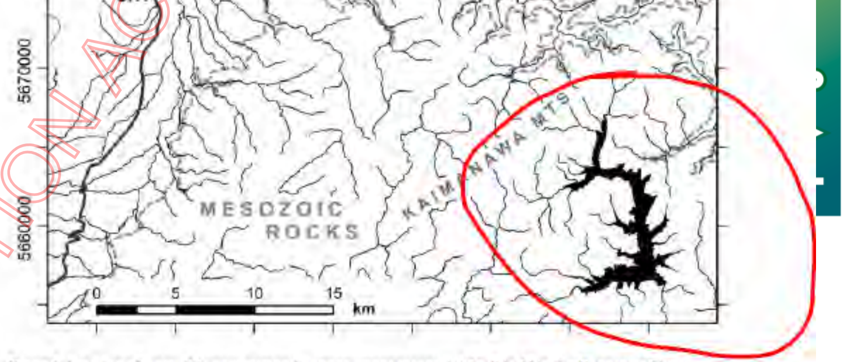
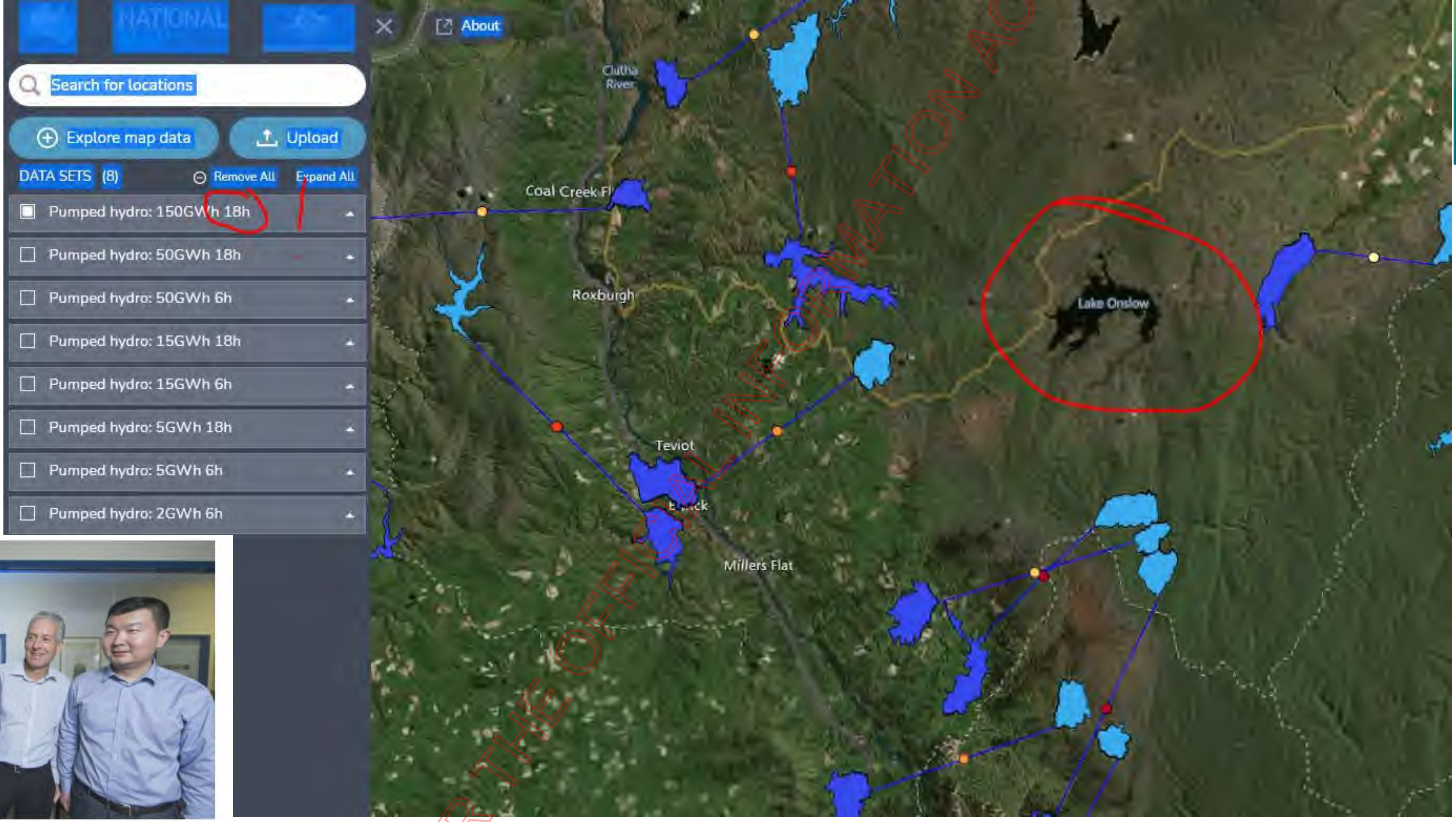


Figure 1. Location of a possible new pumped storage upper reservoir lake (black) in the Ngaruroro River headwaters. Dashed line indicates the boundary between Mesozoic sediments and volcanic rock units around Lake Taupo. Linkage tunnel to Lake Taupo is not shown.

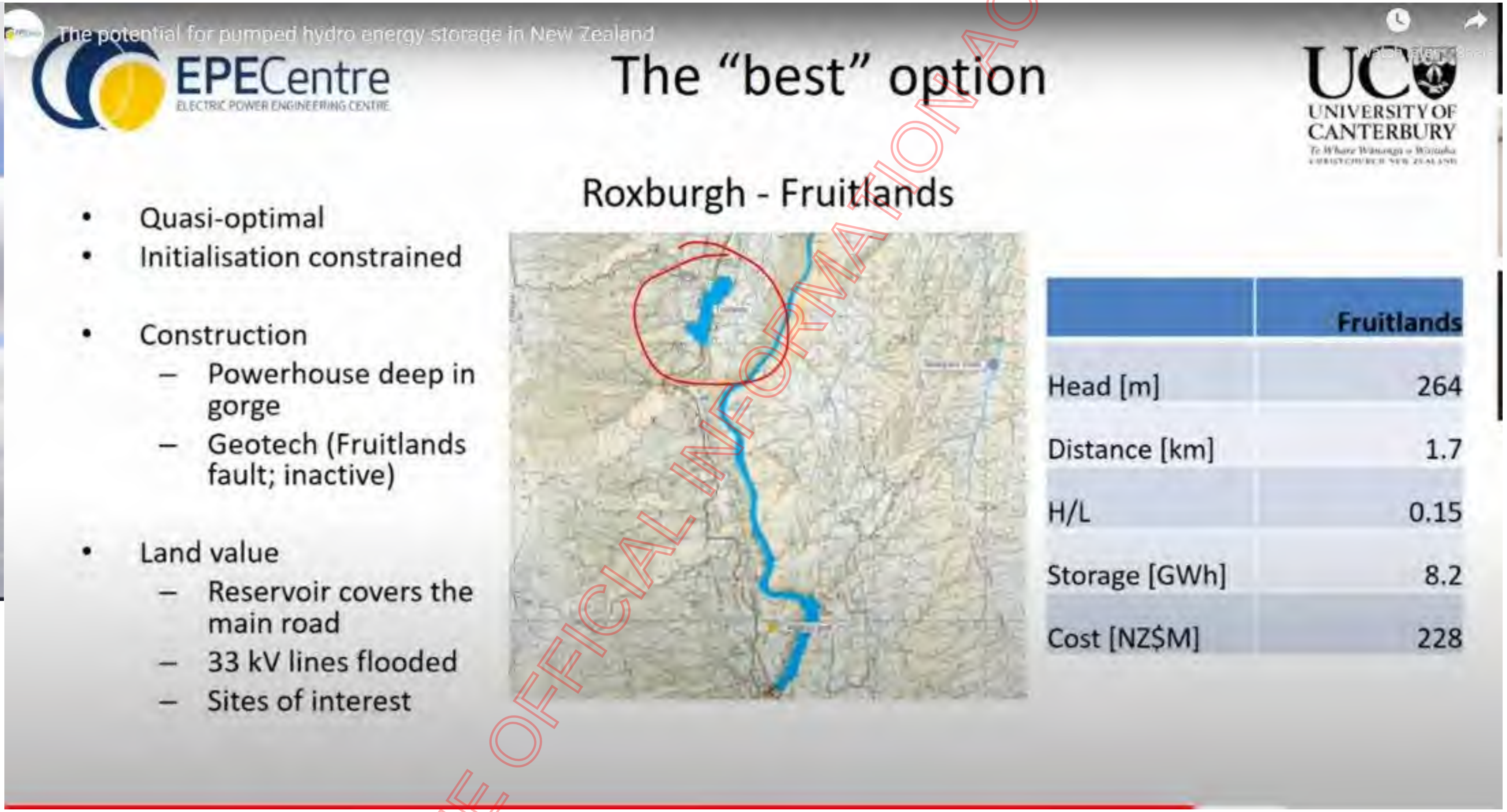
Ngaruroro reservoir setting

Assuming construction to its largest energy storage capacity, the Ngaruroro Scheme would require a high 120 metre dam in the upper Ngaruroro River, downstream of the Panoko Stream confluence. This would create a reservoir lake of surface area 32 km^2 at 1040 metres maximum elevation (Fig.



Dr Matthew Stocks, Professor Andrew Blakers and Bin Lu (left to right). Credit: ANU

ANU – looking for 'small tank, small tap' = no Onslow



2019 Canterbury Uni – 'small tank, small tap'

Tank = big, high, fill-able, dam-able....

BIG

- must be **1 TWh** or larger
- **~5TWh =** the difference between average and driest year (on record)
- needs to impound a lot of water **= 'big tank'**

HIGH

- elevated (volume x height = gives you the energy)
- head > 300m **= 'big, high tank'**

FILL-ABLE

- Access to large water source to fill the 'big tank'
- Distance between water source and 'big tank' ≤ 30km **= 'big, high fill-able tank'**

DAM-ABLE

- Dam length ≤ 3km total
- Dam height ≤ 120 m max = **= 'big, high fill-able, dam-able tank'**

NIWA's approach

1. Is there a big enough water source?

- enough capacity to fill upper reservoir 'big tank' within two years – limited to large lakes and rivers with large flows.....as you can't take all the water out of a river....

2. Are there nearby basins?

- within 30km of water source and;
- 300m or more above water source.

3. Can you dam basins?

- dam up to 120m high and 3km long – does it impound TWhs of potential energy? >1TWh in South Island and > 0.5TWh in North Island
- The method was restricted to building a single, straight dam in this initial approach.

s 9(2)(f)(iv)

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

s 9(2)(f)(iv)

Current approach

1. Find us big, high, fill-able, plug-able tanks....across all of NZ...

2. Screen nothing out in first pass on other values (env, seismic, transmission, etc)...

3. As these values can then be used to screen out options if the options even exist....but firstly we want to know if there are any options from a purely physical point of view...

Known issues

1. It won't find options such as raising existing dams...

2. It won't account for the head of options that may pass through a strings of dams = Waikato, Waitaki, Clutha systems...

3. It won't build multiple dams..plug leaks...

Questions for TRG

1. Are our search criteria 'right'?

2. What changes to search criteria should be made for the next NIWA run?

- BIG ≥½ TWh North Is, ≥1 TWh South Island
- HIGH ≥ 300m+ head
- FILL-ABLE = maximise head up to 30 km tunnel
- DAM-ABLE = 3 km dam length, 120 metres max height

3. Any other advice?

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Communications and Stakeholder Relationship Management

MAHI TAHI
BETTER TOGETHER

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

DRAFT ONLY – NOT GOVERNMENT POLICY

Purpose

Is our comms and engagement approach on the right track?

What, who are we missing?

Any feedback on upcoming activities?

What's the purpose of our communications & engagement?

NZ Battery Project objective

Provide comprehensive advice on the technical, environmental, social and commercial feasibility of a range of dry year risk options management.

These include pumped hydro at Lake Onslow, pumped hydro elsewhere, and other potential energy generation and storage projects.

Guiding principles

- Take people on the journey with us
- Leave a legacy we can be proud of
- Be a good neighbour
- Openness and honesty

- Build trust with stakeholders and general public
- Enhance project's reputation and gain support
- Remove barriers to investigations taking place
- Meet Tiriti o Waitangi obligations
- Build public knowledge about what the project's trying to solve
- Reduce misinformation and proactively respond to concerns
- Share information

Who are the Phase 1 key stakeholders?

Government & political • Minister Woods • Other members of cabinet • Climate Change Commission • DOC • MfE • Electricity Authority	**Industry** • Electricity Retailers Assoc • Energy generators: Contact, Meridian, Mercury, Genesis, Trustpower • Transpower	**MBIE** • Internal communication	**Mana Whenua & Iwi interest** • Ōtākou Rūnanga • Hokonui Rūnanga • Kati Huirapa ki Puketeraki • Murihiku Regeneration • Iwi in other study areas
Local Government • Central Otago District Council • Otago Regional Council • Local government in study areas	**Landowners** • Around Lake Onslow • Along proposed tunnel route • Landowners in other study areas	**Local community** • Teviot Valley community • Community in other study areas	**Interest groups** • Upper Taire Wai group • Fish & Game • Forest & Bird
Enthusiastic commentators • You know who they are	**Media** • Local, national & international	**General public**	**Who else?**

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

[redacted]

Activities

- Hear from TRG
- Refresh Communications & Engagement Plan
- Start engagement register
- Visit Lake Onslow area and meet with key stakeholders
- Comms plan for RFP
- Forward looking plan: Agree progress and milestones to highlight & celebrate
- Look for opportunities to raise profile of approaches
- Continue e-news updates
- Continue communicating with landowners and local community
- Increase proactive media engagement
- Plan site visits to Lake Onslow if option progresses

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NZ Battery's operational governance

Agenda item 8

For this session

Purpose of this session

- To introduce the issue of operational governance (operator, operating and revenue models)
- To discuss and learn from the Reserve Energy Scheme case study

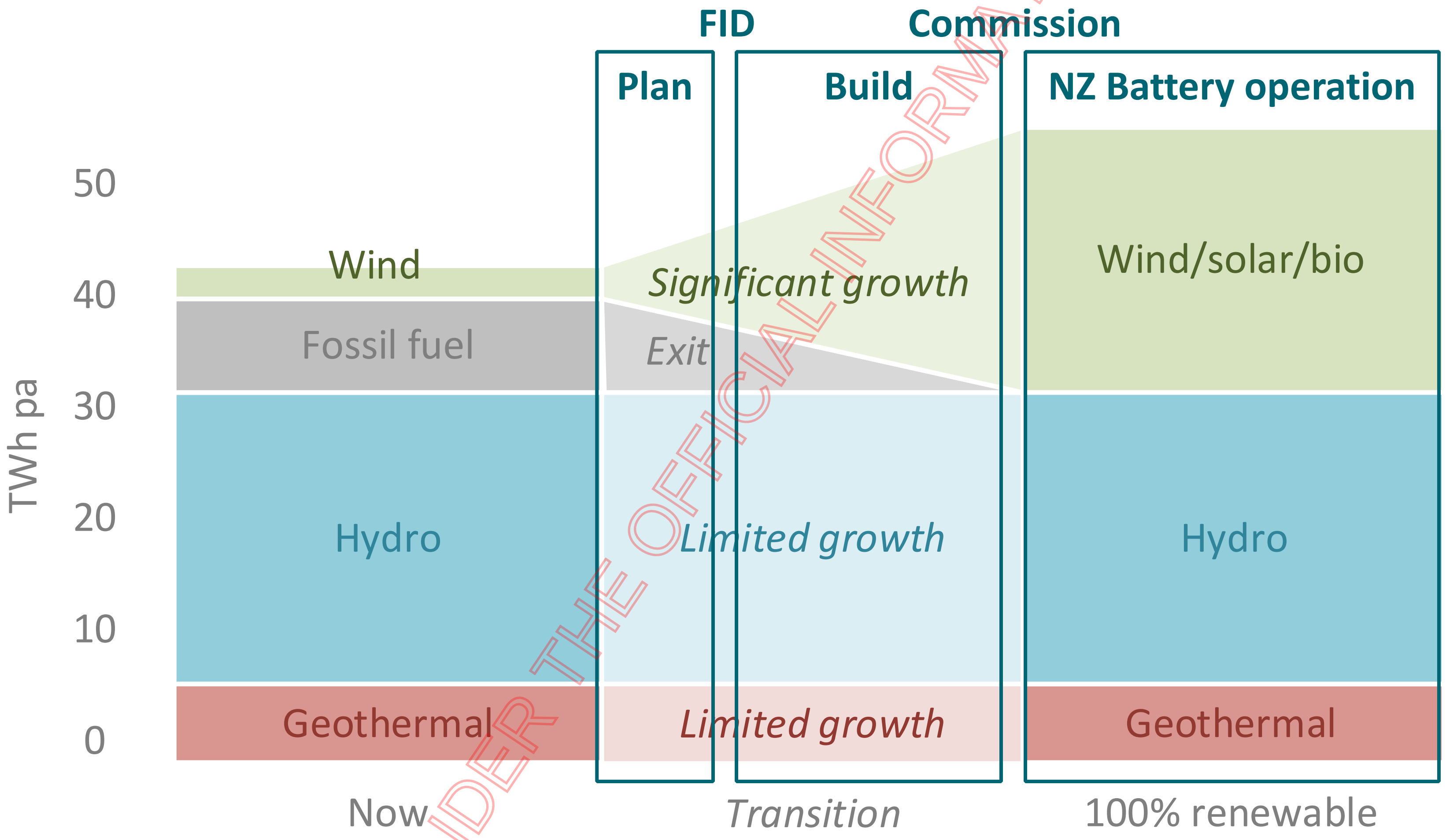
What we want from you

- Early views on who might operate an ‘NZ Battery’
- Insights from the Reserve Energy Scheme case study

Next steps from here

- We will discuss operational and revenue models at a subsequent meeting
- We are drafting a framework to assess operational governance models
- After identifying preferred options, we will likely seek 3rd party review and input

Why do we need to consider operational governance now?



What do we mean by operational governance?

An introduction

What is operational governance?

Operational governance

Operator		Operating		Revenue
Entity Degree of Government control Checks and balances	X	Operating mandate w.r.t.: • Purpose • Bid/offer strategy • SOS or flexibility focus • Market power mitigation? • Offering of hedges?	X	Cost/revenue could be highly variable across years: • Recovery of costs • Allocation of revenues • Inter-year smoothing?

Operational governance is an important part of the project

Market interactions and implications

Determining the size of the dry year problem: **underway**

Potential electricity market impacts of pumped hydro at Lake Onslow: **underway**

Potential electricity market impacts of other technologies: **planned**

Operational governance: **underway**

- Of keen interest to government and industry
- Key to market interactions and implications workstream
- Will inform:
  - value – role it plays, when used and why
  - cost recovery – who pays what and why
  - risk – market power, security of supply, investment
- Important we do in Phase 1 → Phase 2
  - input and output of “best” option(s)
  - certainty for industry investment
- Consider from commissioning (i.e. include fill)
- Will later consider build-phase

We want to identify an enduring solution: History lesson

- Security of supply has long been a hot issue for government and regulators
- Prices during dry years have lead to lobbying and affects perceptions of industry
  - Consumers re-contracting or exposed to spot
  - Retailers seeking risk management contracts
  - Dry-years lead to risk margin in prices for all consumers
- Government reviews in 1992, 2003, 2009, 2018
- Lead to significant evolution of regulatory context and incentives
- The Reserve Energy Scheme case study speaks to the risks

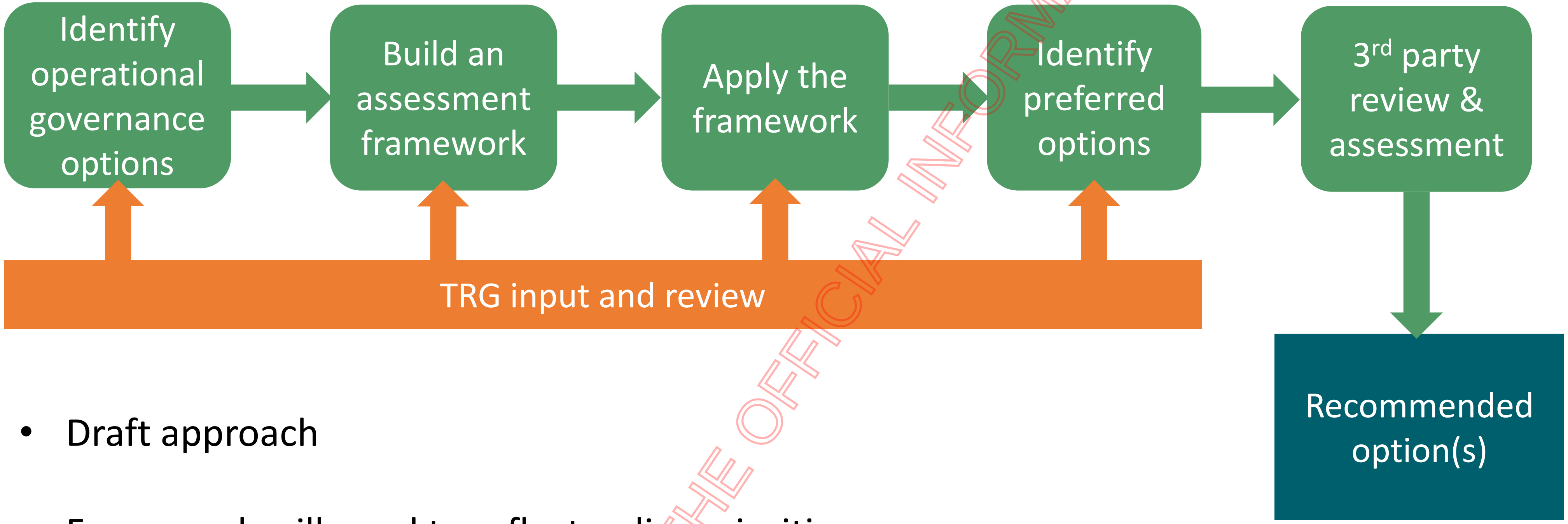
NZ‘s security of supply risk regime has evolved

	Responsible entity	Target security of supply level and measures to achieve it
Pre 1992	New Zealand Electricity Department (NZED) Became Electricity Corporation of NZ (ECNZ) in 1987	1 in 20 centrally planned, but achievement of this level not helped by a $150/MWh price cap in emergency situations
1992 dry year leading to Government review		
1992 to 1996	ECNZ (transmission arm split out as Transpower in 1994)	1 in 60 centrally planned with price cap removed
1996 to 2003	Competing industry players NZEM membership was voluntary	None – outcome of a two-sided market
2001 and 2003 dry years (combined with some perceived market failures on other issues) leading to Government review		
2003 to 2010	Electricity Commission established. It must have regard to Government Policy Statements (GPSs), which were frequently updated during this period	1 in 60, to be met by market backed with Reserve Generation scheme (Whirinaki - see case study 1)
2008 dry year leading to ‘Brownlee’ review 2010, recommended scrapping reserve energy scheme and introducing customer compensation		
2011 to now	Electricity Authority established as an independent regulator Hedge market matures with future and swaptions	Economic level, with incentives provide through Customer compensation scheme and the introduction of scarcity pricing (one-sided market with the Authority setting the compensation and scarcity pricing levels)

Regulatory mandates for security of supply so far

	Electricity Commission 2003 - 2010	Electricity Authority 2010+
Entity	• Crown entity • Must have regard to, and align its SOI with, Government Policy Statements (GPSs)	• Independent Crown entity
Mandate	Principal objectives to ensure that electricity is produced and delivered to all classes of consumers in an efficient, fair, reliable, and environmentally sustainable manner, and to promote and facilitate the efficient use of electricity In line these, the Commission must seek specific outcomes including that: • risks (including price risks) to the security of supply are properly and efficiently managed • the electricity sector contributes to achieving the Government's climate change objectives by (inter alia) minimising hydro spill	Statutory objective to promote competition in, reliable supply by, and the efficient operation of, the electricity industry for the long-term benefit of consumers
Policy directives	• GPSs issued in 2002, 2004, 2006, 2008 and 2009, all covering security of supply • GPS 2004 and 2006 directed priority be given to managing security of supply and implementing the reserve energy mechanism • Government introduced the Electricity Governance (Security of Supply) Regulations 2008	• Act requirements ('s42') relating to security of supply • Act required imposing a floor spot price during supply emergencies, which EA met in principle with the current regime • Required 2008 regulations to be incorporated into the Code

How we plan to approach this work



- Draft approach

- Framework will need to reflect policy priorities
  - Justifies in-house development
  - But with 3rd party review and impact assessment (e.g., investment)

Breaking down operation

Who should operate the NZ Battery?

s 9(2)(b)(ii)

See Treasury [site]

s 9(2)(b)(ii)

[redacted]

NZ Reserve Energy Scheme

A case study

NZ Reserve Energy Scheme

- New Zealand had a Reserve Energy Scheme from 2003 until 2011

- There's a few key things we can learn from it:
    - Difficult to limit use of an asset's capability
    - Good to separate operation and policy
    - Important to consider broader incentives on participants
    - Pitfalls to setting offer prices

NZ established a Reserve Energy Scheme in 2003

- Followed two dry years / conservation campaigns within three years
- Minister devised concept and Ministry of Economic Development (MED - MBIE's precursor) set it up
- Legislated through Government Policy Statement
- Once established, Electricity Commission operated the scheme

The scheme was set up quickly and started quite simple

- Max 400 MW / 1200 GWh over 4 months
  (1 in 60 dry year) (avg annual demand of ~40,000 GWh)

- Tender for demand response and ring-fenced generation (low capital cost)

- Crown to invest in Whirinaki (155 MW) diesel power plant in Hawke's Bay
  - Offered at $200 / MWh price or lower if dry

- Costs recovered from spot (operating costs) + levy on wholesale purchasers (capital costs)

Further detail was added as the policy was implemented

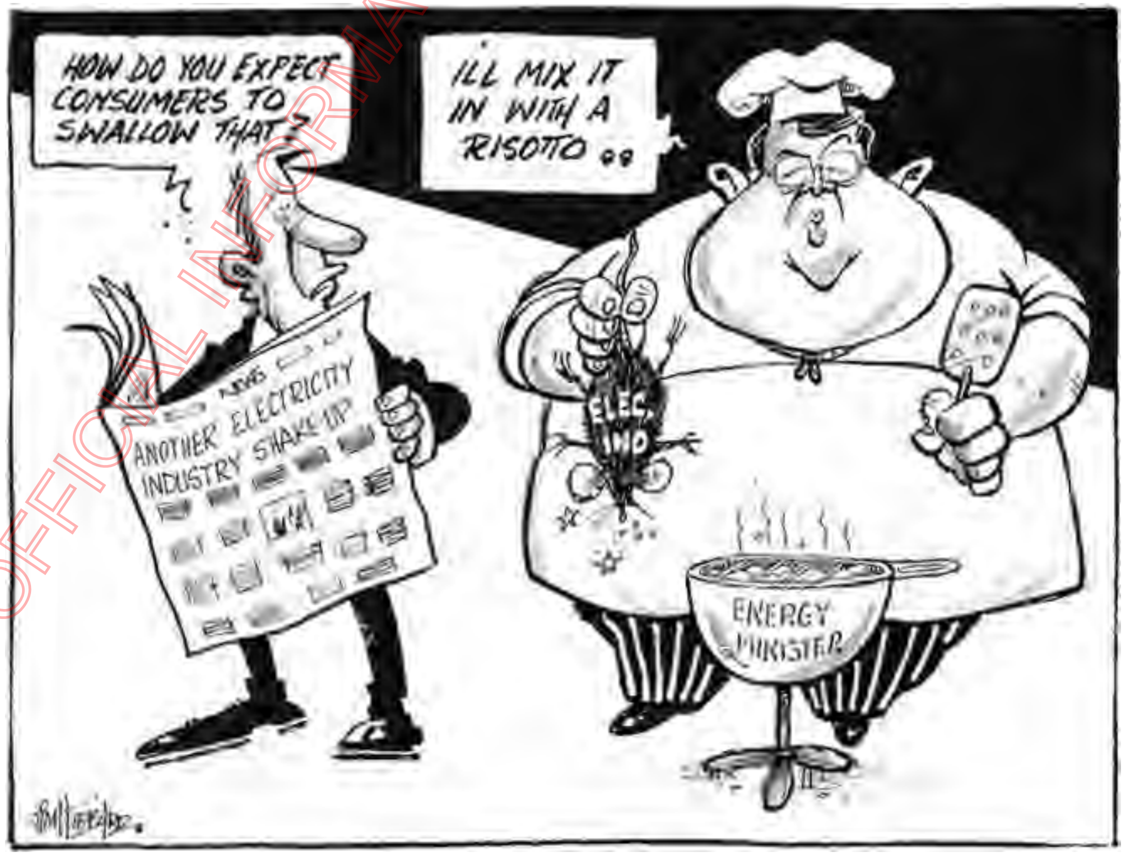
- Higher of $200 / MWh or variable cost, or less in ‘min-zone’
- Enough procured to meet calculated security margin
  - Just Whirinaki
  - Regular reviews suggested no need for more
- Also used for other unexpected supply contingencies (plant/fuel/grid disruptions)
- Each contracted option to have its own offer and trigger
  - Whirinaki offer
    - $1000/ MWh standing offer
    - $200 / MWh or variable cost (ie, diesel fuel cost) if high prices in schedules
    - potentially less in min-zone
- Requirement for periodic review
- The Electricity Commission’s hydro risk calculations, monitoring and info provision improved in the background

But it unravelled during the 2008 dry year

- First time used in min-zone/dry-year operation
  - Min-zone assumed all thermal operating, but it wasn't
  - Some thermal not offered – Electricity Commission enquired, "tense" exchange, no action in response
  - Whirinaki offers would drop some thermal out of the stack
- Changes were made on the fly
  - Electricity Commission chose Chose not to reflect higher fuel costs in offers to keep Huntly in stack
  - Electricity Commission started procurement for demand response
  - Changes caused confusion, winners and losers
- Whirinaki not recovering its costs
  - Levy recovery encouraged free-riding
  - Opposition to change in levy

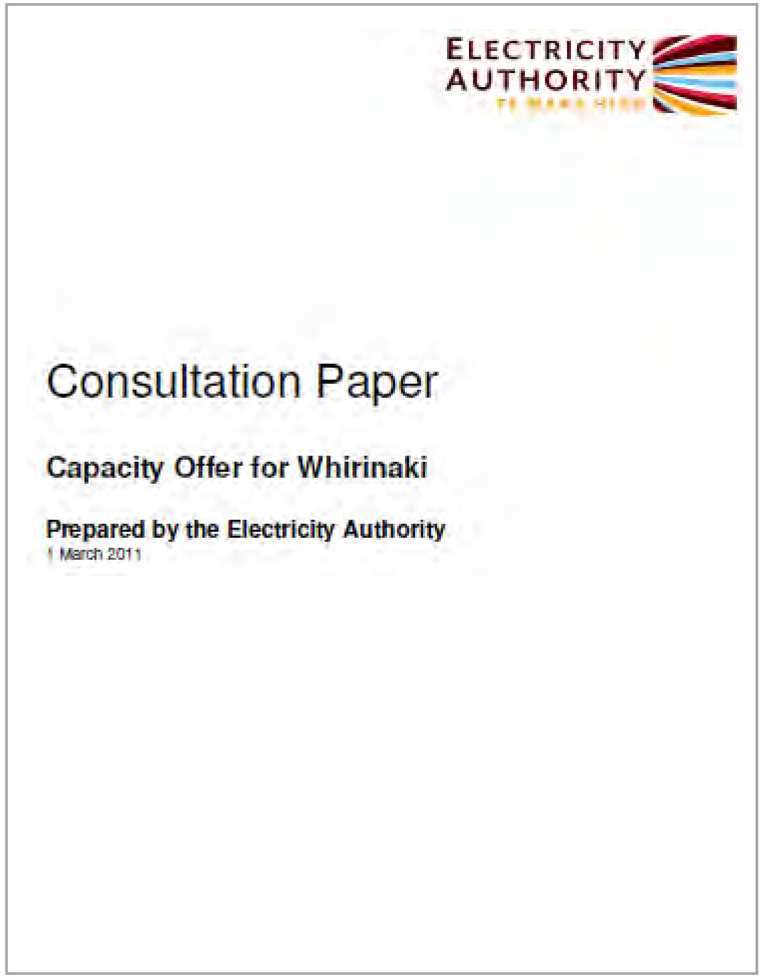
It was dis-established given the issues it caused

- 2009 'Brownlee' Ministerial Review recommended phase out of the scheme and sale of Whirinaki
    - Reduces participant incentives to manage risks
        - operational and investment incentives
        - "regulator will do it"
    - Incentivised lobbying
    - Whirinaki's location (and diesel fuelling) sub-optimal



There were changes to the arrangements during wind-down

- Electricity Commission increased Whirinaki's $1,000 / MWh standing offer to $5,000 / MWh
    - ~LRMC
    - Reflected concerns about peaker investment incentives
    - Transitional until sold
- But high price acted as a target -> competitors exercising market power
- Views government was profiting
- Electricity Authority subsequently dropped it to SRMC (~$500 / MWh)
    - Assuming capacity margins confirmed



ELECTRICITY AUTHORITY

Consultation Paper

Capacity Offer for Whirinaki

Prepared by the Electricity Authority

1 March 2011

Time series of Reserve Energy Scheme changes

Milestone	Developments
Announcement	• Generation • Ring-fenced for dry years • Offered in at high price
Draft GPS	• Up to 400 MW of low-fixed cost gen and demand response • Incl. Whirinaki plant that Crown planned to purchase • $200 / MWh offer or lower when dry
2004 GPS	• Procure enough to meet security margins • Higher of $200 / MWh or variable cost, or lower during 'min-zone' • Can be used for grid emergencies • Periodic reviews
Electricity Commission established	• Security of Supply Policy details min-zone and RES policy • Whirinaki offer published, incl. $1,000 / MWh standing offer
2007 RES Review	• Legislative detail moved out of GPS • Decision not to specify procurement approach
2009 Brownlee Review	• Decision to disband the scheme and sell Whirinaki in light of 2008 Winter Review
Electricity Commission 2010	• $1,000 / MWh standing offer increased to $5,000 / MWh
Electricity Authority 2011	• $5,000 / MWh standing offer decreased to SRMC • Scheme disestablished, Whirinaki sold, replaced with other security of supply measures

The Reserve Energy Scheme teaches us some important lessons

- Difficult to limit use of an asset's capability
  - Pressure to use for more than originally intended
- Good to separate operation and policy
  - To maintain independence of decisions
- Important to consider broader incentives
  - Reserve Energy Scheme created confusion but industry lacked right incentives as well
- Pitfalls to setting an offer price
  - Affected investment incentives
  - Didn't always help security of supply (displaced thermal plant)
  - Acted as a target
  - Open to gaming
  - Difficult to integrate non profit maximizing entity within profit maximizing market

There may be further insights we can gain

Question: What other lessons or insights can we take from the Reserve Energy Scheme?

Question: How should we reflect these insights into our future consideration of the operational governance of an 'NZ Battery'?

We are planning further case studies to inform our work

- Other examples of strategic reserve – Sweden/Finland/Germany/Belgium
- Other large generation with potential market power (eg, Tasmania hydro, Bath pumped hydro in Virginia)
- Strategic oil reserves

Question: Do members have any suggestions of other case studies we could learn from?

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11.	2.30pm - 3.30pm	DOC update • Why are they involved? • Project Impact • What is covered in the report and what is not included • Land Ownership • Outline of the conservation values at site together with analysis on what the losses and gains in those values might be.	s 9(2)(a)
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NZ Battery project - Lake Onslow Option

Assessment of conservation values

24 June 2021

Department of Conservation
Te Papa Atawhai

New Zealand Government

Climate change is the greatest challenge facing the planet, and it is exacerbating the biodiversity crisis. Questions around the Lake Onslow proposal highlight the difficulty in making a judgement between two contrasting environmental priorities, one focused on the present and the other on the future.

The picture can't be displayed.

Source: DOC, Lake Onslow, 2020

Why is DOC involved?

- Protecting New Zealand's natural heritage is at the heart of the Conservation Act 1987.
- DOC has signed a Memorandum of Understanding with MBIE to provide an assessment of conservation values.
- As a statutory manager of indigenous terrestrial and aquatic species, DOC has both an advocacy role and a statutory mandate for being involved in this feasibility study.

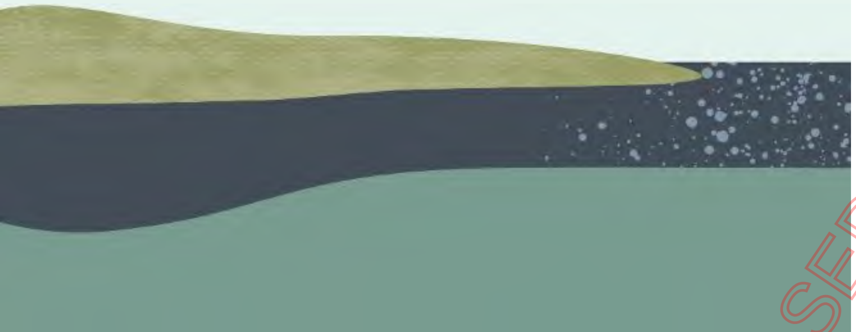
DOC Site Visit: eDNA testing at Lake Onslow and measuring the teviots found – May 2021

Project impact

- This project would have significant effects on the ecosystem and to both terrestrial and aquatic species.
- The non-migratory Teviot flathead galaxias is a Threatened - Nationally Critical freshwater fish species. It exists only in tributaries of Lake Onslow and the Teviot River downstream of the lake.
- The project would also result in drowning other nationally and regionally significant wetlands as well as resulting in other potentially negative effects on other native flora and fauna.

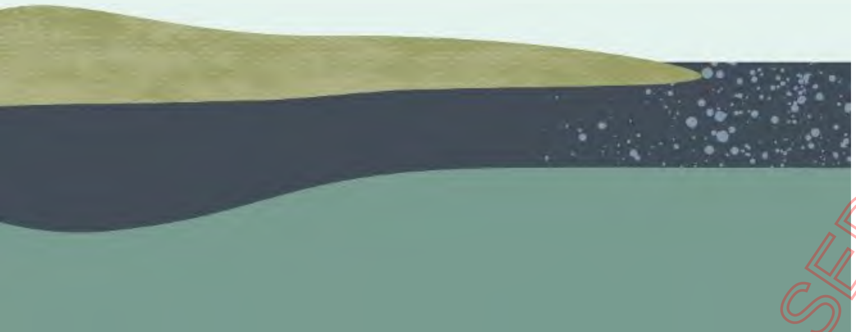
What the report does not cover

- It is DOC's role to ensure all conservation values at Lake Onslow are clearly documented to support and inform a robust decision-making process.
- What the Department will not cover is any historic, cultural or heritage values assessment.
- It is important to note that this report does not advocate a position on the proposed NZ battery project at Lake Onslow.
- If the project proceeds to the next stage, a full impact assessment report will be undertaken as part of the part of resource consent application.



Aerial view, Lake Onslow – Source Department of Conservation, 2021 DOC

Climate Change



- The effect of climate change on conservation, both nationally and globally, continues to increase in severity.
- Left unchecked, the impact of climate change on conservation values and ecosystems at Lake Onslow could be dire.
- Based on the current state at Lake Onslow, we will assess (to the best of our ability) the potential impacts of climate change on Lake Onslow and the surrounding area, as part of our wider analysis.

The crux of the NZ Battery project presents the difficult question of how to balance global climate considerations against national conservation values. This is not for the Department to decide but a political judgement to be made at a national level.

Land Ownership

- Lake Onslow is located in the Waipori Ecological District, with the lake sitting at 700m above sea level and surrounded by upland plateau mostly covered with tussock grassland.
- s 9(2)(b)(ii) [redacted]
- Pastoral modification has been intensive in the Lake Onslow basin due it being adjacent to large tracts of privately owned farmed land.

s 9(2)(b)(ii)

[redacted]

Manorburn conservation area

- Affected public conservation land includes marginal strips that adjoin the lake for access and a small portion of the nearby Manorburn Conservation Area.

- The Manorburn Conservation Area lies between Lake Roxburgh and Lake Onslow and is 700 to 900 metres above sea level. It covers nearly 3,000 hectares of relatively unmodified, semi-arid tussock land making for a stark but uniquely wild landscape.

s 9(2)(b)(ii)

Conservation assessments

- The project area has a wide range of biodiversity values based on the Department's current information and initial assessments.
- The field studies that will be undertaken in November and December 2021 will help to gain a better understanding and overview of the projects' impacts.
- Going forward, if the proposal proceeds, it will be important to understand the project's impacts during both the construction and operational phases.
- **Recreation** (angling) report is underway
- **Landscape** values report underway

s 9(2)(f)(iv)

s 9(2)(f)(iv)

[redacted]

s 9(2)(f)(iv)

s 9(2)(f)(iv)

Offsetting and mitigation requirements

- DOC's report will aim to provide an outline of the conservation values at site together with analysis on what the losses and gains in those values might be.
- The Department will look to apply offset methodology and principles, including best practice.
- Biodiversity offsets aim to replace the <u>same values as those</u> lost (where technically and practically feasible). No net loss or net gain outcome.
- Environmental compensation provides positive environmental outcomes that <u>differ from the values lost</u>.
- This section of the report will not include specific proposals for offsetting or compensation as this is the task for the applicant, as part of the environment assessment of effects.

Any questions?

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