Potential uses of Battery Energy Storage Systems for industrial consumers

A report for EECA

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Glossary

AMD	Anytime Maximum Demand tariff
BESS	Battery Energy Storage System
CMD	Coincident Maximum Demand tariff
FIR	Fast Instantaneous Reserve
IR	Instantaneous Reserve
LFP	Lithium-ion phosphate battery chemistry
Li-ion	Lithium-ion battery chemistry
Na-ion	Sodium-ion battery chemistry
Ni-MH	Nickel-metal hydrogen battery chemistry
SIR	Sustained Instantaneous Reserve
TOU	Time-of-Use tariff

Executive summary

This report, commissioned by the Energy Efficiency and Conservation Authority (EECA), investigates the potential value of Battery Energy Storage Systems (BESS) for industrial process heat users in New Zealand. A use case for an Electric Vehicle depot is also included. The study examines how BESS can support the transition to electrification. The analysis is based on three specific industrial sites, with the aim of generalising findings to typical use cases.

Key Objectives and Scope

The primary goal of the study is to model and optimise the value streams of BESS in industrial settings, particularly focusing on

- energy arbitrage
- reduction of electricity network charges
- accommodating electrification loads such as heat pumps or electrode boilers, and
- co-optimised with gas boilers.

The report also explores the integration of BESS with vehicle depots at industrial sites, where the vehicles have been converted to EVs.

Methodology

The analysis involved enhancing an existing BESS optimisation model, and incorporating new use cases specific to industrial process heat and electrification. The study employed an existing market-based optimisation approach using historical data and a bespoke algorithm to determine the economic value of BESS deployments in the New Zealand electricity market.

New logic was added to assess the specific use of BESS for the industrial use cases, process heat and EV depots. The new logic defined the BESS required to manage demand to a capacity limit. Separate logic was also added to fuel switch between electricity and gas boilers.

Findings

1. **BESS Value Streams**: BESS could be defined to meet the requirements of each use case in theory. However, the cost effectiveness of the required BESS is highly context-specific, depending on the nature of the industrial load and available network capacity.
2. **Battery Chemistry and Configuration**: Different battery chemistries (e.g., Lithium-ion, Nickel-hydrogen, Sodium-ion) were evaluated for their suitability in the industrial applications. The study found that although Li-ion is the most common, it may not always be the best option, especially for applications requiring long-duration discharge or high cycling rates. Emerging technologies like Sodium-ion and Nickel-hydrogen could offer better performance but at a higher cost.
3. **Process Heat Use Cases**: The study modelled industrial process heat scenarios based on three selected use cases, and found that – although BESS can help manage peak demand and

network capacity constraints the required battery size and cost can be substantial. For applications with long-duration peaks, BESS may not be economically viable compared to network upgrades. Shorter duration peaks would require smaller batteries and would likely be more cost effective.

4. **EV Depot Use Case**: For an EV depot, BESS showed potential to offset significant network costs by improving network utilisation. However, the high power and energy requirements for charging large fleets (assuming BAU operating conditions) necessitate expensive and complex BESS solutions, possibly requiring hybrid battery technologies or emerging chemistries.

Insights

- **Cost Drivers**: The cost-effectiveness of BESS is driven by the specific industrial context, particularly the nature of demand peaks and network upgrade costs. BESS is more suited to managing short, frequent peaks rather than long, sustained ones.
- **Technology Evaluation**: Although Li-ion is currently the dominant technology, alternatives like Sodium-ion and Nickel-hydrogen may offer better long-term solutions for specific industrial applications, despite their higher initial costs. Further research is needed to determine practicality.
- **Predictability of Demand**: Predictability of demand can significantly improve the economic case for the BESS. With high predictability, BESS can be used for market revenue. In the best possible assessment for the selected process heat cases, market revenue could produce revenue worth 25% of the BESS cost.
- **Network Charges**: Managing network charges with BESS is challenging due to the risk of creating new demand peaks. However, maximising the utilisation of network capacity using BESS remains key to minimising overall costs.

In conclusion, although BESS offers promising opportunities for industrial users to manage energy costs and support electrification, the decision to deploy BESS must consider the specific industrial load profiles, available battery technologies, and long-term economic viability. Emerging battery chemistries, although currently more expensive, may provide better solutions for certain industrial applications in the future, particularly where peaks are long and sustained.

1. Introduction

Interest in Battery Energy Storage Systems has been growing worldwide and in New Zealand, thanks to the various value streams these systems can provide in a power system with increasing penetration of intermittent generation, and for individual applications that seek to transition away from fossil fuel use to electrification.

Sapere has been engaged by EECA to understand the business context for New Zealand process heat users, the implications for how a battery could be deployed on their site, and the potential value streams that a battery could deliver to them.

This report generalises the findings based on three actual industrial sites selected by EECA.

1.1 Scope

The objective of the work is to model BESS value streams for generalised industrial process heat use cases. This involves enhancing the market-based BESS[1] optimisation model previously built by Sapere, and augmenting that to include use cases specific to industrial process heat use. The model would also output the expected battery configuration (e.g. capacity vs storage) that will suit the use case.

Overall, the use cases can be described as follows. More detail is provided in sections 3 and 4.

1. A process heat user simply installs a battery onsite and uses it for electricity price arbitrage, where the battery charges during low price periods and discharges during low price periods. These prices arise from either the wholesale market or time-of-use retail electricity tariff. There are also opportunities to earn instantaneous reserves market revenue.
2. A process heat user installs a heat pump or electrode boiler and installs a battery onsite to maximise the benefit from (1) above as well as reduction of electricity network charges (where these are based on AMD, CMD or TOU for site consumption as a whole).
3. Where relevant, situation (2) plus the use of the battery to limit the amount of network investment required to accommodate the heat pump or electrode boiler.
4. A situation where the use of gas and electrode boilers can be co-optimised depending on the relative prices of respective fuels.
5. To allow for fuel switching between gas and electrode boilers plus also use gas switching and the BESS to reduce electricity consumption during peak charging times
6. An EV depot at the process heat user's site, providing charging for heavy electric vehicles.

[1] This includes energy arbitrage and Instantaneous Reserve value streams.

1.2 Approach

The BESS market-based value streams (energy arbitrage and IR) has been modelled using R programming language. The economic value of BESS market-based opportunities were determined using a bespoke algorithm for charge and discharge optimisation, using historical and PRSS data from Electricity Authority's EMI dashboard.[2]

The process-heat specific use cases have been modelled in Excel, based on electricity use profiles provided by three sites selected by EECA. An output of this modelling was the battery characteristics needed to meet the requirements of the use case (e.g. BESS size in kWh, charge/discharge rate in hours). The resulting capital costs of a BESS for a given use case can be used as a benchmark for the minimum benefit that should be required from implementing a BESS, e.g. as measured by avoided network upgrade costs.

A discounted cash flow analysis was then undertaken in Excel, to determine the present value of the totality of value streams, depending on their applicability to the given use case.

[2] https://www.emi.ea.govt.nz/

2. Understanding BESS

The value streams that BESS can provide are influenced by their chemistries. Table 1 defines the various characteristics of a BESS, of which we highlight three important ones for the purpose of our modelling:

- To describe battery performance, we refer to BESS **charging hours** - the length of time (hours) over which the battery can fully charge or discharge (see Table 1).[3] This is, effectively, the inverse of C-rate which is usually used for batteries. However, we find using charge hours works better with energy and power calculations. Nickel-hydrogen chemistry (NiH2) can provide discharge hours of up to 12 hours, compared to up to 8 hours by lithium-ion (Li-ion) (see Table 2).
- The **round-trip efficiency** affects the net energy available for use, after accounting for battery losses. Table 2 shows that BESS efficiency can range between 80% and 99%, depending on chemistry.
- The **size** of a battery system – and therefore its charge and discharge hours – can be tailored to the specifics of a use case through parallel or series daisy chaining of individual batteries to the inverter. Figure 1 shows that a parallel chaining decreases the charge/discharge hours, whereas a series chaining does the opposite.

Another important concept is the **total opportunity cost of cycling**. This is used to determine the optimal BESS charge and discharge decisions when trading in the market, as described in section 2.3.

2.1 Components of a BESS

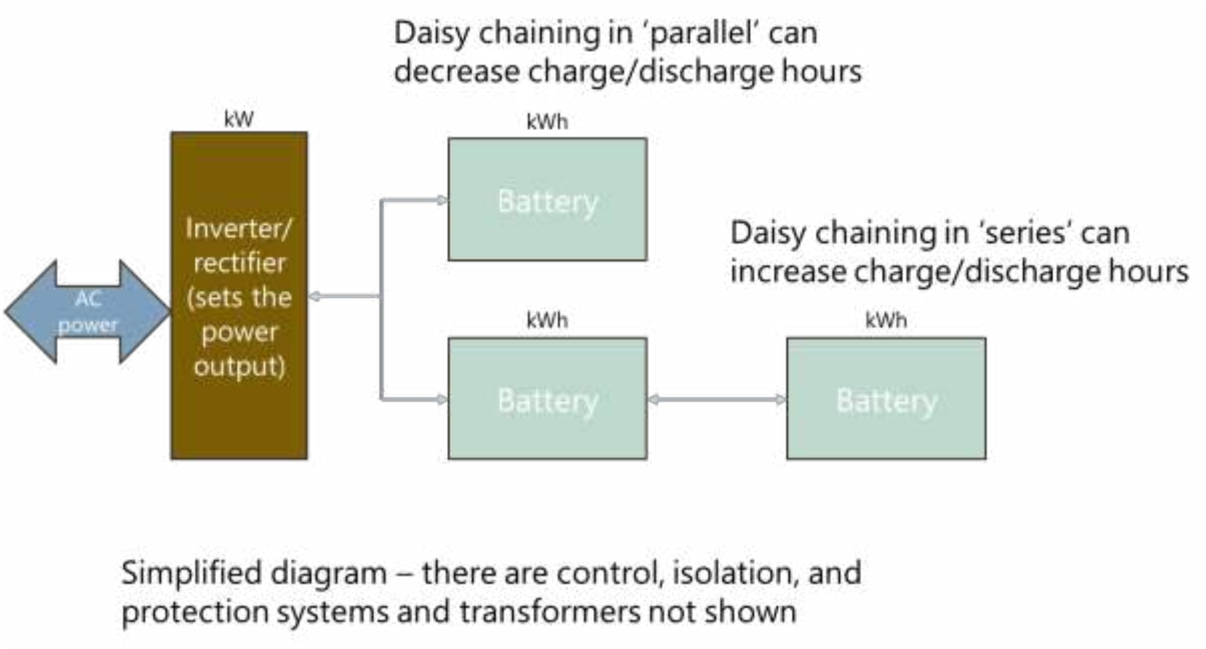
Table 1 – BESS terminology

Term	Definition
Rated power output (kW)	The theoretical maximum amount of instantaneous power, measured in kilowatts, which can flow into or out of a battery.
Rated power energy (kWh)	A theoretical measure of battery power delivered over a given time period i.e. 1 kWh is equivalent to 1 kW of constant power over the period of 1 hour. 1 kWh is also equivalent to 3.6 megajoules (MJ).
Specific energy (Wh/kg)	This measures the battery's energy density, with implications on battery footprint. Long runtime batteries are optimised for high specific energy.

[3] Charging hours can be viewed as the inverse of C-rating (or charge/discharge rate), where the latter is a measure of the rate at which a battery is discharged relative to its maximum capacity.

Term	Definition
Round trip efficiency (%)	The percentage of energy used to charge the battery (i.e. put into storage) which can then be later retrieved. This is essentially a measure of the energy lost during a given charge-discharge cycle.
Daily self-discharge rate (%)	Energy loss per day
C-rating (hours^{-1}) **(Input charge rate)**	The charge/discharge rate is a measure of how much time is required to fully charge or discharge a battery. Note that the C-rating of a battery impacts power output e.g. a 120kWh battery with a C/2 rating will provide 60kW of power over 2 hours. A C/12 equivalent would provide 10kW over 12 hours.
Output charge rate	An inverter can put a limit on the battery's charge rate, so that output charge rate is less than the battery's C-rating by design. For example, a 2MW 1C battery is capable of charging/discharging 2MW in 1 hour but if the inverter is only 1MW, then it will only charge/discharge 1MW.
Ramp rate (sec or ms)	The speed at which BESS can change from import to export, with implications for power swing.
Lifetime degradation (%lifetime)	A process which permanently reduces the amount of energy a battery can store, or the amount of power it can deliver. This can be due to time degradation or cycle degradation, usually presented on a per year or per cycle basis.
Battery lifetime (years or cycles)	Battery lifetime is equivalent to the number of cycles or period of time before the battery will either no longer hold charge or performance is significantly reduced. This lifetime may also be converted to years.

Figure 1 – BESS parallel vs series daisy chaining



2.2 Battery chemistries

The table below maps the BESS characteristic to the relevant value streams, and assesses three BESS chemistries against that BESS characteristic. A darker green means the chemistry performs relatively better against the respective BESS characteristic.

We note that our model back-solves some key BESS characteristic that are a required for a given use case, such as C-rating and the charge/discharge rate. We then compare these modelling outputs against real-world characteristics of known BESS chemistries.

Table 2 – Battery characteristics by chemistry

BESS characteristic	Characteristic is relevant for:	Lithium-ion (LFP)	Nickel-hydrogen (Ni-MH)	Sodium-ion (Na-ion)
Nr of cycles (lifetime)	Economics (all value streams)	2,000-5,400	30,000	30,000
Expected lifetime (years)[4]	Economics (all value streams)	15	30	25

[4] The number of lifetime cycles and economic lifetimes shown here represent the maximum potential at which the battery technology can be spec-ed for. In reality, lifetime battery performance will be significantly affected by

BESS characteristic	Characteristic is relevant for:	Lithium-ion (LFP)	Nickel-hydrogen (Ni-MH)	Sodium-ion (Na-ion)
Energy density (kWh/m3) / footprint (m3)	Footprint (all value streams)	80-200 / 15.2	70-100 /14.6	>20
Discharge hours	Energy/capacity value streams	Up to 8	2-12	Up to 5
Daily self-discharge rate	Energy shifting	0.1-0.3%	1%	n.a.
Response rate (ms)	FIR/SIR	ms	n.a	0.001
Round-trip efficiency	Economics (all value streams)	80-98%	81%	99%
Flammability	Economics (cost of installation, O&M)	Extremely	Not flammable	Not flammable
LCOS ($/MWh, 300 cycles p.a.)	Economics (all value streams)	$250-275	$190-230	$553

Source: Sapere analysis

2.3 Charging and discharging decisions in the wholesale market

Sapere has developed an algorithm to optimise charging and discharging decisions when trading in the wholesale market (spot and reserve), based on the (i) BESS opportunity cost of cycling and (ii) BESS opportunity cost of charging or discharging (together referred to as the total opportunity cost of cycling).

the way in which it is operated (e.g. how hard it is cycled, ambient temperature etc.), given the associated cycle and lifetime degradation. As such, the relationship between lifetime number of cycles and economic lifetime is not linear.

Opportunity cost of cycling

Battery cycling has an opportunity cost, which is a function of days of battery life and is the opportunity cost of battery degradation. For a lithium-ion technology, the typical number of cycles over the lifetime is 5,000. There may also be limits on number of cycles per day. If the battery is cycled harder (i.e. harder than the implied cycled rate on average), the time for the battery replacement is advanced. The opportunity cost of degradation is used to determine an optimal cycling of the battery.

Appendix A describes in more detail how charge and discharges decisions are made when trading the wholesale market.

Opportunity cost of charging

The opportunity cost of charging is the cost of charging from the market, and is measured by the difference between the low price when the battery is charging, and the high price when the battery is selling into the market (see **Error! Reference source not found.** in Appendix A)).[5] The high future price needs to be expected to exceed the opportunity cost of cycling plus the actual cost of charging, whilst also accounting for BESS round trip efficiency (i.e. the future price also needs to pay for energy losses in the round-trip cycling of the BESS).

The opportunity cost of charging for FIR and SIR is low, providing that the required storage is retained in the BESS then multiple periods of FIR and SIR revenue can be earned. Sometimes this storage may be better deployed for extending slightly price arbitrage, but the price opportunity would then need to also be worth missing the number of periods of FIR and SIR revenue until the next charging opportunity.

Opportunity cost of discharge

Once a battery is charged, the opportunity cost of discharge is the best revenue outcome that can be obtained before the next charging opportunity. This is expected to be the price forecasted when the charging decision is made, that recovers cycling costs and charging costs (including round trip efficiency), but there will be times when prices differ from forecasted. This is not inefficient but is the reality of trading in a dynamic market.

[5] These low and high points are the outputs of a battery cycling optimisation algorithm that make cycling decisions to maximise profit; this algorithm requires assumptions on future expected prices.

3. Typical use cases

Our analysis of typical process heat use cases was informed by actual examples from sites selected by EECA.

We were provided data from three actual industrial sites. Two were very similar process heat users, so they were combined into a single use case. We have used this data to build an internally consistent BESS model, and to define typical use cases that can show how BESS can be used.

3.1 Process heat user

Two industrial use cases had similar characteristics:

- Quite high and stable power consumption but with variable demand at the margin
  - One case had a seasonal demand
  - One case reduced load significantly in the weekends.
- An opportunity to electrify and expand operations but with limited available electricity network capacity.
- Retaining gas boiler capacity to enable dynamic fuel switching and further electricity demand management.

3.2 EV depot

One use case was an EV depot looking to completely electrify the fleet:

- The depot has an existing baseload of demand
- There would be some top up charging but a significant peak when vehicles return to the yard
- There is very restricted network capacity.

4. New modelling

New functionality needed to be built to assess BESS in the applications identified. The improvements are outlined below.

4.1 Improvements to market optimisation

Energy arbitrage logic in the model has been enhanced to allow partial charge or discharge, thereby enabling the algorithm to optimise for different battery chemistries, sizes and use cases. The previous logic was optimised primarily for fast charge and discharge and relatively small batteries compared to the power output. Sensitivity testing was also undertaken to determine how the net payoff might vary depending on the length of the trading period over which optimisation decisions are made, to get a sense of the impact of price uncertainty.

4.2 Network utilisation and capacity scheduling

To assess the use case for BESS to effectively increase demand capacity by increasing the utilisation of existing network capacity, new logic was added to the model. The resulting schedule is then also used to determine when the BESS can be used for market revenue. Meeting network capacity is the highest priority. This new model logic includes:

- An ability to expand network capacity. The model includes existing capacity either total or spare capacity) but sometimes more capacity is needed, and this is another input to the model.
- An ability to add a new load (i.e. electrification load) as either a set baseload or a profile.
- The logic reverse engineers the BESS sizing (both inverter and battery size) from simulating demand and available capacity over time. The simulated BESS discharges when demand exceeds available network capacity and can then charge when demand falls below that level.
- The logic makes estimates of the capital costs and BESS specifications, such as maximum and minimum charging hours.
- The charge/discharge schedule can then be used to determine market opportunities (price arbitrage and IR). Although this also requires a judgement on whether the BESS capacity must be retained for unpredictable peaks.

4.3 Electricity vs gas trade-off and CPD scheduling

To allow for fuel switching between gas and electrode boilers, plus also use gas switching and the BESS to reduce electricity consumption during peak charging times (when they can be determined), another new logic was added. This new model logic for switching between gas and electricity supply for boiler steam supply includes:

- An existing gas consumption profile
- A specified electric boiler size

- Inputs for gas, carbon, and electricity costs
- A schedule for reducing electric boiler consumption during network pricing periods, which can be switched on and off.

4.4 Cost assumptions

The BESS capital costs are summarised in the following table.

Table 3 – Assumptions on BESS capital costs

	Li-ion	Ni-MH	Na-ion
Power ($/kW)	$150	$165	$150
Energy ($/kWh)	$310	$330	$550
Min charging hours)	1	1	0.001
Max charging hours	5	12	5

Source: Ara Ake (2023)

5. Results

The BESS profile is reverse engineered from the demand. First, the demand profile is operated in parallel to the network capacity limit, with any exceedances of the capacity limit being 'supplied' by an imaginary energy source. This source can get energy back from the network when the industrial demand is using less than the network capacity limit but it may not stockpile energy, i.e. it is limited to zero at the maximum. There is an efficiency loss in both directions of supplying energy and recovering it for roundtrip efficiency.

The highest level of cumulative energy the imaginary energy source must supply determines the battery size. The regime is then run again except this time the energy to supply the industrial demand comes from both a BESS of the defined capacity defined above and an imaginary energy source. The imaginary energy source can still be necessary because the starting charge of the BESS isn't right, and the BESS can run out of energy. If a third run with the corrected start charge yields a repeatable charging profile with the defined BESS, then that specification is deemed feasible.

Charge and cycling rates can then be determined from the final regime and a practical BESS configuration determined. A fourth run can also be done to assess any opportunities there are to use the BESS for market opportunities when available.

5.1 Process heat modelling

We used two methods to increase the demand of our example process heat user to allow for a new electrode boiler. One was to simply apply a baseload of demand to the example profile to get a new demand profile. For example, if we added a 3.5MW boiler using this method, the example demand profile would lift up by 3.5MW in every period.

We could also apply a boiler demand profile based on a fuel switching model, which we describe more about below.

Figure 2 shows a one-week sequence of demand flow and BESS activity. The orange line is network demand, and it shows that the BESS is effective at limiting the demand to the network capacity of 12.5MW. The gold line is the process heat user's demand (with 3,800kW boiler) and can exceed the network capacity by almost a MW. When the gold line exceeds the orange line the BESS discharges (purple line) matching the user demand. When the user demand falls back below the network capacity then the BESS charges again to be ready for the next discharge cycle.

Although the BESS can manage to the network power limit in theory, there are some practical problems, not least that the BESS needs to be quite large (in energy storage terms) to meet this requirement.

Figure 2 – Example of BESS operation to limit network capacity

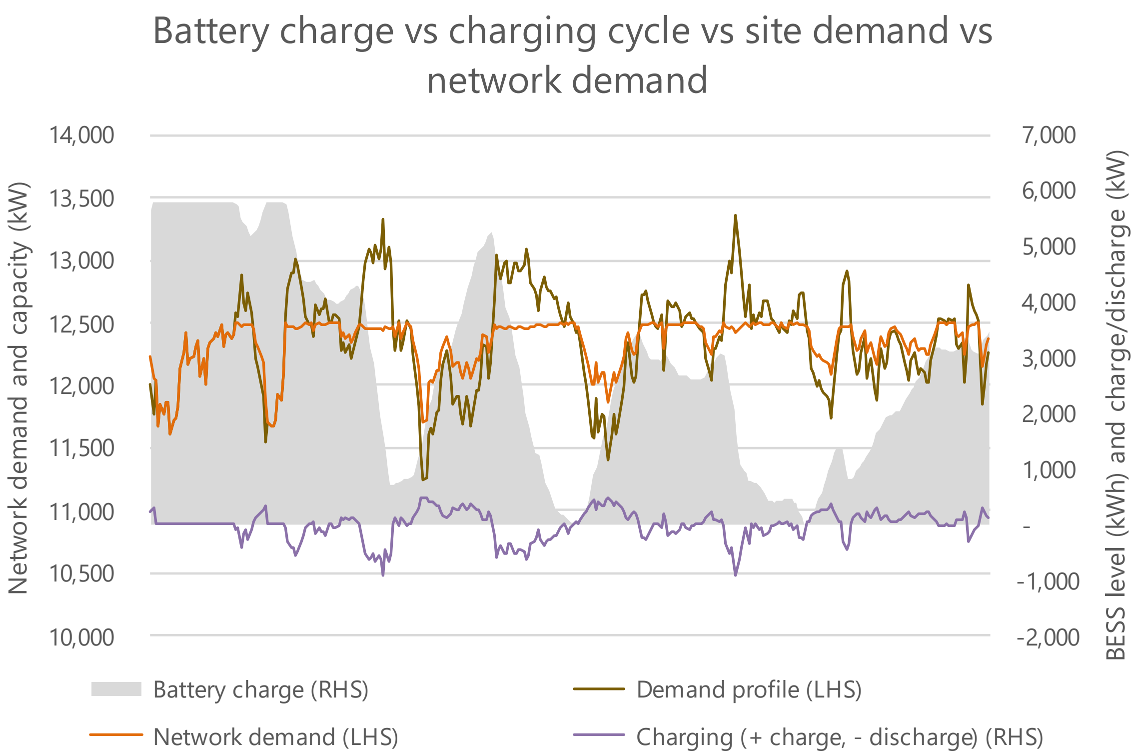


Table 4 has the modelled results for using a BESS to manage the process heat user's example demand with a 3,800kW boiler added as baseload. While the BESS achieves an impressive utilisation factor for the network capacity (94%), it needs a large battery and has very long charge times. The size of the battery adds significant cost and yet the BESS utilisation is only 8%.

Table 4 – BESS specification and results for adding 3.8MW boiler

Characteristic	**Value**	**Unit**
Average demand (with boiler)	11,766	kW
Network capacity limit	12,500	kW
Maximum BESS power (charging)	895	kW
Maximum BESS power (discharging)	932	kW
BESS energy storage	5,639	kWh
Max BESS charge (or discharge) time	36	hours
BESS utilisation	8	%

This is a characteristic of the example demand. We found this characteristic with both sets of example data. There are long periods of time where the user demand is less than the network capacity even with the new boiler. In both cases when the demand peaks it peaks above network demand, or near network demand for long periods. This may be a feature of industrial users that dry a product, i.e.

when there is a peak of product to be dried then the drying sequence for that flush may take a long time. We note that any ability to manage this peak demand would help a BESS system to be more economic.

This characteristic is difficult for a BESS application. To meet the specification, we look at the capital costs for three battery chemistries, Li-ion, Na-ion, and Ni-MH, which yield the following capital costs.

Table 5 – indicative capital costs for different technologies

Chemistry	Capital cost (total)	Capital cost (per kW)[6]	Bespoke design
Li-ion	$1.90 million	$2,000	Yes
Na-ion	$3.26 million	$3,500	Yes
Ni-MH	$2.01million	$2,200	Yes

These numbers aren't directly comparable as the BESS technologies have different economic lives. Li-ion has the shortest economic life, which would make the other two technologies potentially cheaper. However, there is another characteristic that would affect costs in practice. All of the technologies would need a bespoke design to work in the process user application. This is because the duration of charge exceeds the standard specification of all technologies (Ni-MH has the longest at 12 hours).

All of the battery technologies would need a sequential charging design where one battery pack charges, and then more packs charge sequentially to get to the required duration of charging hours. However, Li-ion has another problem. If you divide the specified BESS capacity for this application (5,239kWh) into enough packs to meet the longest charge duration, the resulting battery packs aren't large enough to meet the minimum charging hours required.[7] This can be addressed by using a larger battery, but this adds significant cost to the design. Overall, Li-ion probably isn't a practical chemistry for this application. Both Na-ion and Ni-MH might be better suited, but each would still need a bespoke design for them to work. We note that they should work in theory but would need to be evaluated in practice.

Depending on the cost of network upgrades, i.e. if significant network upgrades are required upstream to get new capacity, then the costs for the BESS solution may be competitive. However, the BESS application has limited ability to scale. The peak demand periods for the example data were not only of long duration, but also do not fall much below peak levels for even longer. Therefore, adding in a slightly higher baseload boiler (3.9MW) significantly increases the BESS requirements as shown in Table 6.

[6] This is the cost per kW to achieve the effective capacity. In this case it needs not only the inverter but also a battery of minimum size. This cost equivalent includes both capital costs.

[7] i.e. each individual battery charges of discharged too slowly.

Table 6 – BESS specification and results for adding 3.9MW boiler

Characteristic	Value	Unit
Average demand (with boiler)	11,875	kW
Network capacity limit	12,500	kW
Maximum BESS power (charging)	978	kW
Maximum BESS power (discharging)	1,040	kW
BESS energy storage	14,265	kWh
Max BESS charge (or discharge) time	61	hours
BESS utilisation	12	%

Adding just 100kW of extra baseload demand increased the BESS storage requirement by almost three times, and almost doubled the charging hours. This significantly increases costs as shown in Table 7.

Table 7 – indicative capital costs for different technologies with larger boiler

Chemistry	Capital cost (total)	Capital cost (per kW)	Bespoke design
Li-ion	$4.59 million	$4,400	Yes
Na-ion	$8.02 million	$7,700	Yes
Ni-MH	$4.88 million	$4,700	Yes

Although BESS could theoretically work for the example process heat applications, BESS is better suited to loads that have much shorter duration peak periods, even if more frequent or even larger. For a frequent but short duration peak the energy storage can be smaller even if quite a large peak power is offset. In this application a BESS is much cheaper and potentially more cost effective.

5.1.1 Using a BESS for network cost management

We looked at using the BESS to manage network charges as an added value stream for the BESS. However, we weren't able to make much difference. In the case of one of the example applications the network capacity was effectively a fixed charge by the EDB, and the BESS could not influence the outcome. In the second example the EDB had a Coincident Peak Demand (CPD) charging regime. Theoretically, if the demand of the industrial user could be moved to a different period from when the network reaches peak demand, the industrial user could lower its network charges. However, the selected industrial user was such a large proportion of the network demand that it couldn't move load without creating a new network peak. Effectively, whenever the industrial user reached its peak demand, that time would be the network peak, and CPD charges would be applied.

We note, though, that flattening a user's demand profile generally yields the lowest overall costs. If a user has flat demand, then they are getting the highest utilisation for both connection assets (and therefore charges) and network charges.

5.1.2 Fuel switching

Process heat users have the opportunity to retain a gas boiler for resilience and to arbitrage between fuels (gas and electricity). To work out how this might affect the BESS economics, we developed a fuel switching model.

The fuel switching logic uses a gas price, carbon price, and relative gas and electrode boiler efficiencies to determine an electricity-equivalent gas price. This electricity-equivalent gas price is then used as a strike price in deciding when to use gas or electricity, i.e. if electricity is above this price gas, then the electrode boiler is used and vice versa. It was assumed that the fuels can be switched quickly and needed to be used for as little as 30 minutes.

The steam load of the industrial use case was also converted to electricity consumption to determine volumes. The electrode boiler was sized based on our standard scenario (3.8MW). Sometimes the steam demand was less than could be produced by the electrode boiler and the boiler demand was limited to the steam demand. Alternatively, the electric boiler cannot always meet the full steam demand, and the gas boiler is sometimes needed as well as well as the electrode boiler.

Using a gas price of $20/GJ and a carbon price at $80/t gives an equivalent price of $93/MWh. This is then compared to an electricity price sequence, and either full gas boiler or maximum electric and rest gas modes are chosen. The electric boiler profile is then used in the network demand logic, where the fuel switched profile is used instead of the baseload assumption, to assess the operation of the BESS in this case.

The fuel switching didn't make much difference to the size of the BESS energy storage, as shown in Table 8.

Table 8 – BESS specification and results for adding 3.8MW boiler and gas switching

Characteristic	Value	Unit
Average demand (with boiler)	9,695	kW
Network capacity limit	12,500	kW
Maximum BESS power (charging)	461	kW
Maximum BESS power (discharging)	677	kW
BESS energy storage	5,504	kWh
Max BESS charge (or discharge) time	36	hours
BESS utilisation	4	%

The average electricity demand drops significantly with fuel switching (~2MWh). However, although the peak duration and size was reduced, there was still a significant amount of electricity consumed over the peak requiring a 5.5MWh BESS, only slightly smaller than the base case. Therefore, costs are lower but not much as shown in Table 9.

Table 9 – indicative capital costs for different technologies with fuel switching

Chemistry	Capital cost (total)	Capital cost (per kW)	Bespoke design
Li-ion	$1.82 million	$2,700	Yes
Na-ion	$3.14 million	$4,600	Yes
Ni-MH	$1.93 million	$2,800	Yes

As the fuel switching had more effect on the size of the peak (250kW lower) than the storage requirement, the cost per kW rate went up significantly.

The modelling still showed significant gas consumption, even though it didn't make that much difference to the peak electricity demand. In a future with potentially high gas and carbon prices, and if the electricity market returns to prices more consistent with long-term averages, then there would be far less switching to gas. This would mean that the requirement for the BESS would be similar to the base case.

5.1.3 Electricity market revenue

In the base case we assumed no revenue from the electricity market. This is due to the uncertainty of when demand might peak. While it would not be worth risking network capacity chasing market revenue being able to reliably predict when peaks occur can yield significant market revenue, which changes the economics of a battery solution.

We did assess market revenue under the case of perfect foresight, i.e. assuming that any time that the BESS isn't being used to manage peak demand that it is used for market revenue. As the BESS utilisation is relatively low then the perfect foresight revenue isn't much less than using the BESS only for market revenue and gives the results in

Table 10.

Table 10 – Market revenue from base case and perfect foresight

Market revenue	Annual value	Approximate PV
Reserve revenue (FIR and SIR)	$51,000	$437,000
Discharge revenue	$45,000	$385,000
Charge costs	-$38,000	-$325,000
Total	$58,000	$497,000

A PV of around $500,000 is relatively small compared to the capital cost of the base case ($1.9 million for Li-ion). This is relatively small for two reasons. First, the battery required for the network management is significantly larger than the battery required for market revenue. Second, even if the battery size is optimised for market revenue the New Zealand electricity market only yields about 60-70% of the required revenue for a BESS. Nevertheless capturing some market revenue changes the economics of the BESS significantly.

5.2 EV depot modelling

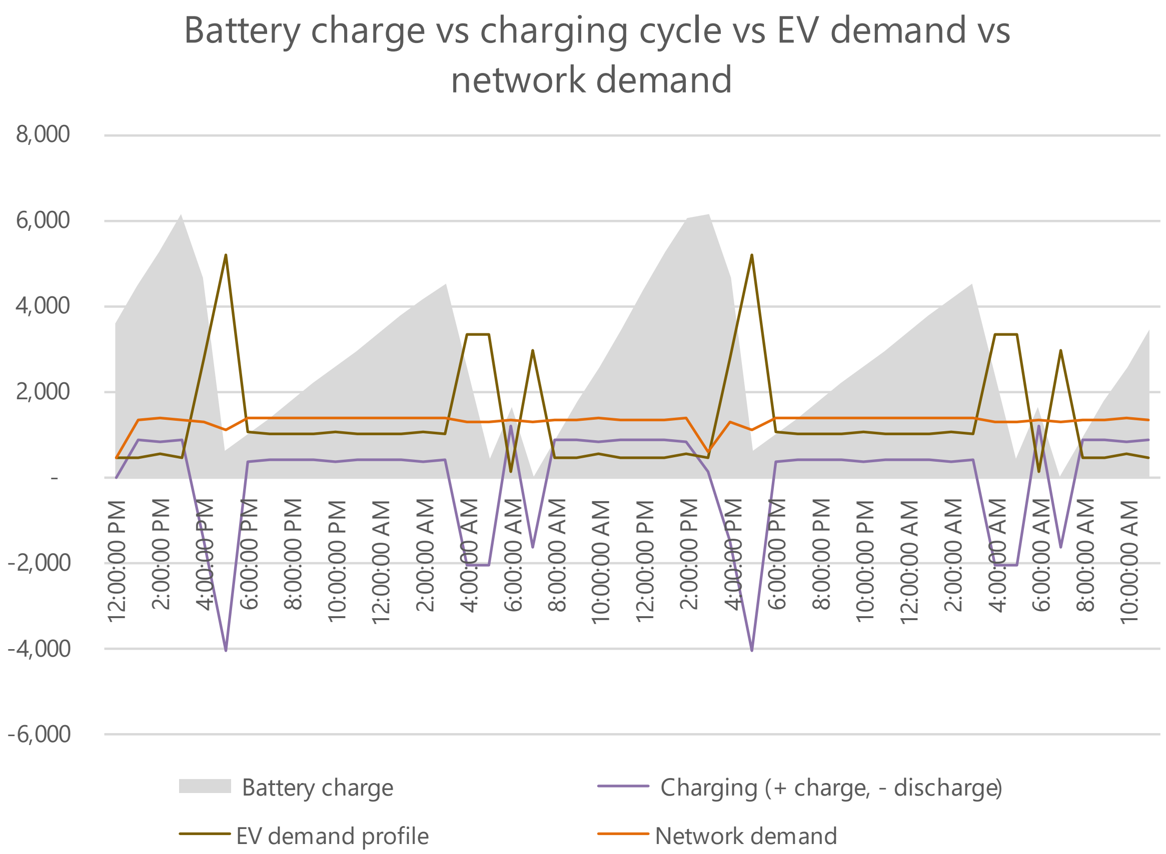
The use of BESS for avoiding network upgrades for a yard that has a large number of high-usage EVs is interesting. On the one hand, BESS can significantly improve the network utilisation, potentially allowing significant cost savings. On the other, the EVs have both a significant energy and power requirement that requires a large BESS.

To give an indication on the practicality of using a BESS in this application, an EV depot owner made an estimate of a day's charging profile for their fleet if it was fully electrified. The operation of the EVs means that the depot peaks twice a day, creating a significant peak in the morning and an even larger peak in the late afternoon.

We used the day's profile through the capacity utilisation model, which gave the result shown in Figure 3. The EV and yard demand profile (the gold line) is very peaky reaching as high as 5.2MW, but the morning peak also reaches 3.3MW. This is multiples higher than the depot's existing spare capacity. There would also be baseload demand of charging for vehicles with ad-hoc schedules, which means that the power available for charging is quite low, resulting in long charge times, while the discharge times are very short. Note, in this case we modelled the increase in demand for EV's and the incremental capacity rather than total demand at the depot.

In this particular case, the existing depot capacity cannot physically deliver enough energy for the assessed EV demand, even if the network capacity is utilised to a maximum. However, a BESS could allow a significant increase in the EV demand with a moderate increase in network capacity. We assumed the network capacity would be increased by 930kW to give 1,430kW of spare capacity. As shown in Figure 3, the BESS manages very closely to the spare capacity (orange line). It cannot perfectly match to the network capacity due to charging losses.

Figure 3 – charging regime for a BESS in an EV depot



In this application, a BESS could avoid significant network costs. However, the BESS solution is not cheap and needs significant energy storage as shown in Table 11.

Table 11 – BESS specification and results for EV depot

Characteristic	**Value**	**Unit**
Average increase in demand	1,428	kW
Network spare capacity limit	1,429	kW
Maximum BESS power (charging)	1,216	kW
Maximum BESS power (discharging)	4,070	kW
BESS energy storage	6,169	kWh
Max BESS charge (or discharge) time	10	hours
BESS utilisation	98	%

The maximum power discharge from the BESS is also significant at 4MW. Therefore, the required BESS is quite expensive as shown in Table 12.

Table 12 – indicative capital costs for different technologies for EV depot

Chemistry	Capital cost (total)	Capital cost (per kW)	Bespoke design
Li-ion	$2.58 million	$600	Yes
Na-ion	$4.06 million	$1,000	Yes
Ni-MH	$2.71 million	$700	Yes

As the BESS cost is offsetting a significant peak demand, the per kW costs look very competitive. However, this application is pushing the technology hard. With very high utilisation and the high levels of cycling, Li-ion probably won't be suitable, and a less mainstream battery technology would need to be looked at.

The minimum charge rates might also be challenging for Ni-MH, although this chemistry easily achieves the maximum charge rate. It might be possible for a hybrid design (say Li-ion and Ni-MH) to meet the specification, but it would also be worth looking at one of the more promising new chemistries such as Na-ion. These technologies (including Ni-MH) have other advantages. As they are not flammable and handle heat better, they have a much smaller footprint than Li-ion and can potentially even be stacked vertically.

A BESS is feasible for the EV depot application, but an engineering study would be needed to establish practicality and cost.

6. Insights

We have derived the following learnings from this modelling work on BESS.

6.1 Value and cost drivers

The cost effectiveness of a BESS is highly context specific. BESS will always struggle if network upgrade costs (the alternative way to batteries, to enable higher electricity demand) are low. Even if network upgrade costs are high, the nature of the demand to be managed drives the BESS size and the cost of any solution. Based on our modelling so far, BESS is best suited to relatively short peaks even if those are sharp and frequent. Long drawn-out peaks need big, high-storage batteries, which increases costs substantially.

Generally, BESS is best suited to loads that have shorter peaks. However, if additional demand and BESS size are coordinated, BESS may be cheaper than network upgrades. However, the economies of scale favour network upgrades. A further small increase in network capacity (if an upgrade goes ahead) can be cheap or even costless on an incremental basis, whereas a further small increment in BESS capacity when it has been optimised for demand and capacity will have some cost. Any ability to manage demand in conjunction with a BESS would help reduce BESS costs.

6.2 Evaluating new technology

The go-to technology for BESS in power applications has been Li-ion. As a result, Li-ion is relatively cheap and preferred by most operators. However, Li-ion doesn't always have the best specification for the applications we have modelled. Emerging battery technologies, such as Na-ion and Ni-MH, would be worth pursuing, but are relatively expensive and there is less experience in using them currently. This would be expected to change with the successful deployment of these technologies.

For example, BESS looks competitive to network upgrades for an EV depot, but Li-ion probably won't be a suitable technology. The EV use case makes most use of a BESS but would probably be best served by an emerging battery chemistry. This would be an innovation and, therefore, may not be a cheap approach, but might end up being a cost-effective approach for this application.

6.3 Value of predictability

When demand is unpredictable, or BESS utilisation is high, then it is difficult to use the BESS for other purposes (e.g. price arbitrage and IR). Even if BESS utilisation is very low but a peak could occur at any time, depleting BESS storage for another purpose risks removing the ability to respond to an uncertain peak. Predictability of demand, or some ability to limit a peak for a while, can help not only reduce the necessary size of a BESS, but potentially also allow more value streams.

The more predictable demand is then the more the BESS can also be used to secure market revenue. In the best possible case for our process heat case (i.e. demand is so predictable that the BESS can be used for market revenue every time it isn't being used for managing network peaks) then market revenue can yield 25% of the capital costs of the BESS. This proportion would be significantly higher in the case where a smaller BESS could be used (i.e. shorter peaks).

6.4 Managing network charges

Unpredictability in demand can also make it difficult to manage network charges. Attempts to push usage down at a particular time could be offset by a new peak if the industrial demand peaks shortly after the BESS has discharged. Industrial users are also often likely to be a large proportion of distribution feeder demand. This gives a similar problem. Significant demand might be shifted away from a coincident peak demand, but the new peak created by moving the demand might create the new coincident peak.

However, we note that the best value for line charges, including connection charges, occurs when the connection assets are near maximum possible utilisation. In this case using a BESS to level out the load profile would mean that network charges, including connection charges, should be constant and be the cheapest they can be on a per unit energy basis.

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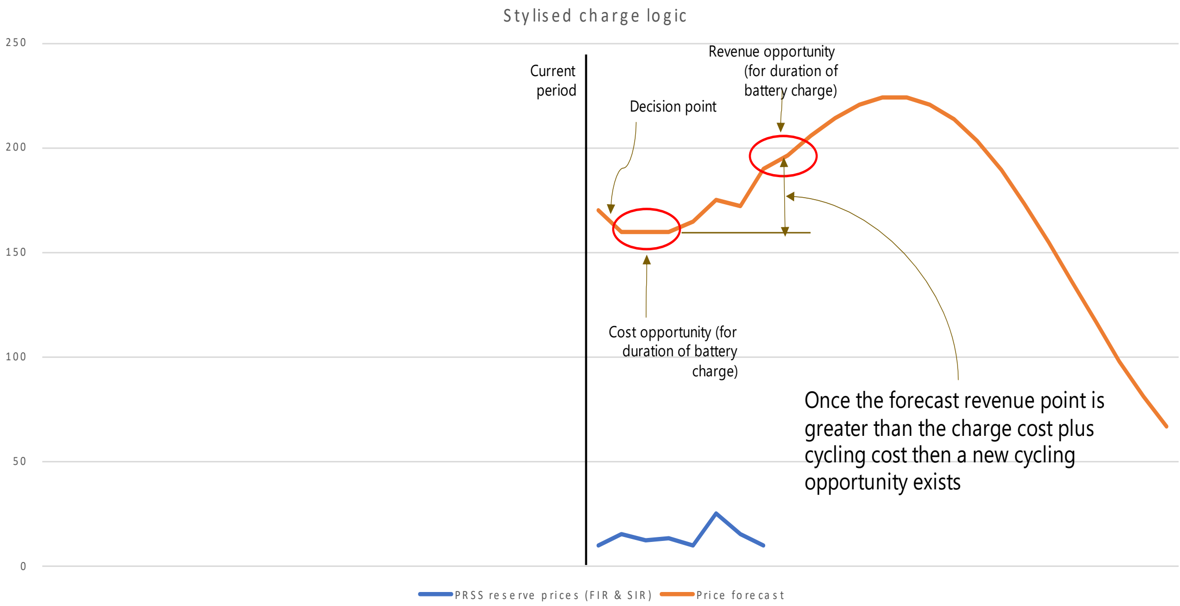
Appendix A Charge and discharge decisions

Charging decision

The figure below shows the logic for the charging decision. The price forecast is based on PRSS for the first 8 periods, and on (adjusted) historical prices subsequently.[8]

Figure 4 – Stylised battery charge logic



Charging signals are made looking forward, and are triggered when there is opportunity in the future where a price for discharge would be greater than the total cost to charge today.

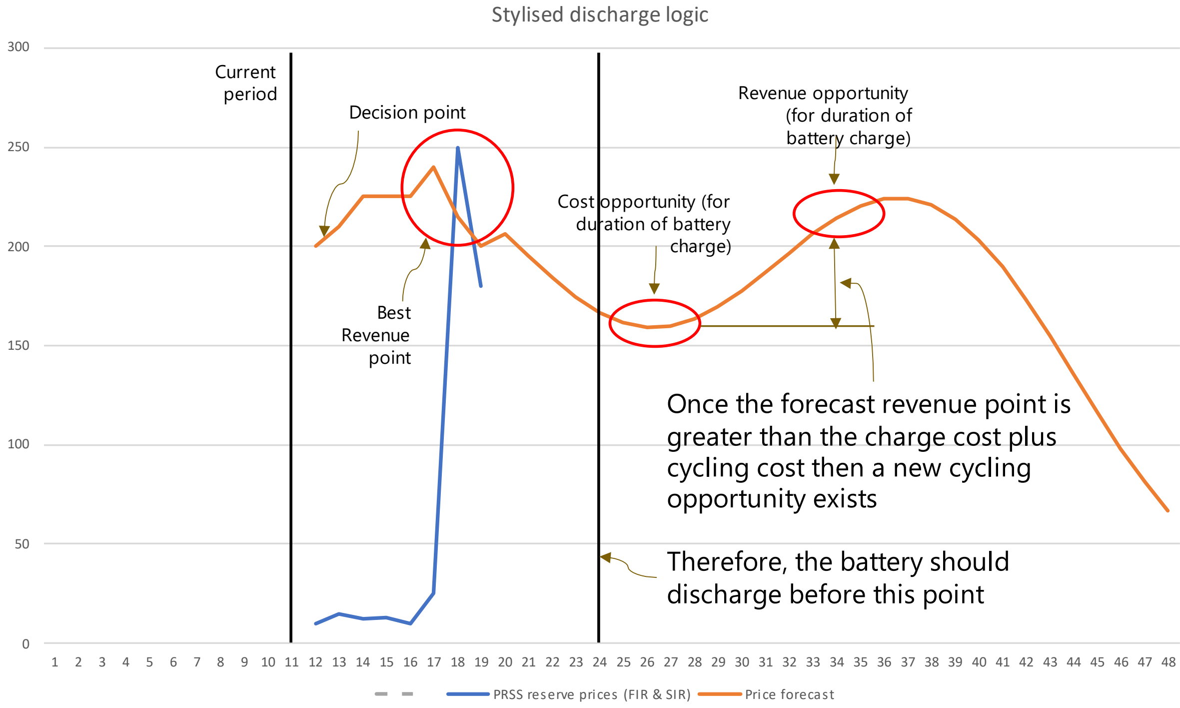
In the figure, once the decision point reaches the total opportunity cost of a new cycling opportunity, then the battery should start charging. We note that, while charging, the charging load of the battery can also be offered as reserve, if the battery has 15 minutes of storage while charging then the reserve volume = the charge volume + the discharge potential.

[8] The adjustments are meant to capture expectations about whether or not prices will be lower or higher than currently based on average price profiles. The PRLS could also be used but it is debatable which is more accurate.

Discharge decision

The figure below shows the logic for a discharge decision.

Figure 5 – Stylised battery discharge logic



Discharge decisions are dependent on charge signals: the objective is to find a maximum expected price between two charge signals.

In the figure, as the decision point price is below the best revenue point then the battery would not discharge at this time.

Once the decision point equals the best revenue point (allowing for the discharge time of the battery) then the battery should discharge (but keep 15 mins of charge for reserve).

Anytime the PRSS reserve price is higher than the energy price, or the battery isn't discharging then it can get reserve revenue.

The BESS can be offered for both energy and reserve but then the full energy dispatch may not occur. When reserve is offered when there is an energy offer then there is an opportunity cost of FIR and SIR. If FIR and SIR are offered cheaply in this case, then the BESS will likely miss more valuable energy revenue. In this case, FIR and SIR should be offered at the difference between the energy offer and the next energy price the BESS could discharge in, i.e. if the BESS gets dispatched for FIR and/or SIR and then discharges in a later period then the combined revenue from FIR, SIR, and the later discharge should at least equal the missed energy price.

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