Power Trip

Making fleet electrification easy

Industry insights and data use pilot for Product Stewardship for large batteries in New Zealand

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Contents

1. Executive Summary

Commissioned by Ministry for the Environment (MfE) and the Energy Efficiency and Conservation Authority (EECA), Power Trip has provided insight to the challenges in ascertaining electric vehicle (EV) battery health in this report.

Battery state of health is an important feature for the battery passport concept proposed in the large battery product stewardship scheme. Understanding EV battery health is also needed in fleet management including how to maximise battery life through charging behaviours and when to repair, when to transfer to second life uses or when to recycle at end of life.

This partnership between Power Trip, EECA and MfE involved more than 60 interviews with people in the EV and large battery sector and the development of a prototype data portal for EV battery information. The portal was populated with data from a trial of advanced telematics devices placed in more than 40 EVs.

Having data available shows how battery passports can be used to track how a battery's capacity changes over time. This information will allow a battery passport to form a trusted source of information for people and businesses engaging with the emerging second-hand battery market, and to organisations seeking to understand the role that batteries will play in a low-emissions future.

This report also identifies issues around obtaining battery data and publishing it to a public battery passport system. Data was captured from several different types of EVs across multiple public and private organisations. This was used to demonstrate several ways for how usable battery capacity could be calculated from EV data. While results varied from vehicle to vehicle, model to model, charging session to charging session, and driving session to driving session, there was enough consistency to be able to reliably calculate each battery's usable capacity over time.

There are many different businesses seeking battery information, and more are likely to appear over time. This software supporting the prototype portal will be available under an open-source licence to support this. Results of the trial and a description of the portal are provided in Part A of this report.

A key issue identified was the need to work with vehicle manufacturers to enable wider access to battery information and to standardise how data is recorded, processed, and shared to support battery passports. This would improve results, support innovation, increase transparency, increase recycling rates, and support second-life applications as well as enabling a stronger, more transparent second-hand market for batteries and EVs.

The interviews involved key stakeholders across different aspects of a large battery's life, from import to first life use, to second-life repurposing and finally recycling at end of life. We conducted these interviews to understand the impact that product stewardship will have on different businesses and their ability to innovate and address New Zealand's need for batteries in the future. These interviews revealed a significant amount of useful information outside of the scope of this report. This information has been summarised and included in Part B.

EV batteries are lasting longer than anticipated and future battery technology could increase this lifespan even further. This implies that businesses are more likely to upgrade their batteries to take advantage of increased range, safety and charging speeds, than in response to diminished energy carrying capacity. On-selling or re-purposing their old batteries will therefore become popular solutions as high-capacity batteries are likely to stay in demand for many years to come.

Long lifecycles and changes in application, use and ownership will impact on how batteries can be tracked to ensure they are recycled. A transparent system for sharing data about batteries and ensuring that all stakeholders and owners can benefit from recording and sharing data will ensure that batteries can continue be tracked for a large portion of their lives, without restricting innovation.

Our interviews noted that tracking batteries to ensure they can be recycled was only half of the solution. In New Zealand most recycling operations must be profitable in order to survive. If a recycler cannot make money from a waste stream, they either do not recycle it or they charge a recycling fee to waste owners. While large batteries were more attractive to recycle than small batteries, electronics or plastic due to their valuable materials, shipping costs and a lack of onshore processing means that battery recycling still produces a loss for New Zealand's recycling businesses in general. This is likely to continue until public battery collection processes can be made accessible and convenient, and onshore processing facilities can be established.

Many of the businesses interviewed were being told they will be able to sell or give end of life batteries back to the manufacturer or distributor, but only a few had contracts in place to support this and recycling businesses we interviewed told us that the Chinese Government has implemented a ban on importing used batteries. This highlights the need for a robust second-hand market and independent, onshore battery management and recycling services.

Battery passports, when properly implemented, will provide first buyers and the PSO with an understanding of the battery at the start and end of its life in New Zealand. However, there is a risk that batteries will be lost, dismantled, modified or incorrectly disposed of during their life. This pilot shows that regular updates supported by closer industry cooperation, coordination between the large and small battery stewardship programmes, and greater engagement with battery data has the potential to create higher levels of EV battery recycling. This approach can also support and encourage continued innovation with these essential, emissions-reducing technologies.

2. Introduction

This report was created for MfE and EECA

Ministry for the Environment (MfE) and the Energy Efficiency and Conservation Authority (EECA) jointly contracted Power Trip to produce this report and to undertake the associated data pilot program.

The purpose of the work is to support the design of the large battery product stewardship scheme[1] by collating information from businesses involved in electric and hybrid vehicles (EV) and large battery innovations. This provides a useful snapshot of EV and large battery use, reuse and recycling in New Zealand at this time.

The second part of the work was to produce a Minimum Viable Product (MVP) data portal providing access to EV battery information gathered in a pilot with more than 40 EVs. These two sections are covered in Part A of this report.

Additional information has been gathered from the interviews undertaken with more than 60 stakeholders over the period from May to September 2022 that has relevance to the sector.

[1] The Large battery product stewardship scheme aims to put a framework in place to increase the responsibility of manufacturers, importers, retailers and consumers/users to better manage end-of-life large batteries, and create incentives to keep using resources. For further details go to www.big.org.nz

This information is presented in Part B as additional content.

Information in this report was provided through interviews with stakeholders and is not intended as an in-depth, researched technical study.

This report is not a technical study or intended to be a definite guide to EV and large batteries in New Zealand. It is a summary of the responses made by those interviewed and as such, it includes people's opinions and experiences. Where necessary, we also provide wider background information in a simplified format, particularly around EV data, technology and its limitations, to help readers who may be unfamiliar with these topics.

Interviews conducted to support this report explore areas where battery use in New Zealand is growing rapidly

A future powered by renewable energy will require a tremendous number of batteries, large and small. Until recently, batteries were relegated to small scale electronics devices, like laptops and cameras. But large-scale applications are rapidly becoming mainstream, including cars, trucks, ferries and even power systems.

Due to the urgent need to decarbonise our society, electricity generated from renewable resources will increase. At the same time electrification of transport, industry, commerce, and homes, will result in increasing demand being placed on electricity supply systems. The use of batteries to support electricity systems, when renewable energy resources are low or unavailable, will grow. Innovation and technology development is likely to require more and more energy storage.
This report assesses the potential implications for the increased application of batteries including for:

- Light and heavy electric vehicles (mopeds, cars and trucks)
- Niche electric vehicles (planes, ferries, ships)
- Small scale stationary storage (homes)

- Large scale stationary storage (grid batteries)
- Battery leasing and rental
- Energy storage as a service, and
- Industrial applications (waste disposal).

Battery stewardship is essential because, despite high recyclability, most lithium-ion batteries are not currently recycled

Despite being highly recyclable, today, most lithium-ion batteries of any size are not recycled and are either sent to landfill, dumped into the environment, stockpiled at facilities or, in the case of cell phones and other consumer electronics, kept in a box or draw in peoples homes. Stakeholders we interviewed indicated that less than 10% of batteries are collected for recycling in New Zealand.

In a future powered completely by renewable energy, a sustainable, circular economy for batteries needs to emerge. This includes uses that prolong battery life in society (often called second or third life applications) thereby reducing fossil fuel dependence in other areas.

Unlike other car parts whose deterioration can be measured simply by looking at them (e.g. inspecting wear on a tyre), measuring changes in battery quality over time presents unique challenges. Capacity loss occurs internally at an almost molecular level. This means degradation is measured either by benchmarking battery performance, or by measuring changes in voltage and current across the battery's cells during a period of significant use. Without this information, second-hand markets present a significant risk for companies and innovators who are looking to integrate large previously used batteries into their applications.

Large batteries should be the easiest batteries to recycle

Large battery applications represent the low-hanging fruit of the battery circular economy. They contain large amounts of rare, valuable, and high-grade materials that are easier to collect and sort than small batteries. Small batteries are also often embedded within small devices that are difficult to dismantle, adding expensive labour costs and time to the recycling process.

New businesses and technologies have emerged that allow large batteries to be linked to a digital 'Battery Passport' designed to make tracking the battery, and therefore ensuring it is disposed of correctly, easier via a digital platform. Tracking batteries and keeping a record of their size, chemistry, make and application will allow future businesses to more easily establish recycling facilities that can handle these batteries before they become a problem.

Batteries are essential for reducing fossil fuel use

Batteries are a key technology to replace fossil fuels as the energy storage medium of choice, reducing carbon emissions and the impact of climate change. The rate at which this happens depends on how quickly battery prices fall, on government policies and on how quickly the technology advances.

Lithium-ion batteries are the current industry-leading technology and businesses are racing to create innovative new technology applications using these batteries. These applications will replace fossil fuels in everything from transportation to industrial processes, while also reducing the impact on our electrical grids.

Batteries will reduce energy prices

The scale of the impact that effective, cheap, reliable energy storage through batteries will have on our future is difficult to comprehend. Our interviews with stakeholders revealed a wide variety of applications. As battery prices fall, more and more applications will become viable and batteries will become increasingly important to our way of life.

Real-time data from a battery Is essential for Its continued use

Over-charging or under-charging a lithium-ion battery can result in irreparable damage to the battery. Having accurate, real-time access to Information about the state of charge of a battery is essential for any person or company using the battery in an application. This Information Is provided either via direct measurement of the battery cells, or through the battery management system embedded within the battery pack. Without access to this information in rea-time, batteries cannot easily be re-used in third-party, life-extending applications.

Historic data is essential for robust second-hand markets

Battery technology is advancing rapidly and under ideal conditions modern batteries can last decades. The longer life span and the growing demand for second-hand batteries are creating the need for second-hand battery markets. Second-hand markets extend the useful life of products that would otherwise be discarded, they can also complicate efforts to track batteries as they change hands, such as providing assurance that they will eventually be recycled.

However, battery owners don’t usually have access to information about the health of the batteries that power the products they have bought until the batteries have deteriorated enough to affect their performance or have failed. Advanced electronics applications, like cell phones and vehicles usually only provide their owners with an estimate of the level of charge held by the battery and an estimate of how long it will last for.

When a vehicle is sold new, there is an expectation that the battery will be in perfect condition, even if the vehicle, or the battery, is one or two years old.

Beyond the initial sale, a battery’s resale value depends heavily on the level of degradation it has experienced over time.

This is most evident in second-hand EV sales. Where EVs that contain batteries with low levels of degradation (also known as a high state of health) often sell for thousands of dollars more than an identical vehicle with average or high levels of degradation.

Figure 1 - A low-degradation (95% SoH) vehicle sold at a premium in New Zealand
Source: https://www.facebook.com/ev.city

When it is available, information about a battery's state of health replaces odometer readings as the key factor buyers look for when purchasing an EV from a second-hand car dealer.

The level of attention battery state of health receives from a customer depends on the availability of that information. Battery state of health information is not widely available for most makes/models of EV but this does not prevent vehicles from being sold, and can often make the sale easier for the person or business selling the vehicle.

Buyers that source batteries from older or written-off EVs currently have no way of assessing the health or history of the batteries they are purchasing, with few exceptions (e.g. the Leaf Spy app mentioned above). The risk that the battery may be severely degraded therefore rests with the purchaser, unless the seller is somehow able to verify the health of the battery before the sale is completed.

While this risk is acceptable for businesses that are experimenting with batteries or providing one-off services, it rapidly becomes a barrier to larger scale operations or to business models that rely on longer battery life (e.g. leasing or financing batteries).

A battery passport has been raised as a potential solution that would allow greater sharing of information about batteries and their states of health, as well as ownership and potentially location information.

Investing in improving the recycling process will be frustrated without an optimised process for recovering batteries from their applications. Maximising the information available about batteries will make creating this recovery process much easier to implement.

Recycling keeps valuable waste streams out of the environment

The materials within batteries and other e-waste can become toxic if they leach out into the environment from landfill (e.g. cadmium). If batteries are encased in concrete, or enter a high-quality, fully lined landfill facility, the effects are significantly reduced, but the materials are no longer easily recoverable. Recycling ensures these materials are kept out of the environment, while also ensuring that rare elements that make up these batteries are not lost.

Manufacturers are rapidly increasing battery production

The coming transition away from fossil fuels will require significant battery energy storage. Not only will cars require batteries, but so too will many trucks, airplanes, ships, buildings and energy distribution networks. This is in addition to our current battery use in applications like cell phones, laptops, consumer electronics and power tools, and in future innovations.

Battery manufacturing will likely continue its exponential growth.

For example, global EV sales were 55,000 in 2011[2] and eight years later in 2019 they had grown to two million. In 2030, EV sales are forecast to reach 21 million[3]. Businesses we interviewed believed that there is not enough material available to produce the number of batteries required meet the world's sustainable development goals, and that battery recycling will be required to fill the shortfall.

The consequences of this growth are two-fold:

- Batteries were previously considered to be environmentally inconsequential, but large volumes will become a much larger problem at the end of their lives.
- The materials contained within batteries are often rare, expensive, or located in very few places on earth, and are already used in many other applications. This imbalance in supply and demand gives a small group of material suppliers significant control over the battery market.

Market demand cannot be relied upon as the driving force for recycling

It is widely believed that demand for these materials will create a market for battery recycling. However, markets are not always predictable, and prices are inversely proportional to supply. For example, nickel metal hydride and alkaline batteries have been treated as throw-away batteries, however demand for nickel in lithium-ion batteries has recently caused nickel prices to increase[4], but there is no way to recover the batteries that have previously been thrown away.

Industries are designing components to be replaced, not repaired

It is widely believed in the industry that modern vehicles aren't built to last. Parts that were previously repairable are now only replaceable. New Zealand is a large importer of second-hand vehicles. Vehicles that are considered to have reached

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[2] https://www.iea.org/data-and-statistics/data-product/global-ev-outlook-2022
[3] https://www2.deloitte.com/uk/en/pages/press-releases/articles/21-million-more-electric-vehicles-expected-worldwide-by-2030.html
[4] https://tradingeconomics.com/commodity/nickel

their end of life in other countries are exported to New Zealand. One respondent estimated that more than 90,000 nickel metal hydride batteries have been imported to NZ inside Toyota Priuses.

Over the last few decades, the world's manufacturing industries have moved away from producing repairable products, in favour of producing cheaper products that can simply be replaced. While this approach makes products like cars cheaper, it also produces significantly more waste.

As the world simultaneously moves more towards a future with more battery-powered applications, the practice of replacing parts will likely mean an increase in battery waste, which will require a significant recycling effort to ensure the materials within these batteries are not lost to landfills.

Lithium-ion batteries can cause fires when they enter waste streams

Lithium-ion batteries are a major concern for waste industry due to fires caused by them. There appears to be a reluctant to implement collection systems because they feel the producers should be responsible for them and do not want to manage the hazards and complexities with mixed battery types.

No one is responsible for these products at the end of their life

While several manufacturers we interviewed are establishing internal processes for handling their own batteries, they had also found that other suppliers in the market were focused solely on manufacturing and believed that their responsibility ended shortly after the sale, or that other businesses would generate revenue through recycling their products in the future.

Subscriptions to batteries, products and data were considered as a possible solution that would allow and incentivise manufacturers to maintain some level of responsibility for their products after the sale. However, several businesses we interviewed believed that vehicle manufacturers will move in this direction anyway (for example, BMW now offer subscriptions to a variety of features that were previously included in the purchase price of the vehicle[5]). The feeling among local EV retailers was that customers are rapidly approaching a point where they have too many subscriptions in general, and additional subscriptions would not easily be taken up.

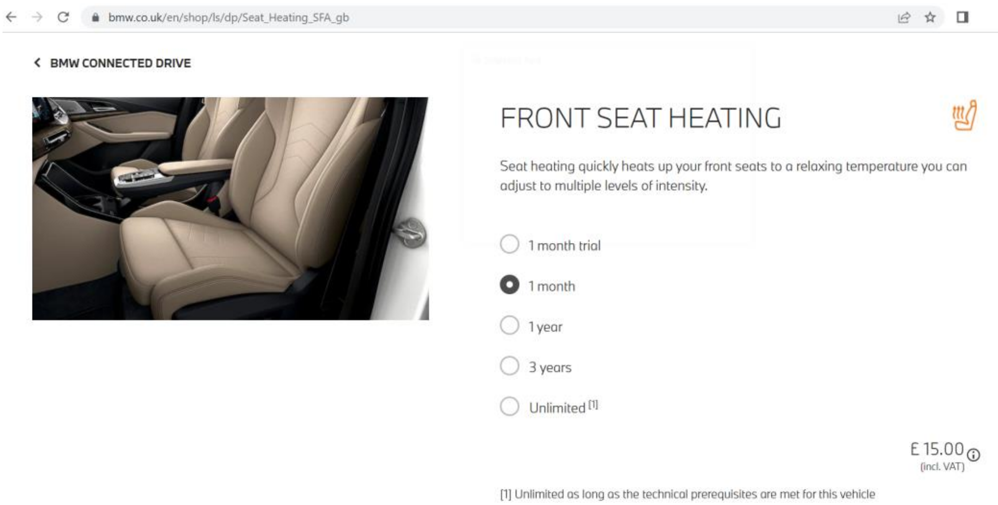

Figure 2 - BMW heated seat subscription, available online as at October 2022
Source: https://www.bmw.co.uk/en/shop/ls/dp/Seat_Heating_SFA_gb

Furthermore, battery recycling facilities do not yet exist in New Zealand, and the shipping and handling costs of offshore recycling are high. Without regulation, this cost disincentivises businesses from collecting back their batteries at the end of their lives.

People have concerns about the effectiveness of recycling

Despite kerbside recycling and public recycling campaigns, less than 10% of plastic worldwide has been recycled to date according to the United Nations[6]. News

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[5] https://www.bmw.co.uk/en/shop/ls/cp/connected-drive
[6] https://www.unep.org/interactives/beat-plastic-pollution/

reports that compare the promise of plastic recycling to this reality[7] and media coverage of the current lack of battery recycling[8] have created a greater awareness of the failure to recycle plastic and the challenges of battery recycling. This awareness is leading to concerns about whether or not batteries will actually be recycled.

Sales businesses we interviewed reported that one of the first questions their customers ask is whether the batteries in their applications can be recycled and believed that product stewardship would help to put customer minds at ease.

Access to recycling options is very limited for New Zealanders

People do not know what to do with batteries, and often do not want to hold on to their end-of-life batteries, but there are currently no easy, accessible, well-publicised, responsible ways for people to dispose of them. Several businesses we interviewed were simply storing batteries in hazardous material storage centers while they waited for battery recycling facilities to become available in New Zealand. Current solutions available to the public included dropping off batteries at local landfill transfer stations or encouraging retailers and workplaces to provide battery collection bins.

Lack of incentives, low confidence in recycling and lack of access mean batteries are simply thrown in the bin

In the worst-cases, this leads to people either throwing batteries in the bin, or placing them into other recycling streams, like kerbside plastic recycling, scrap metal recycling or lead-acid battery recycling collections. Battery fires caused by power tool and consumer electronics batteries are growing increasingly common due to incorrect disposal practices. Waste management facilities report batteries

[7] https://www.npr.org/2020/03/31/822597631/plastic-wars-three-takeaways-from-the-fight-over-the-future-of-plastics

[8] https://www.engineering.com/story/will-your-electric-car-save-the-world-or-wreck-it

fires on an almost weekly basis, scrap metal recyclers are finding lithium batteries in their waste streams, and WasteMINZ are now running workshops on dealing with battery fires.

Trust and transparency are required to overcome these hurdles

Establishing reliable, transparent, and effective stewardship and recycling practices for all materials, let alone batteries, is essential to overcoming this cynicism and ensuring consumer confidence in battery-powered technology as an effective tool for reducing our society’s net-carbon impact.

If recycling is to remain a market-driven industry, then product stewardship regulation, greater engagement in recycling, transparent, convenient access to useful data and accessible technology will be an essential part of ensuring that the industry is competitive, battery lifecycles are optimised and that high recycling rates can be achieved in the future.

Part A

This section of the report covers the original scope – to pilot an MVP data portal for EV battery data, and to gather information from stakeholder interviews regarding EV and large battery challenges and opportunities.

3. Fleet data collection trial

Purpose

This trial demonstrates how battery life and impact can be enhanced when data is tracked using a battery passport system.

Large batteries are often hidden from view (e.g. under the floor of a vehicle) and the key parts of a battery, the cells, are further hidden from view within a battery's casing. This makes inspections difficult. Identifying the chemistry and origin of the battery cells, and any degradation or damage is almost impossible without access to specialised diagnostics tools, or to data from the battery management system itself.

Battery passports can provide owners, buyers, sellers and recyclers with a central record of this information as it is captured over time. Keeping them in use longer, tracking ownership and increasing the chance that they will be recycled.

Proposed battery passport designs will only be updated at the start and end of the battery's life, seldom in between.

Under the proposed battery stewardship direction, information about batteries will be recorded by the importer when the batteries enter New Zealand and then again by the recycler when they exit New Zealand or are recycled. People or businesses repurposing the battery may also record data if required, or if they will receive a subsidy for doing so. Depending on the battery and how it is used, these events could be over 20 years apart and ownership could change hands several times during that period.

A lot can happen to the battery over a 20+ year life.

The battery recorded at the end of life may not be the same as the battery that was originally recorded on import. These changes could include:

- Impacts from use in multiple applications.
- Dismantling and redistribution of cells or modules in other applications.
- Exiting and then re-entering New Zealand.
- Damage to battery cells or other components.
- Replacement of cells or other components.
- Capacity loss due to cell degradation.
- Environmental damage or misuse
- Combustion or other means of destruction.

Updating battery passports after the sale is difficult

Battery passport platforms (e.g. Everledger[9]) currently work with manufacturers to provide transparency over the origin of the materials that make up a large battery and its history up to the point of first sale.

Tracking data about a battery throughout its life after the first sale either requires that batteries or the devices they power are internet-enabled, or that manual updates are periodically added to the platform by the battery owner.

[9] https://everledger.io

This trial explored the possibility of automating the capture of EV battery data from fleet vehicles for the purposes of providing updates to digital battery passports.

Data was collected from Geotab telematics devices, provided by Direct Track. These were connected to the vehicle's on-board computers via the on-board diagnostics (OBD) port. They collected and reported information about the battery from the vehicle's CAN bus (network of electronic controllers) to the fleet owners, who then made this information available to Power Trip via the Geotab application interface (API).

Power Trip created a prototype piece of software that transformed the incoming vehicle data from Geotab's API into a format that is compatible with battery passport specifications provided by Everledger.

The information collected and transformed was also made available on a dashboard to showcase the type of data that is available and to explore how this data could provide useful insights for battery owners.

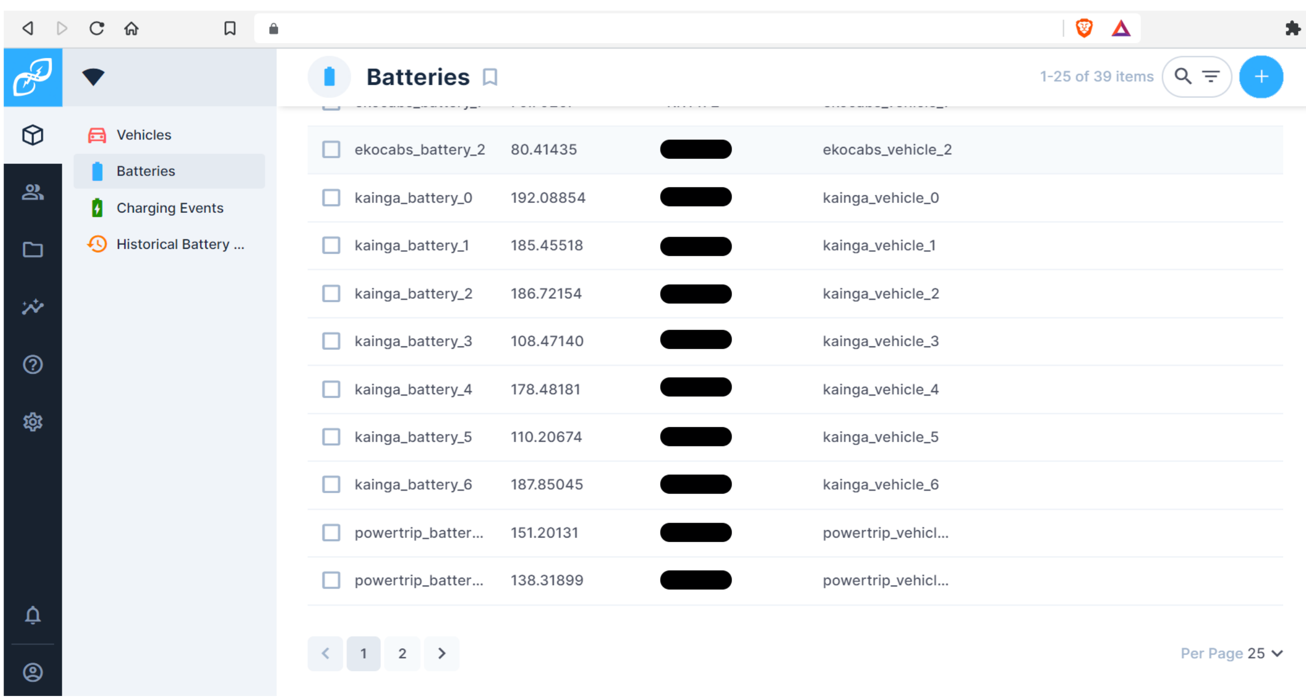


Figure 3 - Software developed during the battery stewardship trial

This trial, and the accompanying interviews, demonstrate the value of regular updates to battery passports

The variety and regularity of data captured during this trial demonstrates how ongoing records can provide insights that could prolong the life of batteries and provide future buyers with confidence in the future lifespan of second-hand batteries.

Method for estimating remaining battery capacity

Data privacy

This project undertook a data security and privacy assessment via Nine Dots, an IT security consultancy, and data use was agreed on with each contributor before the project commenced...

This trial used data captured by OBD-II connected telematics devices

This trial utilised Geotab GO9 telematics devices, provided by and installed in participating vehicles by a local Geotab reseller, Direct Track.

Figure 4 - Geotab GO9 devices

The Geotab GO9 device is a small vehicle tracking device that plugs into a vehicle's OBD II port (often located underneath the steering wheel) where it accesses information about the vehicle and its battery from the vehicle's onboard computer network (CAN bus). Once installed, the device activates when the vehicle is next driven.

These devices provided access to battery data recorded by the vehicle's BMS

While the GO9 devices recorded traditional telematics data, including vehicle location, speed, engine idling and distance travelled, none of this data was used for this trial.

Battery data made available by the GO9 device that was recorded included:

- Vehicle identification data (license plate, VIN)
- The status of the vehicle (on/off, driving, AC charging or DC charging)
- Battery pack voltage

- State of charge (the usable energy held by the battery as a percent of its estimated total, usable capacity)
  This refers to usable battery charge. While driving and charging, battery charge is reported every 1% change in value by the GO9 device.
- Total energy flowing into the battery since the device was installed (in kWh), including:
  - Total energy added to the battery from all non-charging sources since the GO9 device was installed, such as regenerative braking, driving down a hill, and engine charging in a hybrid.
  - The total energy going into the HV battery via AC charging since the GO9 device was installed.
  - The total energy going into the HV battery during DC charging since the GO device was installed.
- Total energy leaving the battery (in kWh) since the GO9 device was installed, consumed for driving and operating the vehicle. This includes propulsion and all auxiliary loads.

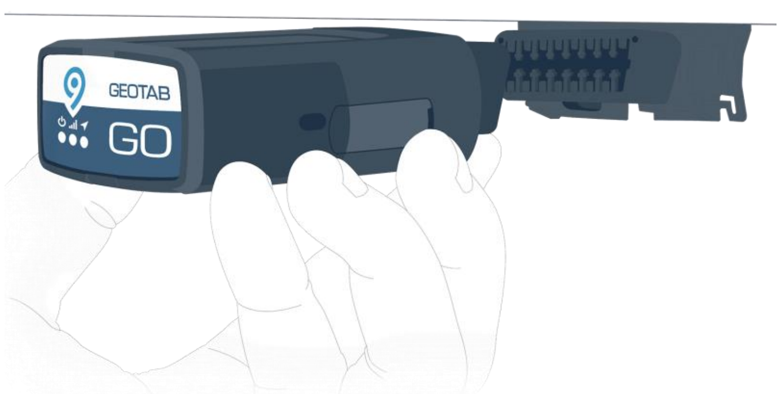


Figure 5 - A GO9 device connecting to the OBD-II port

This data was used to estimate battery health and track performance and use

Regular battery health estimates and information about how batteries were being used was derived from this data, including:

- The time the battery spent in 'stress zones'
  - high states of charge above 80%
  - high states of charge above 95%
  - low states of charge below 20%
  - low states of charge below 5%
- The charge level at the beginning of charging sessions
- The charge level at the end of charging sessions
- An estimate of total battery capacity, calculated during charging sessions (and therefore an estimate of the battery degradation percentage)
- An estimate of the total battery capacity, calculated during driving sessions (and therefore an estimate of the battery degradation percentage)

Devices were installed for a three-month trial period in EVs across several local and central Government organisations

These vehicles belonged to:

- Kāinga Ora (7)
- Auckland City Council (5)
- Waka Kotahi (5)
- Wellington City Council (5)
- Wellington Regional Council (4)
- Eko Cabs (3)
- Power Trip (1)
- Direct Track (1)
- Asthma New Zealand (8)

And included the following vehicle models:

- Hyundai Kona (14)
- Nissan Leaf 2015 - 2017 (8)
- Nissan Leaf 2019 (1)
- Nissan e-NV200 (1)
- Tesla Model S P85 2014 (1)

- Hyundai Ioniq 2017 - 2018 (8)
- Hyundai Ioniq 2019 - 2021 (4)

Battery health and degradation was not reported by the telematics devices

While it has been shown that battery health data can be made available from the CAN bus (for example, the free Leaf spy app provides access to battery health data recorded by the Nissan Leaf) this information is not publicly available and is not collected by Geotab's GO9 devices.
One possible reason for this is that third parties must currently reverse-engineer CAN bus data for all past, present and future EVs on the market. Numbers that remain unchanged over long periods of time, like battery health, would be very difficult to identify and easily confused with other pieces of data.

Usable battery capacity was calculated during AC charging sessions

The Geotab GO9 devices used during this trial recorded the following data, which was used to estimate the remaining capacity while a vehicle was charging.

- Changes in status (used to identify charging from AC, DC or regenerative braking)
- State of charge (the remaining battery percent reported as available to the driver)
- Energy flowing into the battery (in kWh)
- Energy flowing out of the battery (in kWh).

For each charging session, the following calculation was applied with support from Geotab's tech team:

1. Identify the start and end of each AC charging session
2. Check if the charging session ended above 80%
3. Check if the amount of charging done during the charging session exceeded a 20% change in state of charge. This minimised rounding errors as state of charge data was rounded to the nearest 1%.
4. If the above criteria were met, then usable capacity could be calculated.

5. Calculate the energy added to the battery during that session
6. Subtract the charge at the start of the session from the charge at the end of the session to find the total change in state of charge
7. Divide the figure from 2 by the result of 3 to estimate the total battery capacity available to the driver when the battery is charged to 100%.

- For example, if charging from 20% to 40% added 12kWh to the battery, then the total battery capacity was calculated as 12kWh / (0.4 – 0.2) = 60kWh.

Usable battery capacity was calculated during driving sessions

The Geotab GO9 devices recorded the following data, which was used to estimate the remaining battery capacity while a vehicle was driving.

- Status of the vehicle (charging or driving)
- State of charge
- Energy added to the battery while driving (i.e. from regenerative braking)
- Energy used while driving (the kWh recorded exiting the battery while the car was not charging)

Electric cars cannot drive while charging, but they can be charged while driving. Estimating battery health from driving sessions therefore must also account for the many small charging events caused by regenerative braking (e.g. at traffic lights or when driving down hill). We expected this method to be much less accurate than calculating battery health from charging sessions.

For each driving session, the following calculation was applied:

4. Identify the start and end of a driving session using the change in status from charging to driving (start) and from driving to charging (end)
5. Calculate the energy used during that driving session
6. Calculate the energy gained during that driving session
7. Subtract the figure from 3 from the figure from 2 to calculate the energy consumption that aligns with the observed change in state of charge
8. Subtract the charge at the start of the session from the charge at the end of the session to find the overall change in state of charge while driving

9. Divide the result of 4 by the result of 5 to estimate the total battery capacity available to the driver when the battery is charged to 100%.

- For example, if a vehicle started driving at 80%, completed driving at 20%, used 12 kWh while driving but regenerated 1 kWh while driving, then its battery capacity was calculated as (12 – 1) / (0.8 – 0.2) = 18.33 kWh

Battery health can be derived from the calculated battery capacity when the original capacity of the battery is known

Data collected from the GO9 devices and the calculations performed in this trial provide an estimate of the total energy holding capacity of the battery in kilowatt hours (kWh). In order to translate this into a battery health percentage, the original capacity of the battery, as it was when sold new by the manufacturer, needs to be known.

This information is available in general from manufacturers and third-party websites online.

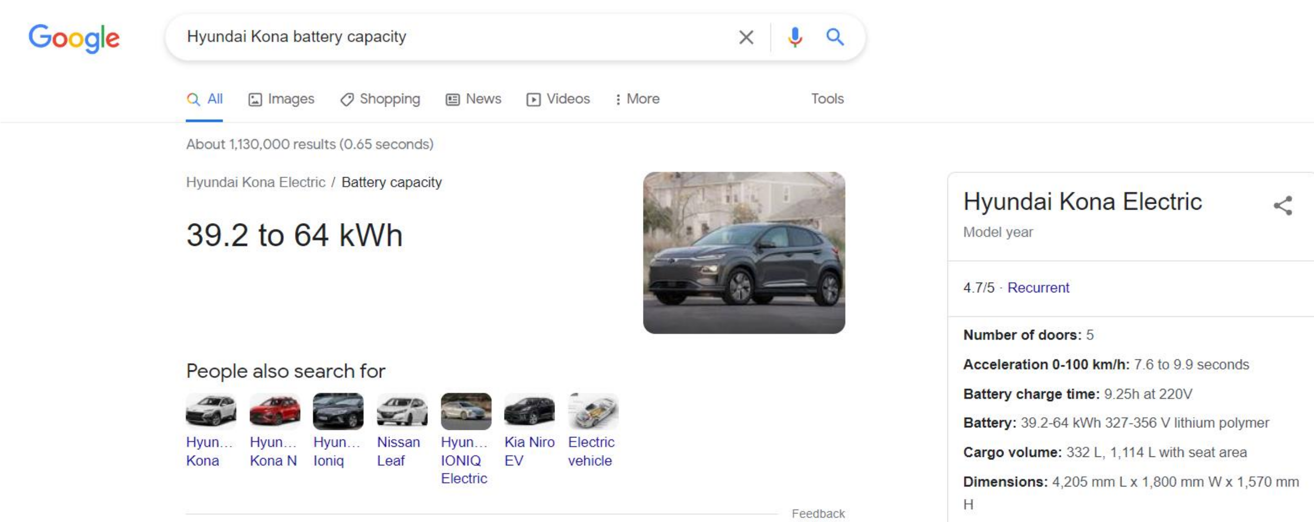


Figure 6 - An online search showing the original battery capacity range of a Hyundai Kona

If a telematics device was installed early enough, and the data was recorded on a battery passport, then the original capacity could be taken as the first capacity entry on a battery passport.

Both capacity and battery health are important. Battery capacity informs an owner or buyer about how much energy they can store in the battery, while battery health provides the owner with a way of estimating the remaining lifespan of the battery. For example, businesses we interviewed did not know the point at which degradation prevents a battery from functioning. A brand new 25 kWh battery is therefore likely to last much longer than a 50% degraded 50kWh battery as it has experienced much less use, degradation and wear and tear.

Results

EV battery data was successfully recorded for supported electric vehicles

Enough data was successfully collected from all supported electric vehicles during the trial to enable regular battery health and capacity calculations to be performed.

However the results show that OEM support for data sharing initiatives would significantly improve the ability of third parties and EV owners to understand and track battery health over time.

Data was also collected from several non-supported hybrid vehicles during the trial. No battery data was recorded for these vehicles. Batteries are deployed very differently in hybrid vehicles that cannot be externally charged and this appears to have been reflected in the data captured by the GO9 devices.

Charging data was not available for the eight early model Nissan Leafs (24 and 30kWh models); however, driving session data proved to be accurate enough to allow for battery capacity and state of health information to be consistently calculated.

Some vehicles tracked during this trial appeared to provide a larger usable capacity than stated by the manufacturer specifications. We were unable to discern if this was due to an error in our calculations, an issue with data obtained from the CAN bus, or if the vehicles allow drivers to access more battery capacity than stated.

Average vehicle battery health results

- Hyundai Ioniq

Hyundai Ioniq	Original Capacity (kWh)		Current, usable capacity		State of Health			
					Charging		Driving	
Year	Usable	Total	Charging	Driving	Total	Usable	Total	Usable
2017	28	30.5	28.9	29.4	95%	103%	96%	105%
2018	28	30.5	30.8	30.2	101%	110%	99%	108%
2020	38.3	40.4	41.4	39.7	103%	108%	98%	104%
2018	28	30.5	30.3	29.7	99%	108%	97%	106%
2019	38.3	40.4	38.9	38.7	96%	101%	96%	101%
2021	38.3	40.4	38.4	36.3	95%	100%	90%	95%
2021	38.3	40.4	39.1	36.9	97%	102%	91%	96%
2018	28	30.5	30.0	29.1	98%	107%	95%	104%
2017	28	30.5	30.1	30.0	99%	108%	98%	107%
2018	28	30.5	28.6	27.5	94%	102%	90%	98%
2017	28	30.5	30.1	30.0	99%	107%	98%	107%
2017	28	30.5	28.2	28.8	93%	101%	94%	103%

Table 1 - Battery health data calculated for Hyundai Ioniqs

- Nissan Leaf

Nissan Leaf	Original Capacity (kWh)		Current, usable capacity		State of Health			
					Charging		Driving	
Year	Usable	Total	Charging	Driving	Total	Usable	Total	Usable
2016	22	24	-	16.8			70%	76%
2016	22	24	-	16.5			69%	75%
2015	22	24	-	16.4			68%	75%
2016	22	24	-	20.1			84%	91%
2016	22	24	-	16.4			68%	74%
2016	22	24	-	19.8			83%	90%

2015	22	24	-	15.9			66%	72%
2015	22	24	-	15.1			63%	69%
2019	59	62	49.3	49.8	80%	84%	80%	84%

Table 2 - Battery health data calculated for Nissan Leafs

- Nissan e-NV200

Nissan e-NV200	Original Capacity (kWh)		Current, usable capacity		State of Health			
					Charging		Driving	
Year	Usable	Total	Charging	Driving	Total	Usable	Total	Usable
2015	22	24	18.7	18.2	78%	85%	76%	83%

Table 3 - Battery health data calculated for Nissan e-NV200

- Tesla Model S

Tesla Model S 85D	Original Capacity (kWh)		Current, usable capacity		State of Health			
					Charging		Driving	
Year	Usable	Total	Charging	Driving	Total	Usable	Total	Usable
2014	77.5	85	68.3	53.6	80%	88%	63%	69%

Table 4 - Battery health data calculated for Tesla Model S

- Hyundai Kona

Hyundai Kona	Original Capacity (kWh)		Current, usable capacity		State of Health			
					Charging		Driving	
Year	Usable	Total	Charging	Driving	Total	Usable	Total	Usable
2021	64	67.5	74.3	71.0	110%	116%	105%	111%
2021	64	67.5	71.2	70.2	106%	111%	104%	110%
2021	64	67.5	68.3	69.7	101%	107%	103%	109%
2021	64	67.5	70.8	67.2	105%	111%	100%	105%
2021	64	67.5	69.9	68.3	104%	109%	101%	107%
2021	64	67.5	73.6	71.2	109%	115%	106%	111%
2021	64	67.5	71.5	67.8	106%	112%	100%	106%
2020	64	67.5	72.1	70.0	107%	113%	104%	109%
2021	64	67.5	72.9	69.5	108%	114%	103%	109%
2021	39.2	42	44.2	42.0	105%	113%	100%	107%
2021	39.2	42	43.8	36.9	104%	112%	88%	94%
2021	39.2	42	43.2	41.5	103%	110%	99%	106%
2021	39.2	42	43.4	41.0	103%	111%	98%	105%
2021	39.2	42	44.0	39.9	105%	112%	95%	102%

Table 5 - Battery health data calculated for Hyundai Konas

For the 2019 62kWh Nissan Leaf e+ we were also able to compare data recorded by the Geotab GO9 device to data recoded by DC fast charging stations provided by ChargeNet. Data recorded across charging stations produced similar results to data recorded by the GO9 devices, varying by up to 4.1% in a charging session. Small charging sessions and charging sessions that ended significantly below 80% produced significantly different estimates for battery capacity than longer charging sessions that finished above 80%.

The GO9 device was installed in the Nissan Leaf in May 2021 and collected 18 months of data. This time period was also sufficient to show a change in usable capacity from about 52 kWh to 49 kWh, equating to a loss of about 5% of the original battery capacity.

2019 Nissan Leaf 62kWh	**Recorded by Geotab GO9 during charging**				**Recorded by DC charging stations**				
Date	Start SoC (%)	End SoC (%)	Energy in	Usable capacity	Start SoC (%)	End SoC (%)	Energy in	Usable capacity	**Difference**
11/05/2021	18	80	31	50	18	80	30.8	49.6	0.8%
11/05/2021	10	20	6.9	68.8	10	20	6.9	69.8	-1.5%
11/05/2021	17	87	36.7	52.5	16	87	36	50.7	3.3%
23/06/2021	34	70	19.1	52.9	34	70	18.9	52.6	0.6%
3/08/2021	17	95	42.3	54.3	17	94	42.9	55.7	-2.6%
27/09/2021	28	43	7.3	48.7	27	43	7.6	47.5	2.5%
28/09/2021	16	95	42.9	54.3	16	94	43.4	55.6	-2.5%
11/10/2021	16	79	34.3	54.4	16	80	33.5	52.4	3.7%
25/09/2022	37	66	15.8	54.4	36	65	15.7	54.1	0.6%
29/09/2022	21	88	34.6	51.7	21	88	35	52.3	-1.1%
19/10/2022	11	94	45.1	54.3	11	94	45.6	54.9	-1.2%
21/10/2022	34	79	23.4	52.0	34	80	23.3	50.7	2.5%
21/10/2022	26	71	21.2	47.1	25	70	21.4	47.6	-1.0%
21/10/2022	22	50	12.2	43.4	21	50	12.1	41.7	4.1%
23/10/2022	29	81	25.8	49.5	29	81	26.2	50.4	-1.7%
24/10/2022	29	78	24.2	49.4	29	78	23.6	48.1	2.6%
24/10/2022	26	61	16.9	48.4	25	61	16.9	46.9	3.0%

Table 6 - Comparison of capacity calculations between data recorded by telematics and data recorded bed by DC charging stations

A similar analysis of MEVO's telematics and charging sessions showed that MEVO have access to similar information for their AC and DC charging sessions. During DC charging sessions, all information could be supplied by the charging stations, while during AC charging sessions, energy added to the battery would need to be metered by an AC smart charger and the change in state of charge would need to be provided by MEVO's in-car telematics system.

MEVO - Polestar 2	**Recorded by telematics and charging station**			
Date	Start SoC (%)	End SoC (%)	Energy in	Usable capacity
-	13	83	47.9	68.4

Table 7 - Example of data used to calculate battery capacity in a MEVO EV

Charging behaviour affected the battery capacity results

Best practice advice we received from Geotab for calculating usable capacity from charging sessions was to:

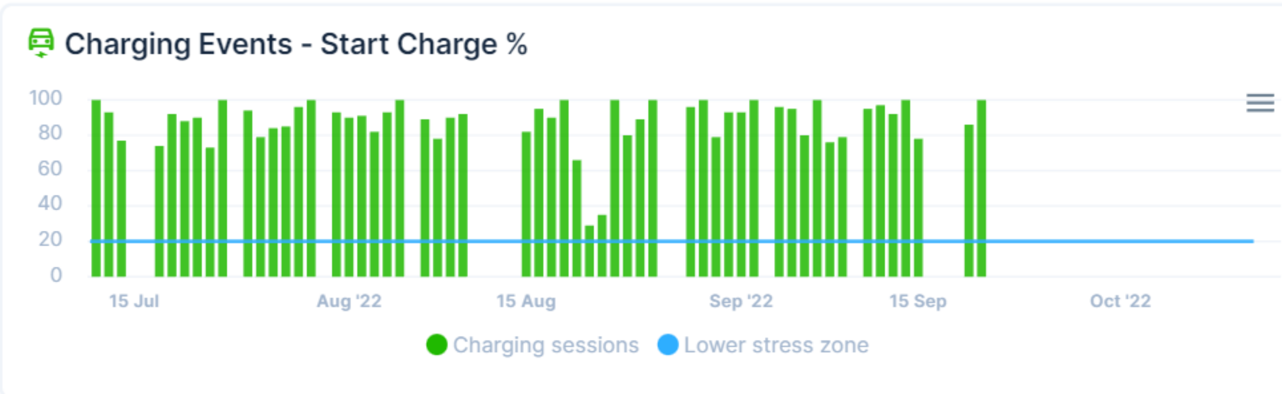
- Estimate state of health when there is a greater than 20% change in the battery state of charge (e.g. charging from 40% to 60% or more)
- Estimate state of charge when the final charge ends at above 80%
- Estimate state of charge using AC charging only

Several of the fleets who volunteered to participate in this trial had a policy of encouraging staff to plug their vehicles in when they finished their bookings, or when the vehicle was at or below 80%.

While this policy meant that the vehicle would be fully charged and ready for the next driver, this charging behaviour is not ideal for maximising battery health and it also meant that fewer charging sessions were large enough to accurately estimate the battery capacity.

For example:
The results below show a 2021 Hyundai Kona where 43% of the charging sessions fell within usable parameters for the calculations. The average usable capacity calculated using charging sessions within specifications was significantly lower than the usable capacity calculated across all charging sessions.

The manufacturer's stated usable capacity for the Hyundai Kona is 64 kWh, about 95% of the stated total capacity of 67.5 kWh. Our calculated usable capacities across charging sessions for the vehicle below ranged from 66 kWh (4% below the calculated average) to 77 kWh (12% above the calculated average).



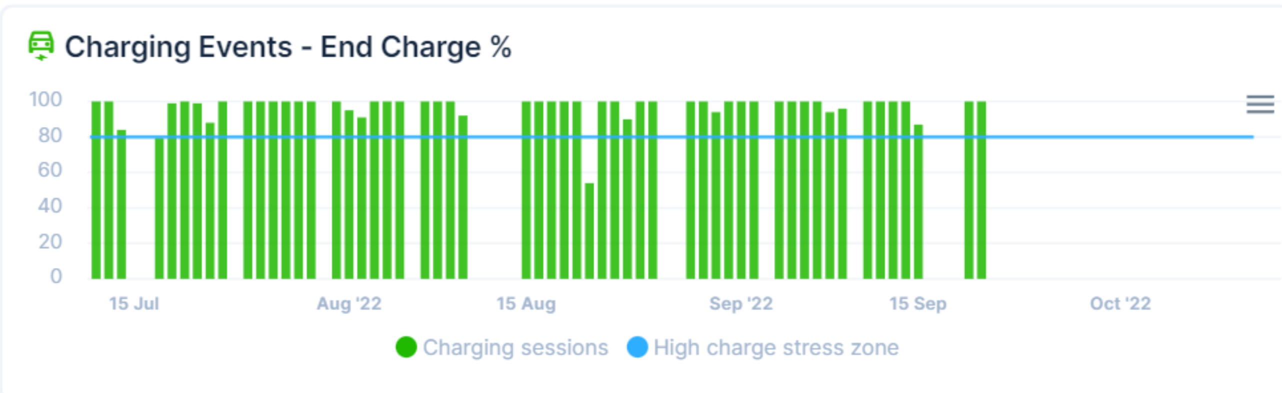


Figure 7 – Battery charge levels at the Start and end of charging sessions for the 2021 Hyundai Ioniq during the trial

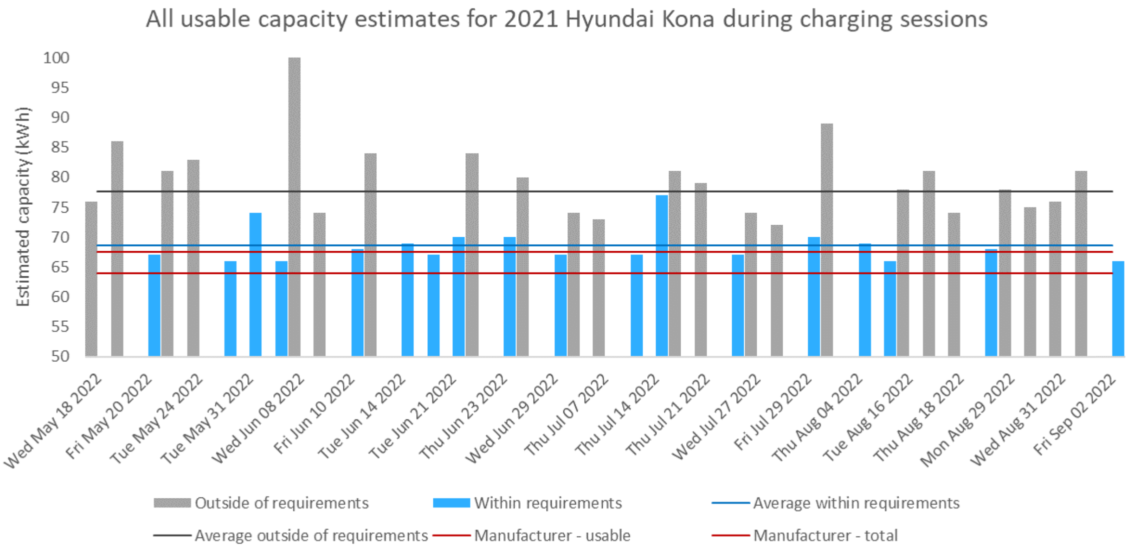


Figure 8 - Individual estimates of battery capacity from a 2021 Hyundai Ioniq

Date of charging sessions that met the advised specifications	**Usable capacity calculated from that charging session**
Fri May 20 2022	67 kWh of usable capacity
Wed May 25 2022	66 kWh of usable capacity
Tue May 31 2022	74 kWh of usable capacity
Thu Jun 02 2022	66 kWh of usable capacity
Fri Jun 10 2022	68 kWh of usable capacity
Tue Jun 14 2022	69 kWh of usable capacity
Fri Jun 17 2022	67 kWh of usable capacity
Tue Jun 21 2022	70 kWh of usable capacity
Thu Jun 23 2022	70 kWh of usable capacity
Wed Jun 29 2022	67 kWh of usable capacity
Fri Jul 08 2022	67 kWh of usable capacity
Thu Jul 14 2022	77 kWh of usable capacity
Fri Jul 22 2022	67 kWh of usable capacity
Fri Jul 29 2022	70 kWh of usable capacity
Thu Aug 04 2022	69 kWh of usable capacity
Wed Aug 10 2022	66 kWh of usable capacity

Fri Aug 19 2022	68 kWh of usable capacity
Fri Sep 02 2022	66 kWh of usable capacity
Average usable capacity across charging sessions within requirements	68.5 kWh usable capacity
Average usable capacity across all charging sessions	77.7 kWh of usable capacity (+13% difference)

Table 8 - Charging sessions for a 2021 Hyundai Kona with an original, usable capacity of 64 kWh and an original, total capacity of 67.5 kWh that could be used to estimate battery health

The wide range of results from individual charging sessions vary by more than the difference in manufacturer stated usable and total capacity. This demonstrates the difficulty in obtaining data without manufacturer support, the importance of collecting regular information over time and for recording the method used to estimate the battery's health. One-off battery health estimates can vary significantly depending on the quality of the data, how it was obtained and how the battery's health was then calculated.

Data from the Geotab API was mapped to many of the required battery passport fields

A battery passport can contain information about a battery's origin, chemistry, manufacture, intended purpose and more.
During this trial we successfully converted data collected from the CAN bus by the Geotab devices into most of the information required for ongoing monitoring in the data schema provided by Everledger as a guide for the EV data portal design.

Attribute	Mapped	Note	Units
Capacity	Yes	Calculated during charging or driving	Ah
Capacity fade or loss	Yes	Calculated over time	%
Total Energy	Yes	Derived from manufacturer details	kWh

Usable Energy	Yes	Calculated during charging or driving	kWh
Nominal Voltage	Yes	Obtained via CAN bus	V
Voltage Range	Yes	Obtained via CAN bus over time	V
Power	Partially	Obtained via CAN bus but only during peak load performance	kW
Power fade	Partially		%
Internal resistance on cell level	No		Ohms
Internal resistance on pack level	No		Ohms
Internal resistance (in Ω)	No		Ohms
Internal resistance increase (in %)	No		%
Depth of discharge in the cycle-life test	Yes	Capable of being calculated during deep discharge/recharge cycles	%
Power capability at 80% state of charge	Partially	Obtained via CAN bus but only during peak load performance	W
Power capability at 20% state of charge	Partially		W

Table 9 - Mapping Geotab telematics data to EverLedger's battery passport platform

Battery power output was available from the CAN bus whenever the vehicle was in operation. However the battery power output was connected to the vehicle motor, This means that the true power capacity of a battery is limited to the output power of the motor and extent to which a driver pushes the battery through extreme driving.

Battery use and charging policies today could impact on future degradation.

Battery experts we interviewed said that the golden rule for lithium batteries is to keep them charged between 20% and 80% (some sources state this rule as 30% and 90%, others state 40% to 60%).

This is because batteries will degrade faster if they are left sitting at high levels of charge, or low levels of charge for prolonged periods of time[10].
This is why computers and phones often come with battery limiting software that attempts to prolong the battery life by stopping it charging beyond 60% or 80%.

For the purposes of this trial we defined 'stress' zones as states of charge above 80% or below 20%.

Battery use and stress varied depending on the fleet policies

During this trial we explored how policies affect charging behaviour and what this could mean for the battery lifespan.

Charging policies of fleets that participated in this trial were:

1. Plug the vehicle in when it is returned.
2. Plug the vehicle in if it is below 30%,
   do not plug the vehicle in if it is above 70%,
   use your own judgement in between.
3. No official policy
4. Vehicles are assigned to one driver, who is responsible for their own charging.

[10] This Information came from interview participants who work with batteries, however two good references we were provided were: http://liionbms.com/ and https://batteryuniversity.com/

The charge level of vehicles in fleets that opted for Policy 1 tended to spend over half of their time in stress zones. The example below compares three fleets, one that used policy 1, one that used policy 2, and another that used policy 4

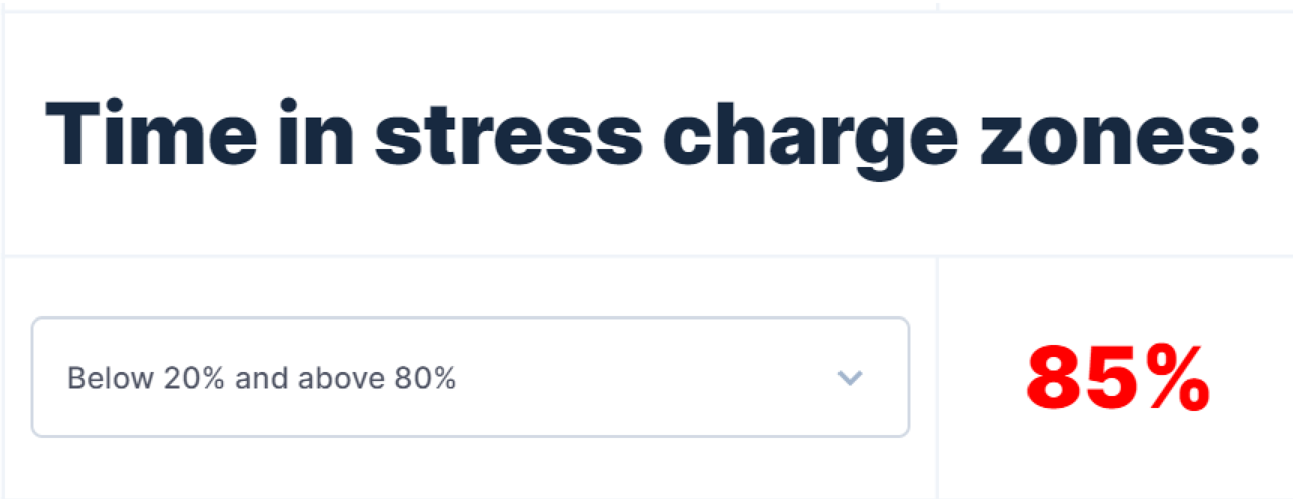


Figure 9 - Battery stress in a fleet that encouraged drivers to plug their vehicles in upon return (policy 1)

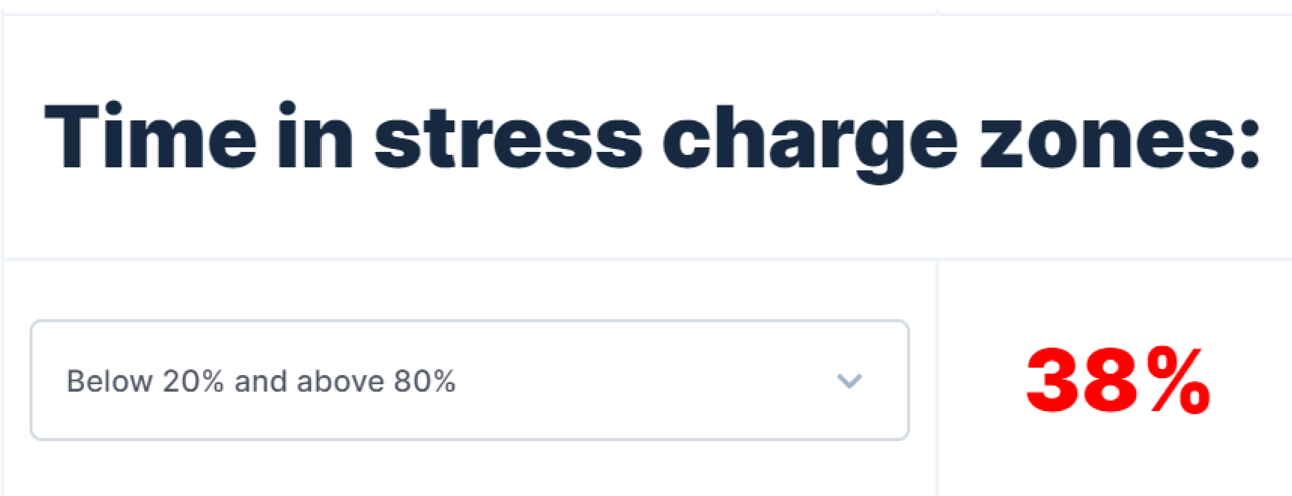


Figure 10 - Battery stress in a fleet that provided employees with their own vehicles and no charging policy (policy 4)

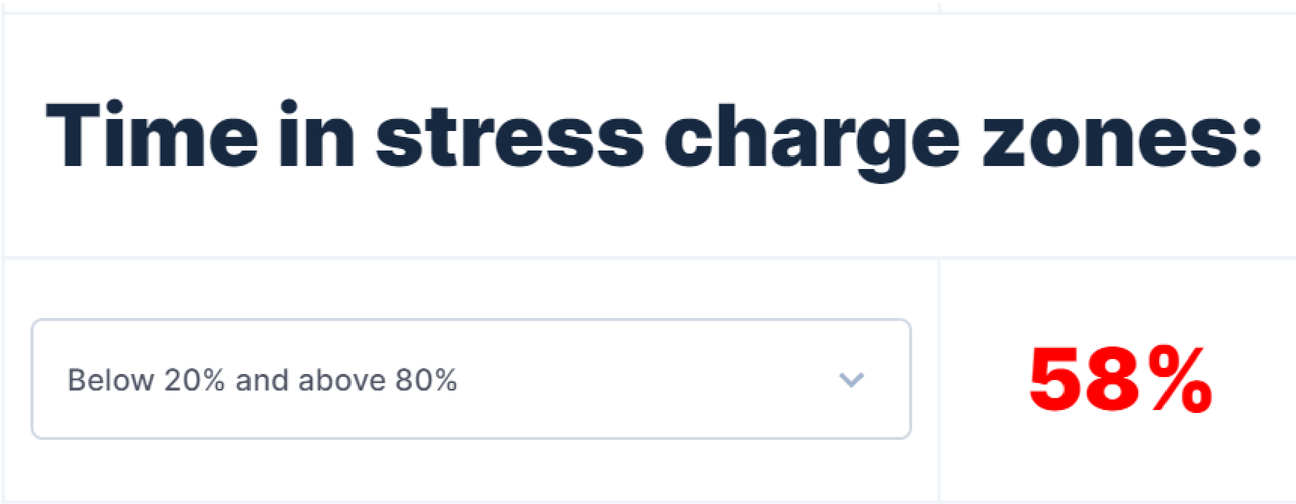


Figure 11 - Battery stress in a fleet that provided employees with their own vehicles and asked them to plug in when the battery was below 30% (Policy 2)

The charts below show the average battery charge per day of the trial for a selection of vehicles in the three fleets that opted for different charging policies.

Fleet 1

Vehicles in fleet 1 showed a much higher daily average state of charge, often spending days at a time fully charged.

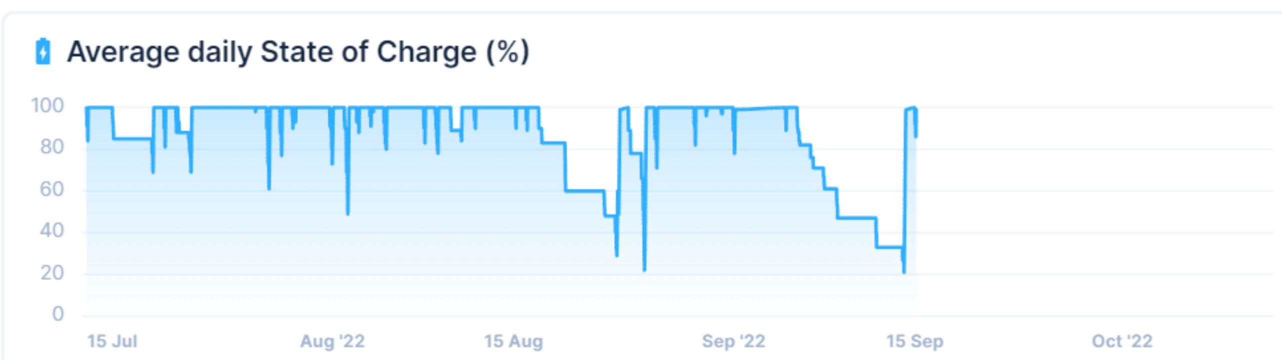


*Figure 12 - Average daily state of charge of Vehicle **A** from a fleet that encouraged plugging in at the end of trips*

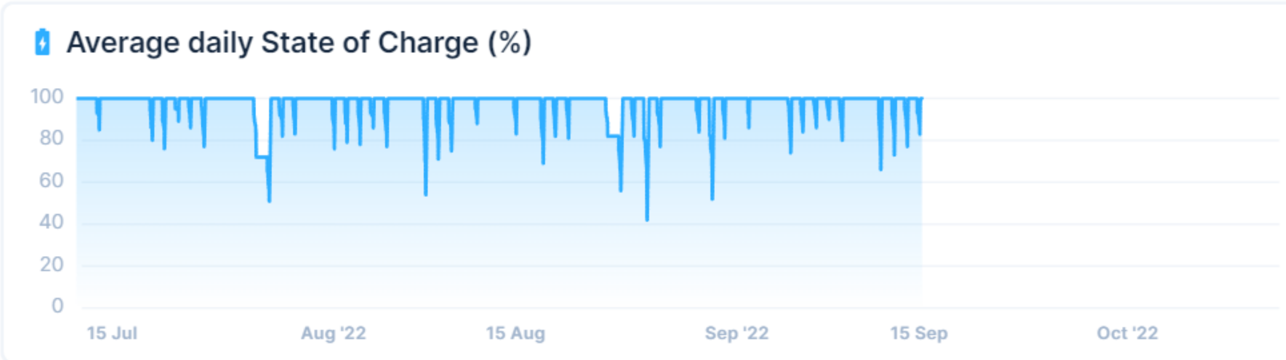


*Figure 13 - Average daily state of charge of Vehicle **B** from a fleet that encouraged plugging in at the end of trips*

Fleet 2

Vehicles in Fleet 2 (Policy 4) showed much higher variability in their state of charge, often driven by the type of charging that the driver had access to (public vs private). In some cases the behaviour indicated that drivers may be trying to adhere to the 20% - 80% golden rule of battery health care.

*Figure 14 - Average daily state of charge of Vehicle **A** from a fleet with no charging policies*

*Figure 15 - Average daily state of charge of Vehicle **B** from a fleet with no charging policies*

Fleet 3

Drivers in Fleet 3 (Policy 2) also showed a wider range of charge, with the vehicles spending much less time at 100% state of charge, and being charged much less frequently than vehicles in Fleet 1.

*Figure 16 - Average daily state of charge of Vehicle **A** from a fleet with a policy of plugging in when the charge was below 30%*

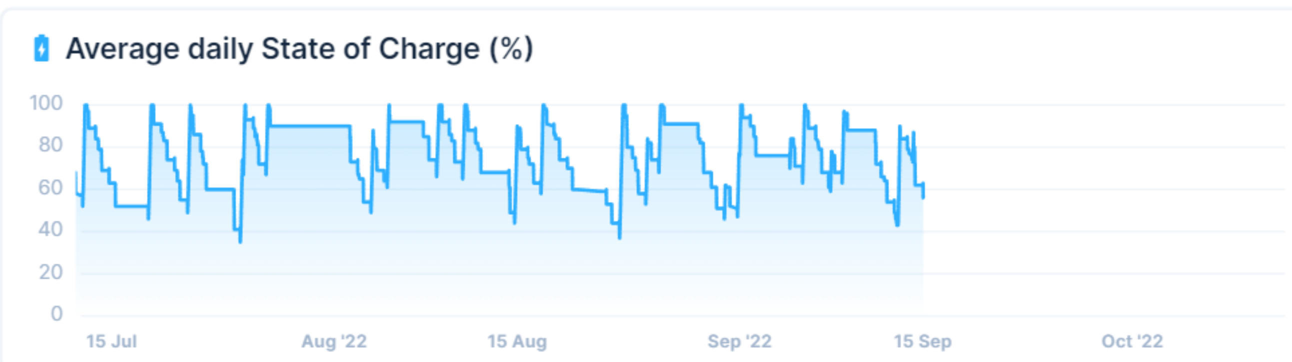


*Figure 17 - Average daily state of charge of Vehicle **B** from a fleet with a policy of plugging in when the charge was below 30%*

Software MVP overview

The software created for this trial is intended to collect data about batteries, report it to a battery passport system and provide the battery owner with access to the information on a dashboard.

An overview of the software's function is as follows:

- **(1)** The software connects to the Geotab API
- **(2)** The software performs calculations to translate the data from the Geotab API into data required by the battery passport platform.
- **(3)** The software updates the battery passport platform with this new data.
- **(4)** The results of the battery analysis are provided demonstration dashboard designed to provide insights to the battery owner.
- **(5)** Future data sources will be integrated into the software and will require their own calculations. By making the software open-sourced, data source providers can contribute to making these calculations more accurate.

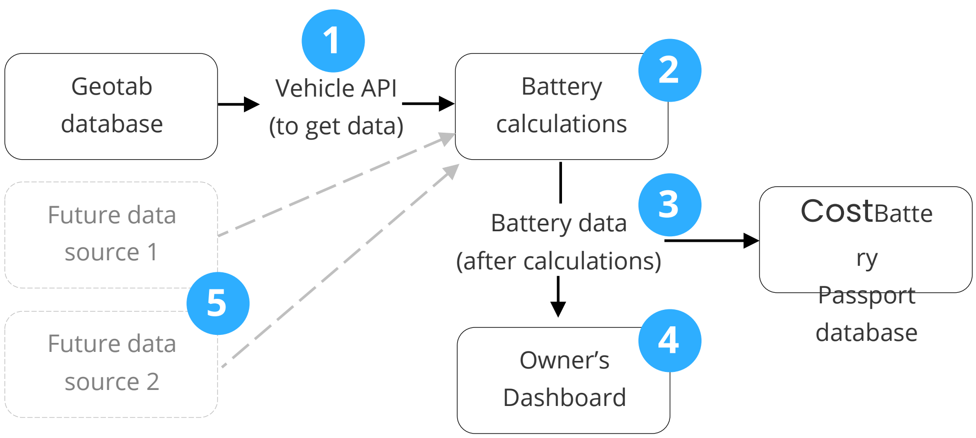


Figure 18 - Prototype software, architecture overview

The software separates the battery data from the vehicle

Using data available from the Geotab API, the software creates a basic profile of the vehicle and a profile of the battery contained within that vehicle. The data is then separated in to these two profiles, which are linked together by their respective IDs.

Temporary battery IDs are used because battery IDs cannot be obtained without inspecting the battery directly

Real-world battery IDs are often adhered or stamped on to the battery pack or module casing. This information can only be obtained by removing and inspecting the battery, a process that typically voids warranties. The software therefore assigns a new battery ID as a placeholder until the real-world battery ID can be obtained in the future.

Real-world battery IDs exist in various forms, generally as either numbers printed on the pack or QR codes adhered to the pack. These IDs and images of any QR codes can be added to battery records in the software.

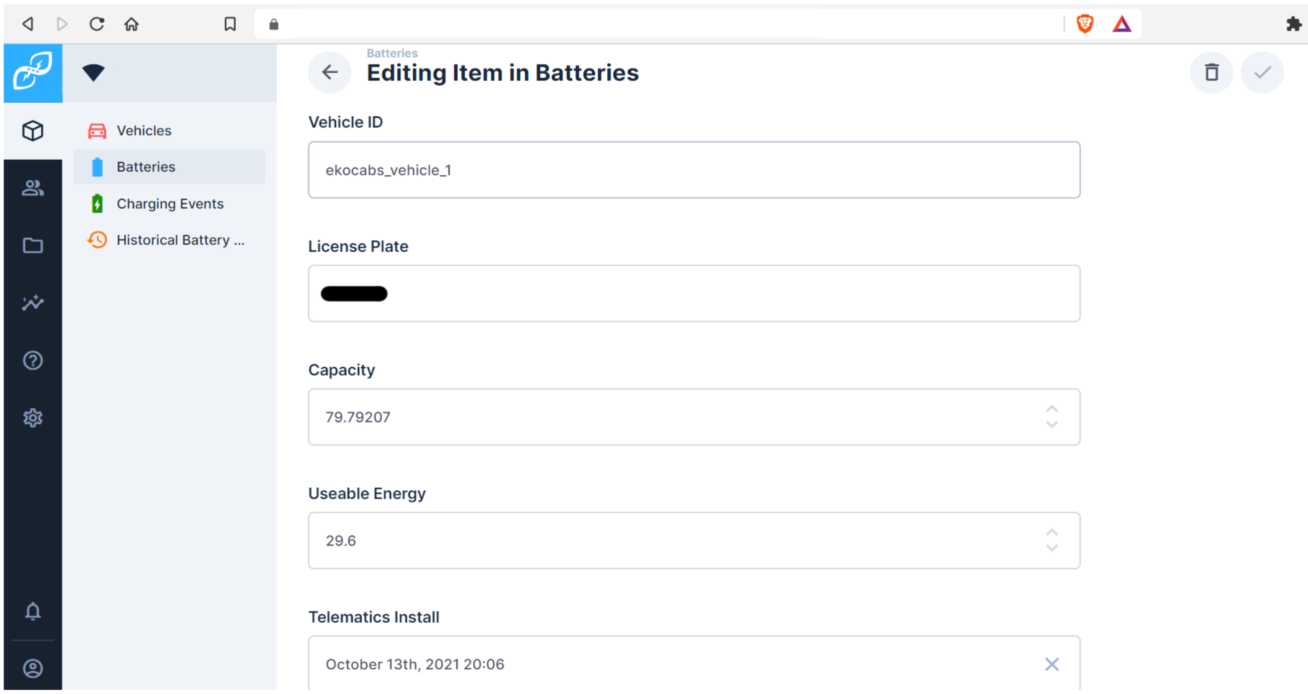


Figure 19 – Updating battery data and IDs in the software

Vehicles have multiple IDs that can be obtained from different sources

Unique vehicle IDs are also generated by the software, and any other IDs that can be obtained via the CAN bus are also added to the vehicle information, this includes the VIN (Vehicle Identification Number) for many makes/models of vehicles, and any registration numbers or vehicle names added by the vehicle owner.

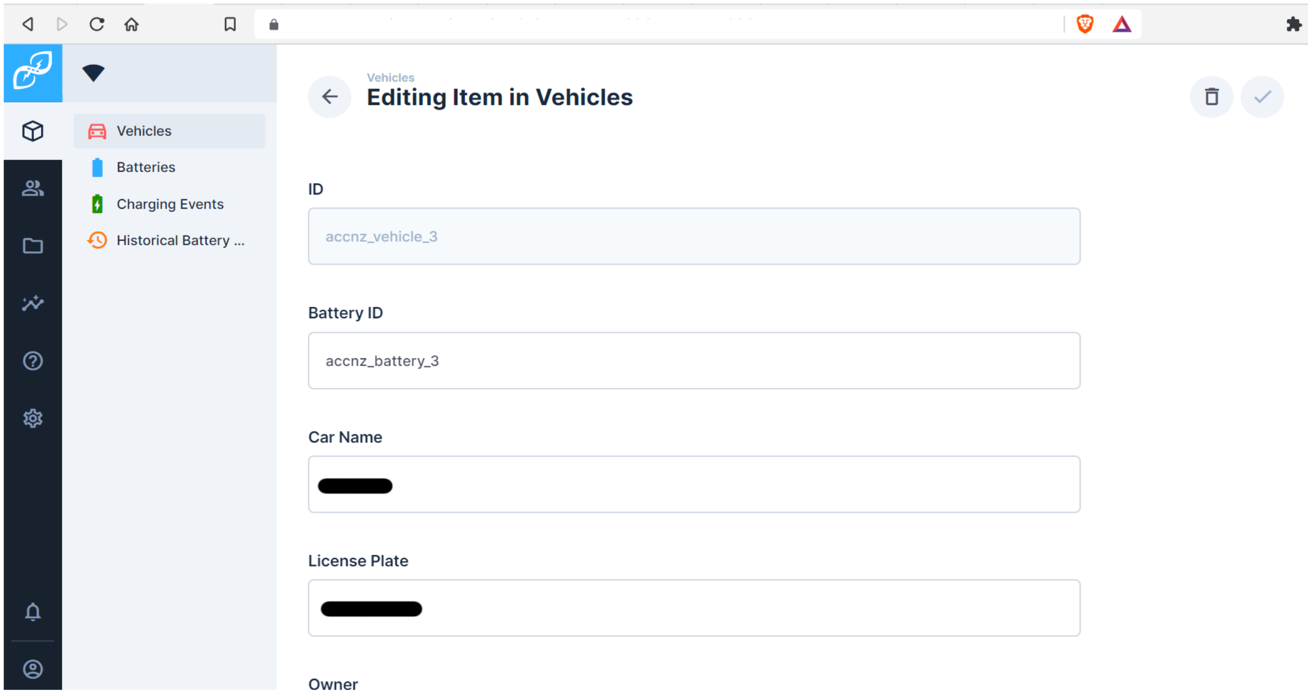


Figure 20 – Updating vehicle data and IDs in the software

Data can be updated manually by the battery owner

This trial used an advanced telematics solution to automate data capture from electric vehicles. However, not every battery application has access to similar data capture solutions or the ability to remotely connect to the battery passport system to update battery data.

To overcome this, a user with the correct permissions can create and update records in the software. These changes can then be passed through to the battery stewardship platform as manual updates added to the blockchain.

The software tracks and displays data on an interactive dashboard

Requiring owners to update their battery data for the purposes of recycling in several decades does little to incentivize engagement or regular updates. This could lead to low engagement, or even enforced data entry in the future.

To overcome this, a dashboard was built into the software to provide battery owners with more value and engagement.

The dashboard provides insights into battery health management

While the purpose of the software is to provide updates to a Battery Passport system, the dashboard has been designed to showcase the value that fleets can obtain through understanding their battery health.

Key items displayed on the dashboard include

- Time spent in stress zones (below 20% or above 80% state of charge)

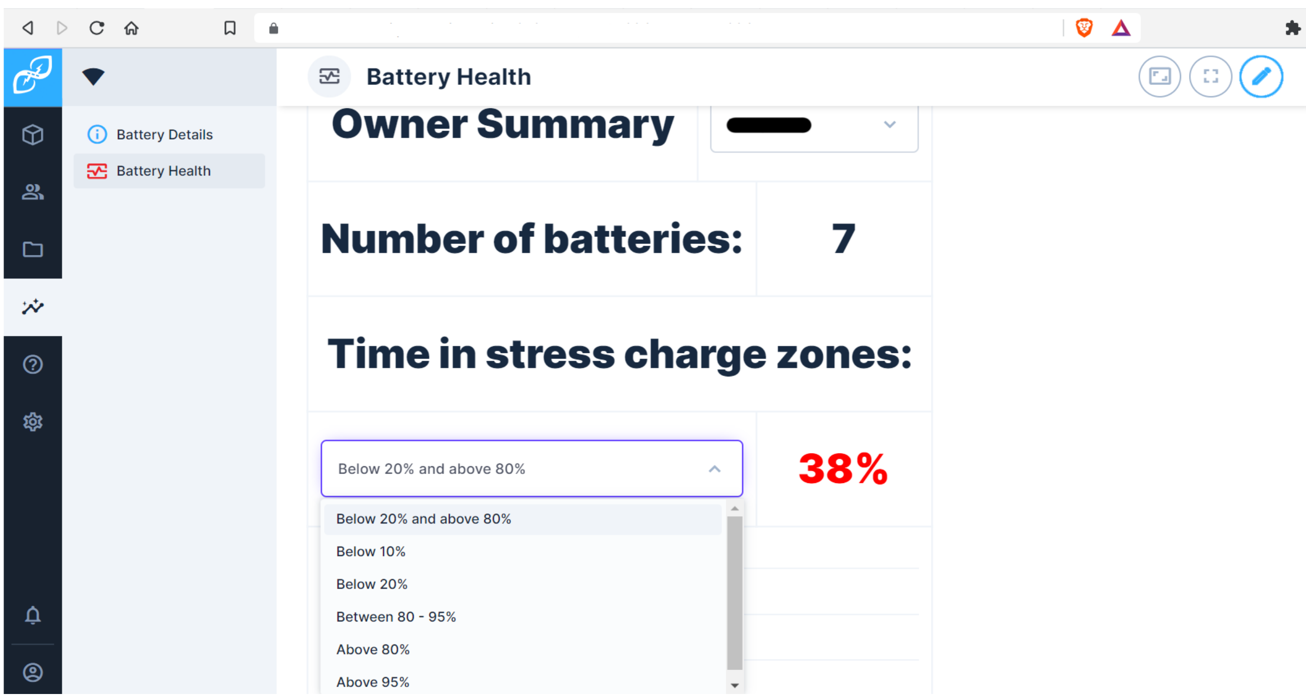
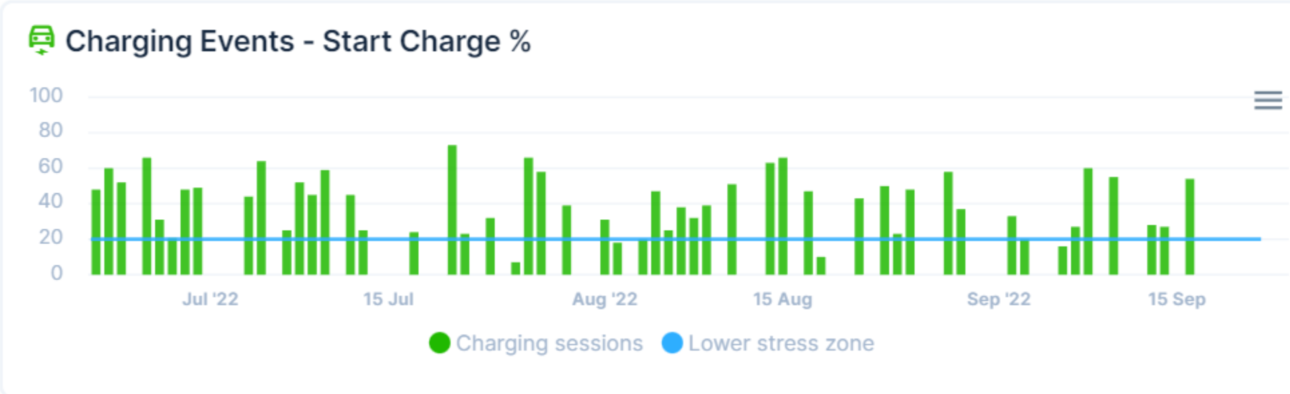


Figure 21 – Time spent in battery stress zones

- The average state of charge recorded each day.
  the Geotab GO9 devices recorded state of charge every 3 to 60 seconds.
  The dashboard shows a daily average across all of those points for the day.

- Driver charging behaviour that could impact on battery health
  Starting and ending state of charge levels for each charging session is displayed on the dashboard.



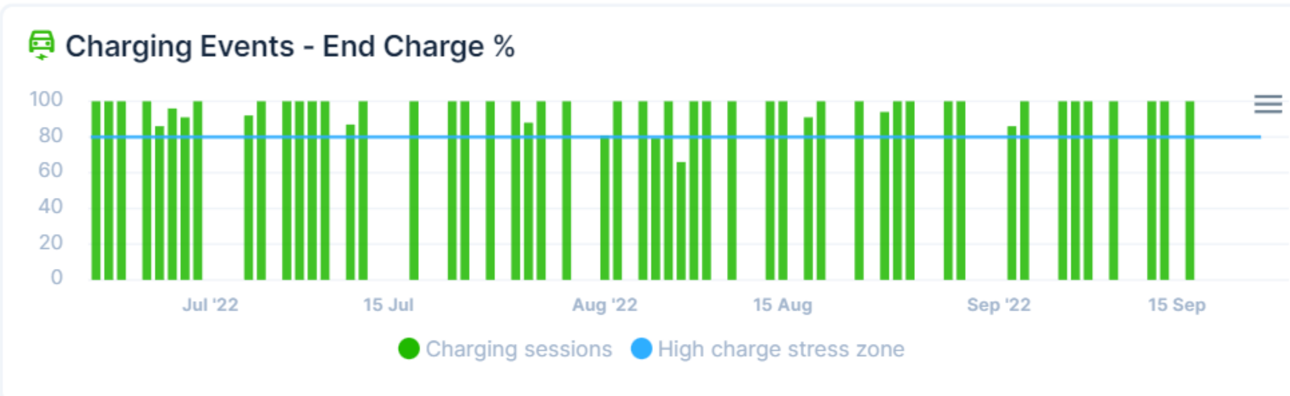


Figure 22 – Charging behaviour

- Average battery pack voltage (across all cells) across all daily records is shown on the dashboard.

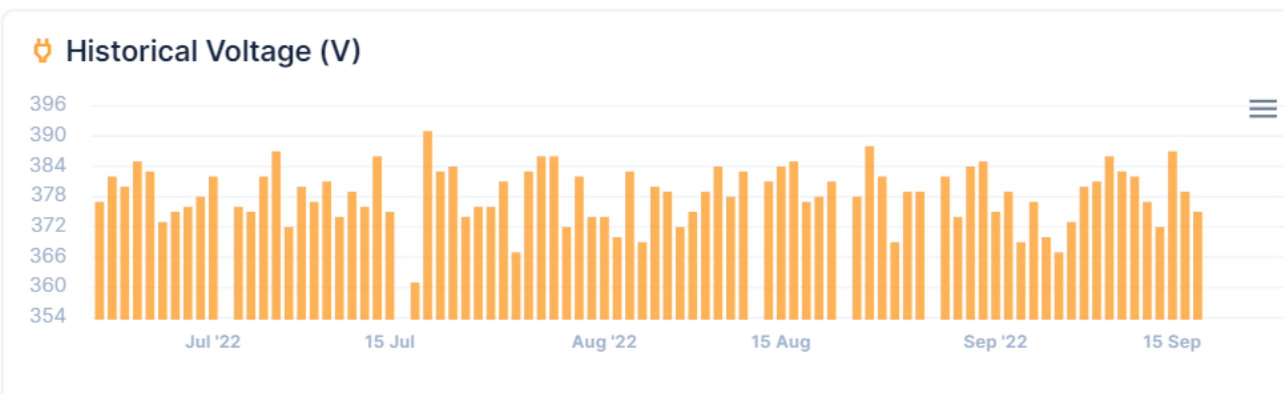


Figure 23 – Battery state of charge and voltage

Ongoing development of the prototype

This software is a prototype, designed to demonstrate what is possible when battery data is made available. Further development and integration with sources of battery data is required to bring it to a market-ready product that will effectively support the many ways batteries will be used in New Zealand.

The following section outlines different applications and opportunities where data Integration could be made possible, and where data is significantly lacking, but could be improved through regulation or technology.

4. Data capture opportunities

The Interviews we conducted explored different ways data could be sourced from battery owners across New Zealand.

While the Geotab devices used in this trial present an excellent solution for monitoring EV batteries in fleets, New Zealand's future will use large batteries in a much wider range of applications for which telematics may not be a suitable solution (e.g. stationary storage applications).

Data sources we explored were:

- Telematics providers
- Charging stations
- OEMs (Original Equipment Manufacturers)
- Third party CAN bus-Interfacing tools
- Third party battery management systems
- Drivers (manual data entry)
- Businesses conducting repairs and upgrades on batteries
- Businesses creating their own battery packs
- Businesses re-using EV batteries in new applications

Data Privacy and reporting

There are privacy issues around data collection and sharing via telematics

Our interviews revealed that manufacturers of vehicles that are supplied to customers with embedded telematics are considering when, how and what data is uploaded and shared, and that access by third parties is likely to be very strict and limited. Data about vehicle and battery use can provide insights that help improve their technology in the future, but much of the information available from the car can be used to identify the vehicle drivers and their behaviours (e.g. location and speed).

Third party telematics providers also had similar concerns, however they have been working with customer location data for a long time and are able to share more of it, so long as the customer agrees and asks them to share the data with the third party.

Brands with telematics appear unlikely to share this data

In New Zealand few vehicle brands provide embedded, functional telematics. Businesses we interviewed that do provide this service, indicated the likelihood of that information going to a third party is almost zero. The core reason for this was that the privacy constraints and policies around sharing data that have been implemented by OEMs are extremely strict.

While customers sign declarations about vehicle privacy, data privacy laws can also restrict third party access to knowing where vehicles are.
For example, one OEM representative told us that in an accident, certain vehicles automatically send an alert signal and GPS location to first responders, so that they know where the car is, however the company cannot provide any more information to any third parties without the agreement of owner.

Vehicle owners appear unlikely to share this data

Over the last decade there have been large privacy breaches that have led to an increased awareness of how personal data can be severely misused.
Data from EVs will be sought after by people and organisations who wish to understand EV driving and the impact of charging behaviours, such as electricity distribution companies, insurance companies, finance companies, central or local Governments.

The general feeling among the businesses we interviewed was that third party access to vehicle data would not sit well with their customers.

Fleets we interviewed also expressed privacy concerns on sharing data.
Businesses have obligations to maintain staff and customer privacy, and their staff often use fleet vehicles for sensitive work purposes, or for private use.

Data from OEMs and APIs

Batteries provided for expensive, high-end applications will often come with a BMS that monitors batteries at the cell or module level

Several businesses we interviewed were deploying vehicles with custom-made batteries. These vehicles came with data monitoring and reporting and occasionally GPS locators embedded in their vehicles' battery management systems. In all instances, this data was collected by both the owner and the battery manufacturer.

The collection and provision of data to the manufacturer was often a requirement to maintain the warranty on the battery. Live data also enabled the manufacturer to provide Immediate support for any issues despite being located overseas.

This data would likely need to be provided to the PSO by the manufacturer with permission from the vehicle owner.

Vehicle and battery OEMs have been trialling implementing a variety of connectivity and BMS systems

For this project we interviewed both local representatives of overseas vehicle manufacturers and businesses manufacturing smaller EVs, for example motorbikes or boats, in New Zealand. Each business we interviewed had implemented their own systems for monitoring battery performance and function over time. Some of these solutions deploy embedded telematics that provide real-time battery data to both the owner (via an app) and the manufacturer; others rely on data collected by dealers and service people at annual check-ups.

This data would likely need to be provided to the PSO by the manufacturer with permission from the vehicle owner.

Several OEMs and OEM representatives we interviewed do not provide APIs or in-car telematics in vehicles sold in New Zealand

While embedded telematics provide many benefits to drivers, these services tend to be implemented region-by-region. Manufacturer representatives we interviewed told us there are very high costs in setting up these connected services in New Zealand. Furthermore, any rollout would need to be approved by their parent companies overseas.

Without a remote connection to the vehicle's computer network, OEM representatives use a hard-wired connection (a scan tool) that connects to the car via the OBD port. This is used when the vehicle returns to their premises for inspection, repairs, servicing or warranties.

This data would likely need to be provided to the PSO manually.

Several OEMs we interviewed already have in-car telematics in New Zealand, but do not offer third party access

A small number of the OEM representatives we interviewed offer a range of vehicles that have embedded sim cards and telematics capabilities in them. One of the most connected vehicle brands in marketplace claimed to have 95% coverage across all vehicles they sold.

Data provided via the embedded sim cards included access to the CAN bus in the vehicle, which allowed access to data the vehicle stored about the battery. This in turn enabled the OEM representatives' technicians to provide remote diagnosis and support services remotely.

In large markets overseas, some OEMs allow vehicle owners to grant third-parties access to data through an API. Businesses we interviewed reported that OEMs aren't providing APIs and had no plans for providing APIs in New Zealand. Any data that companies could provide to the PSO would likely require a custom solution or would need to be provided manually by vehicle owners or servicers, which is challenging.

Embedded telematics seldom work for parallel-imported vehicles

Embedded telematics are linked to the country the vehicle was originally sold in. When vehicles are privately imported to NZ the embedded telematics usually cannot communicate with the manufacturers' local infrastructure without upgrades and support (either from the local OEM representatives or from a third party).

While vehicles are in warranty and in fleets, they require annual check-ups and firmware updates

New vehicles sold in New Zealand, especially vehicles sold to fleets, will require software updates and annual checks (which are often conducted via a scan tool connected to the OBD port), service and maintenance to ensure the warranties remain valid. Occasionally these can be done remotely (for example, over the air software updates in Tesla vehicles) but in New Zealand it is more common that these checks and software updates are done on-site by qualified and appropriately tooled technicians at the dealerships.

Any data collected during inspections would likely need to be provided to the PSO manually, or via an integration with the warranty provider's records systems.

OEMs are introducing new high voltage training for technicians

Some of the OEMs we interviewed are introducing new qualifications and training to upskill existing automotive technicians with high voltage expertise. The more advanced of these training programs enable technicians to do cell and module replacements and repair work. Most OEMs we interviewed employ at least one or two of these technicians, but some are working towards employing at least one technician at each dealership site.

Information collected by technicians would need to be provided to the PSO manually.

The need to sell services to replace maintenance revenue could lead to greater connectivity in the future

Service and maintenance forms a large part of dealer and OEM revenue in general, but EVs need much less maintenance and far fewer repairs. As revenue from maintenance falls, the future of motoring and cars will likely change to compensate for this. Connected services is one area that OEMs are exploring, ranging from Tesla offering full-self-driving capability as a subscription[11], to BMW offering most in-car features on subscription[12]. As these services become more important, the connectivity and data that underpins them may become more available, likely at a cost.

Any data provided to the PSO by OEMs would likely need to be negotiated with the OEM, developed as an integration with their systems or regular data exchange process and then approved by the vehicle owner before their data exchanged hands.

OEM responsibility continues for either the warranty period, the time that a valued customer owns the vehicle or legal protections

Warranties offered on new EVs sold by New Zealand OEM representatives are typically for eight to 10 years. The second-hand imported vehicle network isn't supported by warranties, but some second-hand dealers are confidently offering two to four year warranties on EVs they import.

Most of the OEM representatives we interviewed will offer support to the vehicle owner if it's outside of warranty or outside of their network. In most cases this will be at a cost to the vehicle owner or importer.

Any warranty-related battery data would likely need to be provided to the PSO manually.

[11] https://www.tesla.com/support/full-self-driving-subscriptions
[12] https://www.bmw.co.uk/en/shop/ls/cp/connected-drive

Accessible data is essential for enabling any organisation to retain responsibility or obligations to long-term battery management

Customers are under no obligation to return to a dealer once they have purchased their vehicle. Without embedded telematics, the dealer has no way of tracking or reporting on the status of a battery within a vehicle.

Both second-hand dealers and OEM representatives we interviewed indicated that there is a general customer perception that OEM-representative dealers (dealers who sell new cars) are expensive while second-hand dealers are more affordable, so if and when a vehicle is on-sold in the second-hand market, it becomes less likely that the customer will return to the original, OEM representative dealer for services and maintenance.

The original dealers are therefore likely to lose contact with their vehicles over time without the aid of embedded telematics. This is especially true if the new owner of the vehicle does not consent to the OEM terms and conditions, or has the embedded telematics removed.

Data from the CAN bus via OBD ports

Access to a vehicle's on-board computer is usually available through the vehicle's On-Board Diagnostics (OBD) port

OBD ports & OBD-II data specification standards are mandatory for all cars sold in the United States, Europe, Australia, New Zealand and China. These standards allow for easier, standardised emissions testing, but are also frequently used by OEMs for diagnostics and repair.

EV CAN bus data is not standardised and varies significantly from vehicle to vehicle

While the data extraction through the OBD port for internal combustion engine vehicles follows an industry standard, EVs are not constrained by any standards. The EV data (including battery data) provided through an OBD port therefore varies significantly from brand to brand, model to model, and even from year to year within the same model (for example, the Nissan Leaf 30kWh and 40kWh use different OBD EV standards).

Often vehicles made in factories in Asia will be completely different to the same models made in European factories. Some companies we interviewed that use CAN bus data reported that Asia Pacific CAN bus data is very different to North American CAN bus data across the vehicles they work on.

Access to the CAN bus is usually only available to OEMs and their authorised representatives

Obtaining access to CAN bus data is challenging in the Australia, New Zealand and Asia Pacific regions due to the lack of CAN bus standards. Our discussions with OEMs and businesses that are seeking access to this data show that there is a practice of withholding access to the standards and specifications necessary to access this data.

OEMs we interviewed expressed concern that access to this information would encourage third parties to tinker unsafely with their batteries, while some of the third parties we interviewed who are working with ex-EV batteries feel that not having access to this data puts them, and the applications they are working on, at greater risk.

For example, knowledge about an EV specific CAN bus standard has allowed third parties to develop battery replacement and upgrades for parallel imported Nissan

Leafs in New Zealand, allowing vehicles with a driving range of less than 100km to be upgraded to a driving range of around 220km. Other companies can use access to the CAN bus to communicate with the battery's original battery management system and develop longer-lived, second-life stationary storage applications.

Reliable access to CAN bus data would need to be negotiated with OEMs or mandated through regulation. The New Zealand Government would likely need to work with other countries to successfully implement any regulation without reducing the availability of EVs in New Zealand.

Data at import and servicing

New Zealand businesses are innovating with new and second-hand batteries

Our interviews highlighted a range of innovations happening through businesses accessing new and second-hand batteries. These innovations included:

- Importing large batteries for the purposes stated by the manufacturer, including:
  - In off-the-shelf EVs
  - Custom-made EVs
  - Stationary storage applications (e.g. home solar energy storage)
- Importing new battery cells to assemble new, large EV batteries in New Zealand, used in a variety of applications, including:
  - New, NZ-made EVs
  - Upgrading batteries in old, parallel-imported electric vehicles
  - Creating stationary storage applications
  - Creating batteries for e-bikes
  - General tinkering and experimentation by hobbyists and professionals alike.
- Purchasing second-hand EV batteries from owners in New Zealand and overseas for use in products in New Zealand. While it is common that the

entire battery pack would be deployed in these second-life applications, several businesses we interviewed were also removing modules from battery packs to create smaller batteries for multiple applications. These applications include:
    - Upgrading old EVs with larger batteries
    - Converting classic petrol cars to electric
    - Creating stationary energy storage applications
    - Using individual cells to replace batteries in consumer electronics
- Deploying the second-hand batteries they already own in second-life applications that support their businesses
- Purchasing new and second-hand battery cells to repair existing large batteries in parallel imported EVs in New Zealand.

The use cases for both new and second-hand batteries are expanding so rapidly that many businesses are finding it difficult to find or purchase batteries from manufacturers, or from the second-hand market. At least one business we interviewed occasionally imports used Tesla batteries from the USA in order to supply their needs.

The paths for importing, modifying and re-using batteries are so varied that any software tool for reporting data to the PSO will need to be adapted to fit to the specific circumstances and needs of the stakeholders involved.

Limited information about batteries is currently obtained from EVs when they are imported

Information about vehicles imported into New Zealand has been recorded on import for many years. Traditionally, this has been limited to information about the vehicle, but information about the battery is starting to be provided as well, due to the growing recognition of its importance, the ability to obtain this data, and the demand from buyers who want more clarity over their purchases.

This information is still limited and much of it is derived from the make/model/year of the vehicle that the battery is contained within, or to data provided by the company exporting the product.

Data about batteries collected at import is limited to information about the application, not the batteries themselves. For EVs, more detailed information about batteries could be provided to the PSO by the car dealers that import the vehicles. It is unclear what information would be available for other products, for example stationary batteries, stand-alone battery packs, or batteries embedded in non-vehicle applications.

Businesses that provide software services to dealers are recording this information

Companies that provide data and software services to car dealers, including vehicle data, listings and website management, are now recording this information. Two examples are Autoplay and Motorcentral who, with dealer permission, can often provide battery health, capacity and battery chemistry information to third parties.
Data provided by these companies is based on data that has been provided to them by third parties (for example, by sellers at auctions or by the manufacturer).

Data provided to the PSO from software service providers would require integration with their systems and permission from their customers before any data could change hands.

Service businesses that work on EV batteries are recording information

We interviewed both third party and OEM supported businesses who are providing services for EV owners in New Zealand. These services include regular servicing and maintenance and battery replacements and upgrades. In those cases, information about the battery is recorded. This information helps dealers, EV owners and OEMs understand how their batteries are performing, supports their

warranties and helps them estimate their lifespan. Businesses providing third party battery replacements and upgrades are currently operating on a swap model, where they purchase the existing battery from the owner to offset the purchase and installation costs of the new battery they are selling them.
Accurate information is important for these service providers because the health of the batteries indicates their resale value, and is therefore a key part of how the replacement is priced.

While there are similarities in the data sets recorded by each business, each business records this data using their own system, format and standards.

Data provided to the PSO from service businesses would either require integration with their systems, or incentives to encourage them to provide data manually. Permission from their customers would likely also be required before any data could change hands.

Bridging the gap between OEMs and second-hand importers has traditionally been difficult, but the push to recover batteries and support electrification is improving this

Local OEM supported car dealerships are often separate businesses to the international brand. OEMs often operate through local agents or resellers, with manufacturing and distribution registered as different businesses usually located overseas.

When a vehicle is sold new in New Zealand, the local representatives of the OEMs earn revenue from the sale, from the value of the customer, and retain some degree of control over the product at least for the life of the warranty. Second-hand importers circumvent the need for a relationship with the OEM by purchasing vehicles that were originally sold by overseas representatives of the OEMs.

While local OEM representatives often have (depending on where the vehicle was manufactured and how similar it is to the New Zealand new versions) the capability to solve issues with parallel imported vehicles, and may offer these solutions to EV owners. However, the obligation ultimately falls to the importer of the vehicle, not to the manufacturer.

Despite this, most manufacturers we interviewed understand that their vehicles will eventually become second hand. Several manufacturers we interviewed are working towards providing services and certifications to support their brand's products and reputation in these markets, and to aid in recovering their vehicles and batteries at the end of their life.

Data from third parties

From devices in vehicles

There are limited tools available to support battery checks on imported vehicles

Most of the vehicle business rely on CAN bus scanning tools to obtain information about batteries when the vehicles come into the country.
In the case of brand-new vehicles sold from the OEM, this data is readily available through OEM-provided scan tools available to their dealer representatives.

These tools are generally not available to the public, or to car dealers who parallel import used vehicles from overseas. In most cases, these dealers rely on screenshots of the dashboards provided by agents at auction sites in the countries they are purchasing from, or on third party tools like the Leaf Spy app, which displays battery data for Nissan Leafs and e-NV200 vans, and the EVBatMon app which displays similar information for Mitsubishi Outlander PHEVs.

Without access to these tools, the information a dealer has on the state of the battery in a parallel imported vehicle is:

- **The remaining range estimate shown on the dashboard,**
- **The odometer shown on the dashboard, and**
- **The age of the vehicle.**

None of this data would provide useful battery insights for the PSO.

Accessing battery data via third party warrants and servicing is difficult

Without access to the CAN bus and the vehicle's internal reporting mechanisms, obtaining information about a battery during a warrant or service inspection is difficult and time consuming. Direct measurement techniques have been developed but are nearly impossible to implement during a warrant or service.

To be accurately assessed, EV batteries need to be substantially charged (to more than 90%), then substantially discharged (to less than 10%) and then recharged again in order to measure the state of health. Issues with this process include:

- The battery would also need to be accessed directly, which would require a degree of disassembly for almost all light EVs currently available on the market.
- Discharging and recharging a large battery takes time.
    - Using the tools currently available, this would require the tester to drive the vehicle until the battery is empty, which could be over 500km in the case of some long-range EVs.
    - Charging would require access to a fast charger, which would take around an hour for a vehicle to reach 90% for most of the EVs on NZ roads today.
- Discharging and recharging adds extra expense and requires high voltage charging equipment to be installed at the testing facility.

Accurately determining battery health during a warrant is nearly impossible and very time consuming and provides little value to the customer or the

business conducting the assessment.

Third party CAN bus data for tracking vehicles

Information can be obtained from an EV's onboard computer by third-party solutions that connect to the vehicle's CAN bus via the OBD-II port. Examples include the Geotab GO9 devices used in this trial and the Leafspy Bluetooth app.

In most cases, third parties are required to reverse-engineer the CAN bus for each make, model and generation of EV. The GO9 devices are supported by Geotab's team of engineers and work for a wide variety of EVs, while the Leafspy app only works for the Nissan Leaf and e-NV200 and is supported by a community of early-adopters who shared information and worked together online.

Telematics companies are starting to invest in obtaining this information, however it is an expensive process that requires specialist expertise.

Greater data to CAN bus data would benefit many companies and encourage innovation around EVs and batteries. However, it is unreasonable to expect telematics providers to independently invest in this technology to support the PSO, especially without manufacturer support.

From charging stations

DC charging stations receive some data from vehicles they are charging

EVs communicate with charging stations via the DC charging port. Generally, the charging station receives the state of charge (battery percent), the charging status (if the connection is ready for use), and the make/model from vehicle. The charging station itself measures the energy going into the battery.

Because the energy is measured at the charging station side, losses occurring during the charging process are not accounted for, i.e. the energy entering the battery will always be less than the energy measured at the charging station. The size of these losses can vary depending on the efficiency of the charging station, the ambient temperature at the time of charging, the temperature of the battery and the state of charge of the battery (the more charged a battery is, the more energy that is lost while DC charging).

While DC charging stations collect the type of data necessary to estimate state of health, these losses make DC charging an ineffective means of accurately measuring battery health. The data is also often owned by the charging network and providing access to this data would come with similar privacy concerns as those associated with providing access to embedded telematics data.

Providing battery data to the PSO via charging networks would require integration with their metering and/or billing systems and permission from their customers. It would also be less accurate than data provided by the cars themselves due to energy losses.

AC charging stations do not receive data from vehicles they are charging

AC charging stations, even connected smart chargers, do not record any data from the vehicles they are charging. While they do measure energy flowing through the charging station, they have no ability to obtain information about the battery they are charging.

This may change, as there are new proposed standards[13] that will enable direct data communications via the AC charging port. However, this will only be available in future EVs made by OEMs that adopt these standards.

As well as requiring permission from customers, any data provided to the PSO by AC charging networks would require integration with these networks systems

[13] ISO 15118 https://www.iso.org/standard/77845.html

and would require the user to manually add the start and end State of Charge for each charging session. Any integration with an AC charging network would also require the charging station to be a connected smart charger.

Manual data entry

Accessing vehicle battery data for manual entry is not simple.

Almost all of the information a battery owner has about their battery is provided to them via their vehicle's dashboard. However, battery health and capacity in kWh is seldom displayed. Instead, the driver will often have access to either a "guess-o-meter" (GoM) which shows the expected remaining range before the battery runs flat, or a simple battery %.

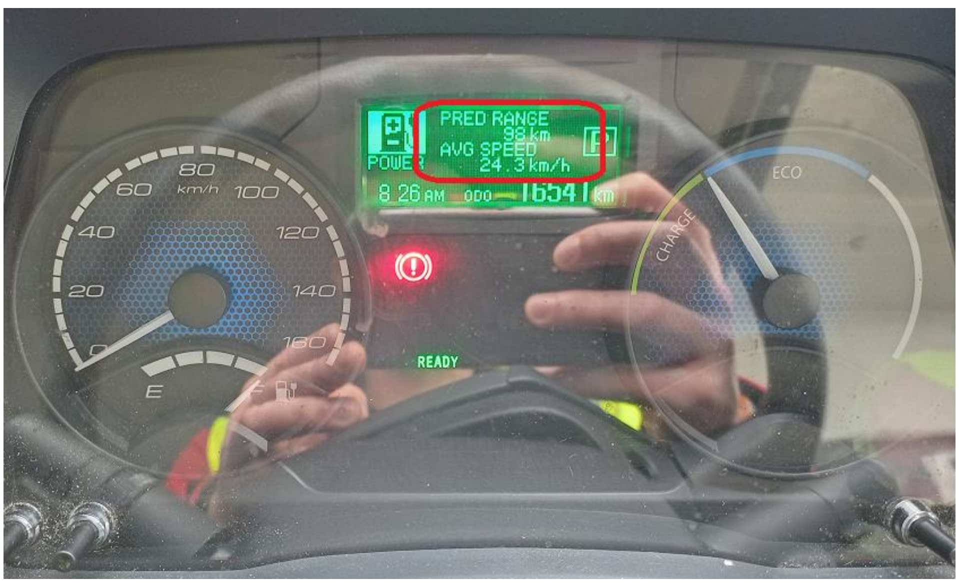


Figure 24 - The Mercedes eCanter dashboard displays the remaining range estimate (indicated in red) as well as the remaining battery % as a traditional fuel dial.

Some vehicles do provide battery health information, however it os not always easily interpreted. The Nissan Leaf provides a battery health gauge segmented into 12 sections, or bars that correspond to the following remaining capacities[14]:

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[14] https://mobility.lk/2020/10/11/soh-capacity-bars/

- 100% to 85% = 12 bars
- 85% to 78.75% = 11 bars
- 78.75% to 72.5% = 10 bars
- 72.5% to 66.25% = 9 bars
- 66.25% to 60% = 8 bars
- 60% to 53.75% = 7 bars
- 53.75% to 47.5% = 6 bars
- 47.5% to 41.25% = 5 bars
- 41.25% to 35% = 4 bars
- 35% to 28.75% = 3 bars
- 28.75% to 22.5% = 2 bars
- 22.5% to 16.25% = 1 bar

16.25% to 0% = 0 bars (16.25% or 2.6 times a “normal” bar).

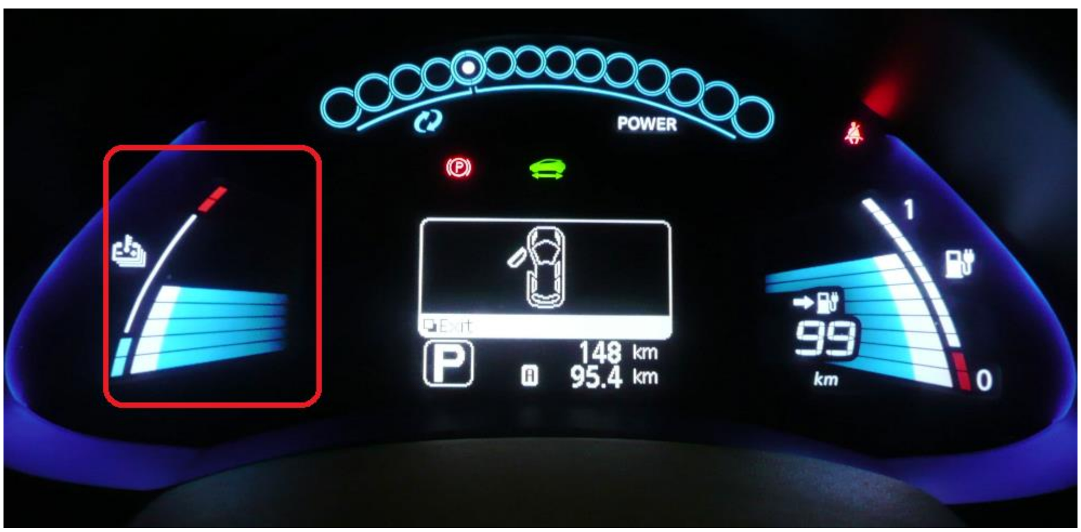

Figure 25 - Early model Nissan Leaf displays the remaining range estimate, the remaining battery as a series of 12 bars on the right of the display, and the estimated battery health as a series of 12 bars on the left of the display (indicated in red)

Figure 26 – Later model Nissan Leaf displays the battery health estimate as a linear bar, but with the same 12 segments (first segment will be lost at 85%, the second at 78.75% etc.)

Some vehicles provide additional efficiency statistics, such as kWh per 100km, km per kWh or Wh per km. When compared to the remaining range and available battery capacity at the same time, these statistics provide an estimate of usable battery capacity. However, these statistics are often calculated using different systems, and while they are better than nothing, they are therefore unlikely to be able to give an accurate estimate of battery heath.

*Figure 27 – A 2020 Harley Davidson Livewire displays the remaining range, remaining battery charge and the average efficiency in watthours per km. Implying that the battery capacity is 76 / 0.34 * 60 / 1000 = 13.4 kWh*

Figure 28 - A Nissan leaf displaying 5.8 km / kWh, 309km remaining and 86% remaining battery charge. This implies a 309 / 0.86 / 5.8 = 61 kWh usable battery capacity, however the actual capacity was recorded as being between 49 and 50 kWh during these trials.

Some EV owners record their own data in logbooks or apps

Many early EV adopters have held an interest in the performance of their batteries over time and have recorded their own information. Without CAN bus tools, this information is normally based on mileage and the vehicle's performance.
To do this, an EV owner will drive a known route, record the state of charge at the beginning and end of the route, and repeat this on a regular basis[15]

A New Zealand-based project, Flip the Fleet, has been tracking manually recorded data from more than 2,000 EVs in New Zealand. This project asks participants to manually enter updated information from their vehicle dashboards or from an OBD scan tool (e.g. Leaf spy) into a form each month.

[15] An example of one Tesla owner benchmarking his battery degradation through driving performance: https://cleantechnica.com/2020/06/17/testing-a-tesla-model-3s-battery-degradation-after-14-months-60000-kilometers/

Any logbook data provided to the PSO would likely need to be manually added by the EV owner.

Regular, manual reporting of data is not a positive or long-term solution for fleet managers

Fleet managers can be responsible for several hundred vehicles in fleets composed of different makes and models, often spread out over large areas. Most fleet managers relied on a combination of telematics and regular servicing by technicians to maintain and account for vehicle health. Adding additional manual work, such as recording data from dashboards or scan tools was seen as requiring significant additional resources that don't currently exist, for little benefit to the fleet.

However, statements of action, such as declaring that the battery is still as-purchased with no repairs or upgrades were seen as acceptable.

While telematics are on the rise, many agencies don't have telematics so adding that as a requirement could be a significant addition.

Fleet managers are highly unlikely to submit detailed, manual updates on battery health and use to the PSO.

The incentive to track health is low, especially when the operator does not own the vehicle, or if the vehicle's battery is being operated in a manner that accelerates degradation

Businesses and fleets we interviewed generally agreed that battery history and state of health data is only really valuable to manufacturers, for academic reasons, or to purchasers at the point of sale. If a battery is degraded, it is in the sellers' best interest not to know about it to keep the sale price high. For some fleets, battery health was considered out-of-scope as they intended on selling the vehicles after five to seven years.

As it is the battery owner who must record information about their batteries, or allow third party data connections to record this, any data collection should either provide the owner with a benefit or should be done by mandate.

Data is more likely to be passed to the PSO if there is well-communicated and advertised value or benefit for the battery owner.

Stationary storage and second life

Stationary storage is the likely final application for EV batteries

Stationary energy storage (e.g. home batteries or grid batteries) are much less constrained by weight or space. As renewable energy generation proliferates, the need to store energy for use during times of low generation will also grow. This will likely ensure that demand for batteries remains high.

Degradation is also less of an issue for stationary storage, e.g. a 50% degraded battery from a 2010 Nissan Leaf will still hold at least 10kWh of energy at a fraction of the cost of a brand new Tesla Powerwall, which can hold 13.5kWh. Even low-capacity batteries can provide temporary energy supply to reduce the shock of price or demand spikes for grid-connected homes, reducing power bills and ensuring the lights stay on.

Data available from stationary storage applications varies

Battery management system (BMS) technology varies in complexity, performance and features. A wide variety of off-the-shelf BMS software exists and many applications come with a custom-made BMS. The BMS software and capabilities are usually designed to reflect the target market they intend to be deployed in (e.g. in an electric vehicle versus as solar home storage).

While battery charge and health data are available through most BMSs, the level of connectivity and open access varies significantly from solution to solution. Some solutions provide data to a computer via a connected port (e.g. a USB port), while other solutions provide data either on a screen or via Wi-Fi or Bluetooth connectivity.

The growing range of proprietary BMSs offered by businesses around the world will make it difficult for information to be automatically passed to the PSO. Aligning with global battery stewardship regulation and standards will likely maximise the opportunity to collect information from any future updates to these systems.

The best BMS for a second-life EV battery is often the vehicle's own BMS

An effective BMS communicates with all parts of the battery system, including the load and the charging unit. Businesses we interviewed that are deploying EV batteries as stationary storage were using either a custom-made BMS or the original BMS that the battery came with. Using the original BMS often means that the application will also use other equipment, such as the charging unit, from the EV.
When using EV BMSs in non-EV applications, engineers need some understanding of the BMS. This is currently obtained by reverse engineering the BMS's software when specifications or documents are not made available by the OEM. This is quite common although obviously quite tricky (or better wording!).

Data from stationary storage is likely to become more connected, especially in the context of electricity grids

Electricity distributors and retailers we interviewed believe that flexible load management will be essential for optimising the future utilisation of, and investment in, electricity networks. This could take the form of a centralised data and dispatch hub for each network company, or a flexible demand response

market that approved providers can operate within.
The largest barrier to implementing these solutions is the lack of communication technology, both in providing real-time visibility into electricity networks demand and use, and in communicating with EV chargers and battery storage options on the network.

Keeping up with the pace of change of internet-connected battery technology will increase the ability of the PSO to obtain data from future battery applications.

Importance of battery data

Data is important for ensuring correct disposal of large batteries

A large battery is comprised of several smaller modules, which are comprised of many smaller cells. In the form of a large battery these cells can be identified, collected and handled appropriately. Individually, these cells cannot be uniquely identified and are much harder and more expensive to collect, sort and account for. Regular updates to battery data will ensure that waste management services can more confidently prepare to coordinate collection and handling of large batteries in the future.

For batteries that are repaired or dismantled, a secondary system, designed to handle the removed cells, would be required to ensure they do not go to landfill. Ideally this would be aligned with e-waste and small battery product stewardship programmes.

Data is important for enhancing extended life applications for large batteries

A battery's future performance often depends on how it has historically been treated. For example, an EV battery that has been left fully charged or discharged for prolonged periods of time will carry a higher risk of degradation and failure than a battery that has been spent most of its life between 40% and 80% charged.

This wear-and-tear is internal and is therefore not visible to a purchaser without detailed information about the battery and its history.

Battery financing relies on good, long-term information

Several businesses we interviewed are exploring split-asset ownership business models for batteries. In these models, one company will finance or lease the battery to another company or individual. In order for this business model to be viable, the financing business requires accurate, historical data about any second-hand batteries they are purchasing.
Accurate tracking of degradation allows the financing company to calculate the residual value and price their services accordingly, even possibly billing customers for damage or degradation beyond what is expected.

Battery information is important to EV buyers, but it does not prevent them from buying EVs

Most customers tend to look for battery health information when purchasing an electric vehicle from a second-hand car dealer, and dealers are increasingly using battery health as a yardstick for pricing their vehicles. Having access to battery information can provide extra peace of mind and assurance of reliable driving range, however vehicles that do not provide access to this information are still selling well.

EV dealers in New Zealand often have to teach customers about battery degradation. Having access to historical data would likely make this education process easier for both dealers and customers.

Reliable, accurate battery data enables innovation

The more accurate and accessible information about battery health is, the more reliably companies can innovate using batteries. There is a growing number of market opportunities for energy storage and a key constraint is access to affordable, reliable batteries. Businesses that are purchasing second-hand batteries currently have to accept the risk of unknown degradation when purchasing batteries for which scan tools are not available.

Part B

The information contained in this section is derived from our interviews and resources provided during these interviews and is shared for general value to the reader. Power Trip are not experts in battery technology and provide no warranties on the accuracy of this information. We present it as a relatively simple summary of the understandings gained through the range of interviews.

5. Ownership models

Private ownership

Most vehicles sold in New Zealand are second hand or parallel-imported

While new car sales are conducted mostly through local OEM representatives, most vehicle sales are conducted in New Zealand's highly competitive second-hand car market.

There are more than 800 second-hand car dealers in New Zealand. While they source many of their second-hand cars directly from owners in New Zealand, some are purchased at overseas auctions in other right-hand drive car markets, mainly Japan and the UK.

Dealers that represent OEMs and sell new vehicles can have a reputation for being expensive, while second-hand car dealers are seen to be affordable options.

As a vehicle ages, the owner assumes more of the responsibility from the dealer

Vehicles, and therefore battery, warranties and guarantees are managed by the dealers who sold the vehicles, for the duration of the warranty period, so long as the dealer's conditions are met (e.g. batteries are not removed from the original vehicle). However, warranties tend to last up to 10 years for new cars and up to four years for second-hand cars. Once warranties end and vehicles are on-sold, the chances that the owners will return to the dealer for servicing are diminished. The dealer therefore retains less access and responsibility for the battery.

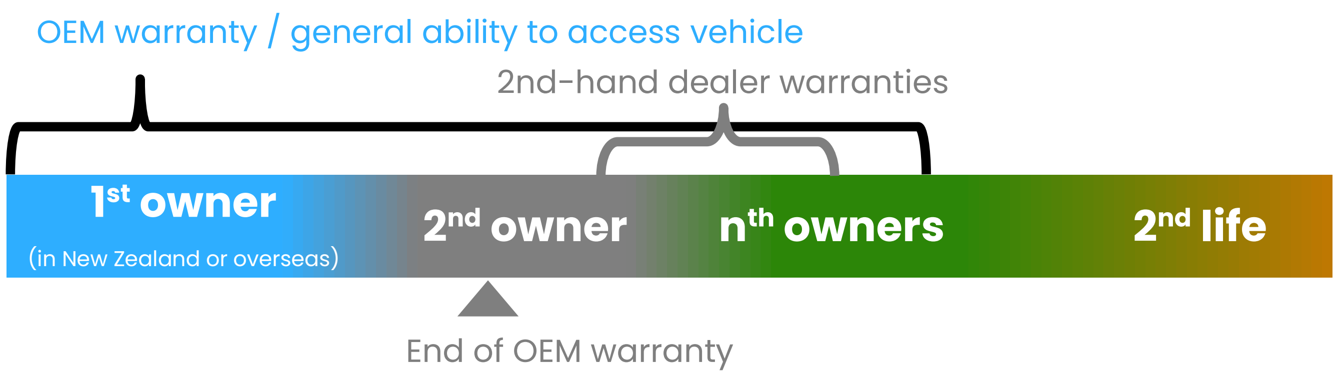

Figure 29 - Representation of the life of a battery with regards to dealer warranties

Dealing with an end-of-life battery is difficult for private owners

End-of-life EV batteries handled by OEM dealers are either shipped overseas by the OEM or handled by local parties who have licenses to ship overseas. Private owners do not have access to these types of arrangements.

If a private owner does successfully remove a battery the OEM warranty is then generally considered to be void. It is currently unclear which OEMs would take the battery back once the warranty has been voided, let alone if it had been re-used in other second-life applications.

The movement of vehicles into the second-hand car market implies that poorer people could be left with the cost of disposal

People in New Zealand prefer to spend less than $10,000 on vehicles, which translates to second-hand purchases of older vehicles.

The most expensive part of recycling is collection and dismantling. Without subsidies or a profitable recycling business in New Zealand, any costs associated with this would currently fall to the final vehicle owner, who is likely to have less resources to contribute.

Owning vs Operating

The owner of the battery is not always the one who uses or benefits from it

Batteries can be owned by one person or company but used by another. The most common example is battery leasing or renting (where the customer leases the battery but owns the device it powers). Other models are forming, such as where one company owns the battery and application but another company operates it (e.g. public transport.)

Battery use and health will form a key part of these relationships

The operator of the battery ideally wants to maximise the use of the battery, and therefore their revenue, through faster charging and discharging. While the owner of the battery wants to maximise the life of the battery, and therefore their revenue, through optimum battery use and care.

Businesses we interviewed are exploring solutions to this in the form of warranties, service contracts and even by pricing charging sessions into their contracts based on how they impact battery life (e.g. pricing 'deep', 'medium' and 'shallow' charges differently).

Leasing vs Owning

Leasing increases battery lifecycle oversight and responsibility by retaining centralised ownership

Finance is being explored by several businesses we interviewed as a tool to reduce the upfront cost of EVs and, in some cases, to ensure control over batteries for future applications. Splitting the product up into vehicle and battery requires good, ongoing data to ensure that batteries are delivering the value promised to the customer, and to ensure the battery finance is priced correctly.

Leasing is not currently financially viable for some organisations or applications

To be a successful business model, leasing needs to be made attractive to the customer. Many businesses we interviewed told us that EV and battery leasing models are currently expensive or overly complicated. Many fleets worked out that it was cheaper to buy EVs outright than to lease them for the intended ownership period. Finance companies they talked to offered EV leases but do not fully understand EV lifecycles and are therefore seeking safe, expensive agreements.

Short term leases make more sense when batteries can be upgraded.

In applications like public transport or aviation, leasing batteries is more attractive because it allows faster access to evolving technology, allowing customers to upgrade their batteries every two to four years increasing their range in the process.

Leasing benefits from longer lasting batteries

Longer lasting batteries generate more revenue through longer initial leases and then through second life leases. This is also better for environment.
For larger applications (e.g. trucks) the running and maintenance costs form a large part of ownership costs, which are also a key part of the leasing costs, making leasing more attractive for large scale applications.

Good data is needed to make battery leasing a functional business

Private importers who can't collect and track battery data will likely have trouble partnering with finance companies to sell their batteries. Pricing residual value or depreciation accurately becomes difficult without it, as does extending the life of the battery and ensuring it is fit for future applications.

Mandated responsibility

Determining who is responsible for the full life of the battery in New Zealand is difficult and could hinder innovation

Mandated lifecycle responsibility compels manufacturers to manage the disposal of the products they produce, which ideally leads to the manufacture of more easily recyclable products.

New Zealand is a small country, often referred to as a ‘rounding error’ on Australia’s vehicle market. As such, it is difficult to compel international businesses to take their products back. Batteries are also imported to New Zealand by a wide variety of businesses with different levels of expertise and business models. These include, but are not limited to:

- New Zealand-owned branches of international OEM brands
- Second-hand car dealers

- EV and energy storage businesses importing batteries as cells which are then assembled into a large battery or custom-made large batteries assembled overseas
- Private citizens
- Start-ups and small businesses for the purposes of
    - Energy storage
    - Vehicle conversion
    - Electric vehicle upgrades or repairs
    - Experimentation
- Lease companies
- Corporate fleets

As demonstrated by New Zealand's second-hand vehicle market, people and businesses that import batteries do not necessarily have the skills or expertise to maintain them or dispose them. They also may not have the financial, technological or administration capabilities to meet their obligations throughout the life of the battery without inconveniencing the end user of the battery.

Some businesses we interviewed import batteries on behalf of customers and wondered if, under a mandated responsibility system, they would retain responsibility, or if their customer would.

Retaining responsibility in a second-hand market would be difficult

Businesses that sell their vehicles into the second-hand market (e.g. fleets, lease companies) currently have no way of maintaining any connection to the vehicle or the new owner.
Second-hand markets are critical for keeping products in circulation and use for as long as possible, and for sourcing parts to repair other products. A mandated responsibility approach may give either:

- the second owner the ability to return the battery to the original seller, or
- the first owner the ability to collect the battery from the second owner.

If implemented poorly, these actions could undermine the core function of a second-hand battery market, stifling innovation.

Mandated responsibility impacts on lease, rental and carshare business models

Many transport-as-a-service business models currently balance depreciation, interest on loan payments and short-run ownership costs with the revenue they generate from their services and the eventual re-sale of the vehicle.

If poorly implemented, mandated battery responsibility could impact on these business models, encouraging transport-as-a-service providers to avoid EVs in favour of zero-responsibility traditional vehicles. This could then reduce the number of EVs on the second-hand market in the future.

Batteries can out-live businesses, making enforcing importer responsibility difficult

Batteries can last several decades, which may often be longer than the businesses that import them, leaving the battery without an ultimate owner at the end of its life.

Several businesses we interviewed suggested that, if poorly implemented, a business could close down and then re-open under a new brand in order to avoid responsibility or paperwork as the batteries they have sold approach their end of life.

Mandated responsibility could negatively affect innovation and EV uptake

EV uptake is being accelerated in New Zealand by subsidies. Additional costs and barriers added to EVs could work counter to this goal, or make it more difficult for New Zealand made EVs(e.g. UBCO, FTN Motion) to compete in overseas markets.

We interviewed several businesses who are repurposing EV batteries. If poorly implemented, mandated responsibility could prevent them from being able to purchase batteries, sell batteries or work on batteries without the original importer's permission.

Insurance and battery stewardship

The concept of insuring batteries and vehicles separately is new to insurance companies

Participants we interviewed who provided or worked with insurance companies reported that there is uncertainty around if or how to insure batteries separately from vehicles. Insurance IT and data management systems are large and complex and are not likely to be set up for vehicle and battery disaggregation. The current approach to insuring vehicles where batteries have been swapped or upgraded is to manually re-assess the agreed value of the vehicle on a case-by-case basis.

Insurance models are not designed to price for long-term future scenarios

Insurance contracts tend to renew annually, which respondents indicated generally leads to year-on-year pricing and risk reviews. Assessing a battery 15 years in advance would likely be too far in the future.
Respondents reported that insurance-backed research tends to focus on the safety of new technology rather than its longevity, but some companies are exploring how environmental impact could be factored into their models too.

Insurance companies seek to maximise the value of wrecks

Until new EV-specific processes are developed the existing processes for traditional vehicles will be applied to EVs. Generally this means insurance companies will seek support from OEMS and/or on-sell wrecked vehicles to scrap collectors.

New processes for handling EV batteries need a to be fully developed before insurance companies will commit to implement them. Respondents generally agreed that they are looking to government and industry for regulation, guidance and support.

OEMs reclaiming ownership

Despite future material shortages, not all OEMs are seeking to reclaim their batteries at the end of life

Companies we interviewed and their customers demonstrated a wide range of approaches to end of life batteries. Broadly speaking, these approaches were:

1. The battery belongs to the purchaser and OEM responsibility ends with the warranty or consumer legal protections.
2. The battery will be taken back if it was originally sold in New Zealand by the OEM representatives, and is returned to the OEM in good condition.
3. The OEM will take back the battery and has a plan for repurposing or recycling the battery (e.g. in solar farms). This was occasionally, but not always written in to contracts with suppliers.
4. The OEM will buy the battery back and may already be taking proactive steps to retrieve their end-of-life batteries.

OEMs that seek to reclaim their batteries are exploring ways to do so.

Manufacturers and their local agents and dealers we interviewed who were committed to retrieving their batteries were creating strategies to make it easier for batteries to make their way back. These strategies included:

- Providing guarantees to customers
- Requiring that customers return batteries as part of a lease or contract
- Working with insurance companies and their licensed repairers or wreckers.

- Offering bounties or payments for returned batteries
- Working with local recyclers
- Setting up their own recycling facilities overseas
- Considering setting up recycling facilities in New Zealand

Currently, each OEM is only looking to recover batteries from their own vehicle models, but it was generally accepted that this would change in the future, either through agreements with other OEMs or through the need for more recycled materials.

6. Manufacture, import and sales

Battery Importers

Start-ups and small enterprises are importing third-party batteries

While most of the businesses and individuals we interviewed were importing battery packs within vehicles, this was not always the case and many businesses we interviewed were importing batteries for innovative purposes.

Some businesses were upgrading vehicles with third party batteries by either replacing a battery pack in an existing EV, or by converting a petrol vehicle to electric. Some businesses were creating battery packs composed of individual imported cells, and some were replacing damaged cells within existing battery packs.

These businesses were almost universally small, locally-owned businesses, or electricity lines companies. Larger businesses we interviewed indicated that they will look to import batteries more, once batteries become cheaper and can support scalable, commercial business models.

Individuals are buying and selling batteries online

Online groups have emerged dedicated to buying and selling aftermarket EV batteries and to building large batteries from scratch using individual cells.

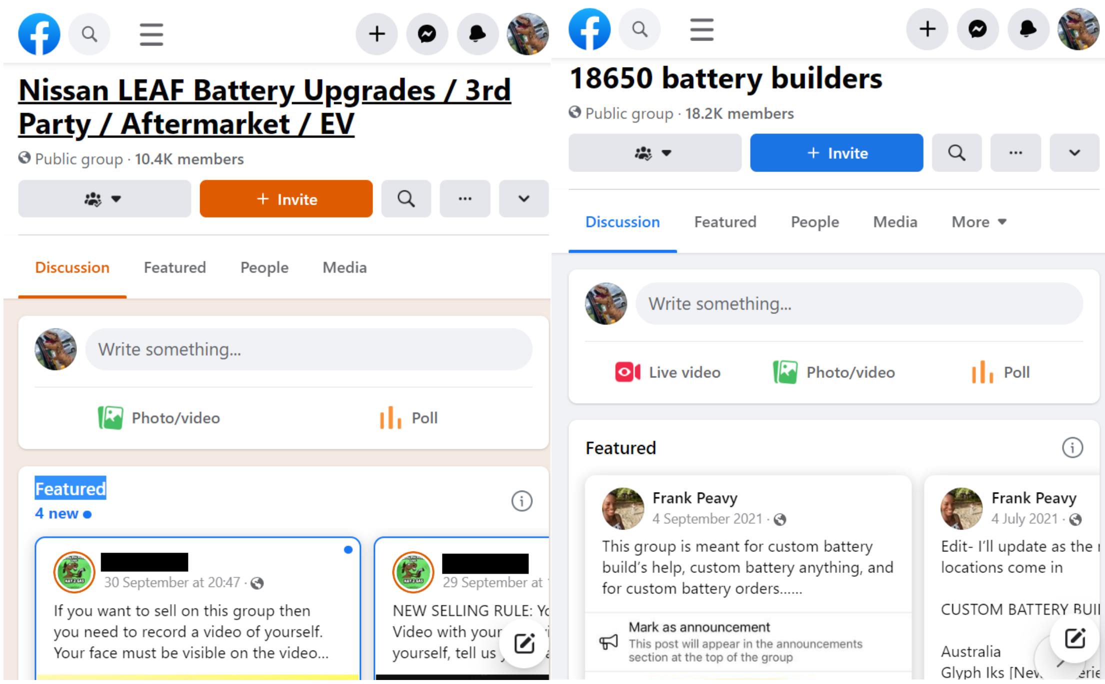

Figure 30 - Two battery-focused facebook groups
https://www.facebook.com/groups/1593989937357038
https://www.facebook.com/groups/274453827624791

People in these groups purchase battery packs and cells from one another and share advice.

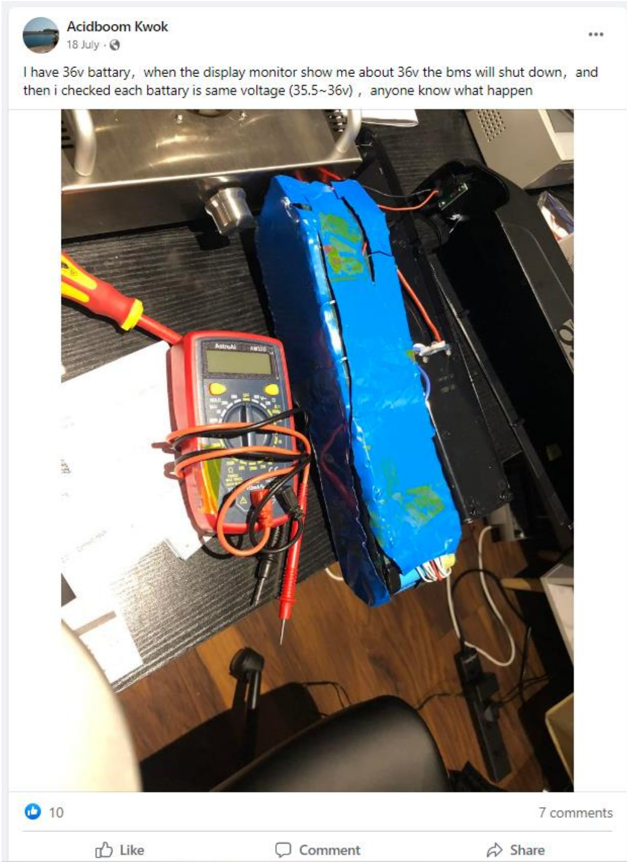

Figure 31 - A home-made 36V battery composed of 18650 cells and Lithium pouch cells for sale in a facebook group

Often the cells used by people in these groups are purchased through websites like E-bay or Alibaba, where hundreds of cells can be purchased from resellers or manufacturers in Asia.

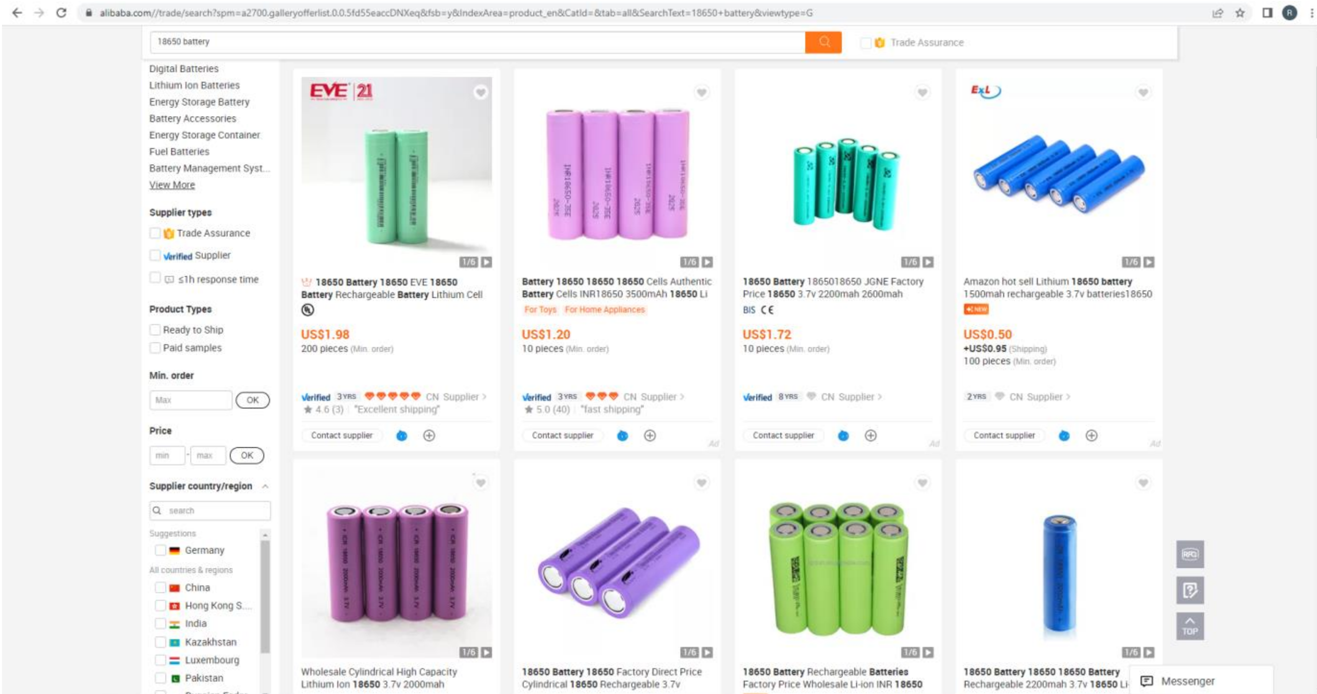

Figure 32 - 18650 cells available for mass purchase via Alibaba

Businesses are also importing used batteries

Due to exceptionally high demand for new batteries, importing new batteries is extremely difficult for individuals and small businesses. Because of this, not all imported batteries are new.

Some businesses we interviewed were importing used batteries for the purposes of vehicle conversions or stationary storage and informed us that even these batteries are difficult to source. Other businesses used specialist battery-sourcing contractors to find batteries that meet their specifications.

Businesses are also dismantling large batteries

While it is not common practice, several businesses we interviewed had explored the possibility of dismantling large batteries for the purposes of repairing consumer electronics or creating new batteries for e-bikes, e-scooters and power tools. These applications are increasingly relying on battery power and sourcing replacement batteries for them may help extend their lives in the future.

Manufacturer responsibility

The more repairable a battery is, the more recyclable it will be.

Waste management professionals we interviewed agreed that the harder a product is to repair, the harder it is to recycle. This is because recycling requires products to be dismantled before they are processed. It appears that one of the key strategies deployed by manufacturers to protect IP, thereby reducing the viable lives of their products is to prevent repair by making dismantling difficult.

Creating more recyclable products is essential, but there is little New Zealand can do to compel these practices

Respondents agreed that the more responsible a manufacturer is for the lifecycle and the quality of the product (in this case, batteries), the more likely they will be to make a product that is easily repairable and recyclable.

However, respondents also agreed that, due to our small market size, New Zealand would not be able to influence manufacturer product design decisions on our own, nor compel them to take back their products at the end of the product's life without risking losing the benefit of access to these products in the first place.

Manufacturers are concerned about second life applications of their products

Battery technology is new technology and is in high demand for many different applications. There is some concern around whether a defective product should be in circulation and who is responsible for removing it, e.g. if a recall is issued on a vehicle model that has been parallel imported.

Risk, responsibility and reputation are key considerations for manufacturers

EV batteries are being used for purposes beyond the manufacturer's intent. Risks of accidents are increased if someone uses a defective, recalled component in a third-party application. Businesses we interviewed were uncertain who would wear the risk and accept responsibility in these cases.

Manufacturers do not provide third-party support or access for their systems

Several small businesses we interviewed have already been prevented from buying batteries directly from manufacturers who did not want to risk their products in new applications made by unknown businesses.

Despite concern over who takes responsibility for the failure of a battery due to poor software management in second life applications, vehicle manufacturers do not provide support or access to their vehicle data or information for third-party re-purposers. Some of the businesses we interviewed are looking to provide in-house battery expertise in the future.

Some manufacturers see opportunity in second-life batteries

Second-life refurbishment, battery leasing or subscription models offer new opportunities to OEMs. Retaining the ability to get their batteries back and track their data through their life is key to enabling this, as is ensuring that battery assets are retained within the OEM's own circular economy processes.

NZ EV businesses are working to create recyclable batteries

Local EV manufacturers we interviewed are actively designing batteries and selecting materials that are and will be more recyclable. However, these goals can conflict with other business goals.

For example, designing a battery casing to manage thermal runaway may make the battery more difficult to disassemble. Using battery materials that will hold value may conflict with ethical material sourcing practices. Businesses are currently using their own best judgement to navigate these complicated, intertwined issues.

Manufacturer incentives

New Zealand OEM branches are largely bound by the decisions of their overseas parent companies

Local OEM representatives generally have no say or jurisdiction over what their parent companies do or manufacture. NZ is generally considered to be a rounding error on Australia's market and local agents are bound by their contracts with the OEMs they represent.

Market size influences what batteries NZ can import

All respondents agreed that the New Zealand market isn't big enough for OEMs to worry about. Some of the heavy transport suppliers are said to be pulling out of NZ due to not wanting to meet our standards, and there is the potential for the same thing could happen to EVs and batteries.

Competition influences what batteries companies import

Commercial companies we interviewed all stated that shareholders want to know what businesses they are supporting when they buy batteries. However, each business has found it difficult to obtain reliable information about their supply chains to date, due to the intense demand for batteries and competition between manufacturers.

Businesses are also finding that not every buyer is concerned with provenance information, and commercial battery-powered products, with certification, sold by NZ businesses are often under-cut by cheaper, copy-cat products with no certification.

OEM Brands in New Zealand aren't always owned by the OEM

Large, overseas OEM brands are typically represented in New Zealand by locally owned or registered dealers, agents or franchises, occasionally with one wholesaler who supports distributors across the country.

Manufacturers are focused almost exclusively on their own batteries

Businesses we interviewed indicated that OEMs want to receive their own batteries back and some are setting up their own circular economies and recycling facilities. OEMs currently are not looking at taking back batteries from other manufacturers, due to recycling costs and concerns around IP, however, this could change if material shortages become more severe in the future.

Manufacturers are not likely to receive their batteries back from the original customer

New dealers have a reputation for being expensive, and second-hand dealers and private sales often offer better returns than dealer buy-back programmes. This means manufacturers are unlikely to service their batteries for the full life of the battery. As the car is sold several times, the subsequent owners are more likely to seek out cheaper services, especially after the original warranty expires.

Most manufacturers are waiting for Government to lead with regulation

Several businesses we interviewed are building the networks and processes required to collect their batteries, from both direct sales and parallel-imported vehicles. However, there was concern about the state that their batteries may be in when they collect them again after several decades. Because there's no legislation, this is simply a part of their corporate good will and they stated that they are looking to work with regulation.

Retaining customer loyalty will become much more important

OEMs and dealers are forecasting to lose significant revenue from maintenance and servicing. One way in which they are looking to make up for this shortfall is in customer loyalty. Some customers stick with a car for 10 years, while some replace their vehicles every two years. Improving technology and better customer engagement could push more customers into the latter category. EV-specific maintenance and upgrades, including battery and software support and retrofitting new technology, will form a key part of this strategy.

The longer the warranty lasts, the longer the relationship lasts, and offering extended warranties that include servicing is another strategy that could prolong the life of batteries, while also ensuring manufacturers retain access to, and some responsibility for, their batteries.

Second-hand importers

Second-hand vehicles are purchased by agents, at markets overseas

New Zealand buyers ask for as much information about vehicles at auction as they can get, and expect it to match, within reason, when it arrives in New Zealand. Battery health information is only available for a small number of make/models of EV, often using third-party tools like the Leaf Spy app. When this data isn't available, New Zealand buyers must use whatever information is available (e.g. remaining range estimates on the dashboard of the car) to make a judgement call on the battery health, and therefore price of the EV.

There is low risk of battery swaps happening in between purchase and delivery

It is a labour-intensive process to remove a battery and replace it, especially at a port or auction house. If the buyer has the battery ID as a part of the auction (this is available for the Nissan Leaf via Leaf Spy), then they can verify the battery when the vehicle arrives. But battery ID verification tools do not exist for most models of EV.

There is a risk of battery data misrepresentation

There is a higher risk that the battery will not have the level of health that the purchaser was informed it has, for example, if the purchaser is shown a Leaf Spy report or dashboard image for another vehicle. Currently, the local auction house and agent's reputations safeguard against this.

Emerging business models

Some car dealers are investing in servicing and maintenance of batteries

Several EV-focused businesses we interviewed have successfully done a number of battery replacements and upgrades for customers. This work is done at the pack, module and cell levels, depending on what is needed and cost effective. These services currently focus heavily on the Nissan Leaf, but will likely expand as other, older models are imported in larger numbers. These businesses purchase the existing battery during the transaction to offset the cost of the upgrade for the customer and to provide batteries for sale to other customers.

New batteries could soon become viable replacement options, reducing the cost of second-hand batteries

Businesses we interviewed indicated that manufacturers in India and China are looking to bring brand new EVs to market for under $40,000 NZD. This includes much cheaper batteries which, if able to be purchased separately, would allow for cheaper upgrades with new batteries, which would then push the cost of second-hand batteries down further. The cheaper batteries become, the more viable new business models will become, like car conversions and home energy storage.

Transport-as-a-service accelerates EV uptake for car dealers.

Car dealers we interviewed all offer different degrees of transport-as-a-service for their customers. Some offered free loaner cars for occasional long trips to customers who purchased short-range EVs, while others were migrating to include leasing and subscription options in their businesses.

Feedback from businesses operating leasing, lending and subscription services was that these models provided customers with several advantages:

- Subscriptions allow customers to do long-term test-drives of an EV.
- Subscriptions provide the flexibly to switch between an EV and a traditional car depending on what the customer needs at the time.
- Long-range loaner vehicles (one dealer called their loaner car a "Prius of shame") give customers confidence when buying lower-range EVs.
- Leasing and subscriptions allow EV-reluctant customers to forgo responsibility for the batteries.
- Cheaper access to electric vehicles, as customers could lease cheaper, low-range EVs and upgrade to long-range EVs when they needed them.

Battery leasing is slowly emerging as a business model

Some special purpose vehicles, like farm vehicles, allow batteries to be swapped far more easily. This provides vehicle dealers with the ability to sell a vehicle and lease the battery separately. This option is finding favour with people who are reluctant to adopt EVs due to battery degradation and recycling challenges. Some businesses we interviewed were able to provide five-year leases for batteries knowing there will still be good residual value in the batteries after that time.

Because leasing is tax deductible and it reduces the capital cost, the customer receives a cheaper EV that will likely get a better battery after five years.

Applying this model to road vehicles would be much more difficult due to the lack of universal standards and OEM cooperation on battery interoperability. Greater third-party access to information about batteries would also be required if battery leasing were to move beyond OEM control and become a competitive marketplace.

Battery stewardship challenges

Extended ownership of batteries would be difficult to enforce

Under current New Zealand laws, any business that retains responsibility for disposal of batteries they have sold could simply shut down to avoid responsibility when large numbers of the batteries they have sold reach the end of their life.

EV batteries are lasting longer than expected, and future technologies are forecasted to last even longer. There is no guarantee that the business who sold the battery will still be around at the end of the battery's life.

Manufacturer businesses are optimised for production, not recycling

International OEMs can't easily be held responsible for their batteries by New Zealand. Unless there are significant incentives or need for materials, these businesses could be resistant to receiving them back after the battery has been used in second-life applications.

Several businesses we interviewed indicated that some OEMs were setting up their own circular economies, while others are only focused on manufacturing and selling, and believe other businesses will deal with recycling.

Battery responsibility currently extends as far as the warranty or Consumer Guarantees Act require it to extend

When a new or used vehicle is imported and sold, the importer has the warranty and a Consumer Guarantees Act (CGA) obligation. The CGA states that products must last a reasonable amount of time, while warranties on new cars are currently being offered for between eight and 15 years and are increasingly including separate clauses about the batteries. Warranties on second-hand cars range from one to three years.

Greater battery knowledge impacts on sales and customer relationships

The Nissan Leaf is one of the few vehicles for which battery health information is readily available to everyone. This has allowed second-hand dealers to better understand, communicate and price their products to buyers.

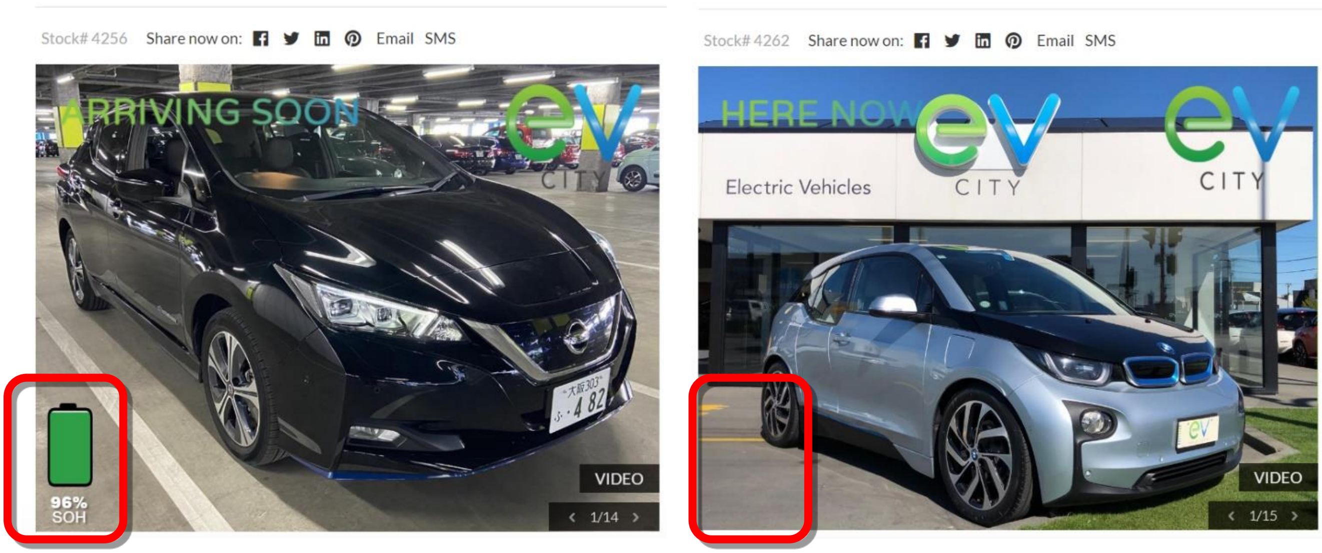

Figure 33 - A NZ EV dealer is able to display battery health for a Nissan Leaf (left), but does not have this information available for a BMW i3 (right)

While this provides transparency on individual transactions and gives customers a better way of benchmarking EV performance, it can negatively impact car dealers.

In 2018 a bug in the firmware for 30kWh Nissan Leafs meant the car reported a lower battery health and faster degradation rate than the car's battery actually experienced.

When this information was published several car dealers were forced to give refunds, or to sell their vehicles at or below cost. One Christchurch-based dealer refunded deposits on 30 vehicles and managed to sell them at a loss before the software bug was discovered and a patch released.

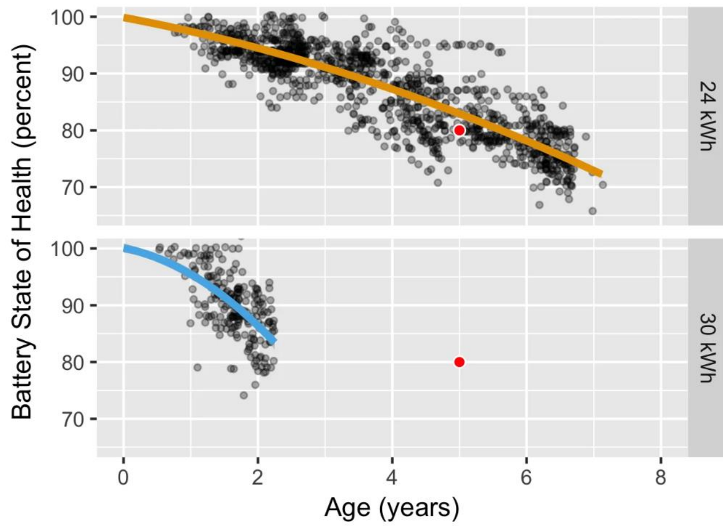

Figure 34 – Reported degradation results for the 30kWh Nissan Leaf, pre firmware patching
Source: https://flipthefleet.org/2018/30-kwh-leafs-soh-loss/

More recently, in 2022 an EV dealer was forced to refund a purchase under the CGA when the battery degradation on an electric van was discovered to be 3% lower than advertised.
Source: https://autotalk.co.nz/news/hamilton-ev-dealer-to-pay-mislead-customer-24000

Several dealers we interviewed have found that battery degradation can increase repeat business if managed correctly. One business had a happy, returning customer who wanted a new battery despite having 74% health on their Leaf.

7. First life applications

Stationary storage applications

Private storage applications at home

Solar businesses in New Zealand currently offer a variety of stationary storage options, sold new from OEMs as a part of off-grid or hybrid solar systems. People buy batteries to future-proof their houses or to enable them to better respond to market prices when they are on spot-market exposed plans.

On a purely financial basis, batteries are still too expensive to pay for themselves within their warranty periods, unless the owner would otherwise face very high energy or grid connection costs.

Residents won’t always be the ones that will own the batteries

Companies like SolarZero and organisations like Kāinga Ora are currently installing solar systems that they own and operate on to houses. The former as a for-profit business model, the latter as a social and community focused effort. In many cases batteries are either explored in pilot projects or installed with commercial solutions.

Electricity distribution businesses are searching for ways to work with batteries on their networks

One of the big challenges electricity distribution businesses (EDBs) face is how to tap into the value stack of batteries in their communities. This could be by virtually dividing a battery capacity in to two ‘buckets’ and selling one ‘bucket’ as capacity to other businesses, or by using batteries to relieve demand pressure on their networks. From a regulatory perspective, dividing an asset in half is complicated.

From a commercial perspective, distribution companies are more likely to deploy their own batteries to manage power quality and do frequency keeping. However, energy retailers and local community hubs are more likely to use batteries to manage power demand and keep electricity pricing at a lower level.

The key feedback from most energy professionals we interviewed was that when battery energy density and costs become a replacement option for diesel generators, the economics of these applications will quickly add up.

Electricity grids are essential services, so batteries need to meet high standards

If batteries are installed incorrectly then it's potentially damaging to an EDB's network. EDBs serve a variety of essential infrastructure services, like hospitals and traffic lights, where downtime can have terrible consequences. Working with third parties to ensure that grid-connected installations are done correctly is essential for EDBs. Businesses we interviewed in this area agreed that this approach also enables more free discussions and relationship building with these operators, with the goal of enabling uptake of renewables and delivering the lowest energy prices to communities.

EDBs are likely to use the full lifecycle of a battery

Energy professionals we interviewed suggested that grid-connected batteries are likely to effectively utilise the full depreciation range of the batteries, as frequency keeping (balancing immediate energy demand with energy supply) tasks do not always require batteries to be fully discharged in order to provide effective power management. Any batteries owned by an EDB are therefore more likely to be recycled than on-sold.

Fleets and their EV strategies

Fleets are mostly buying EVs instead of leasing

Most fleet managers we interviewed are focused on immediate decarbonisation of their vehicles, either because they have been mandated to by government, or because of social corporate responsibility. The long-term impact of batteries is not a consideration in their purchasing decisions because they need to switch to low emission travel. In their view, EVs are the best option available and they have no control over addressing issues around batteries.

Many of the local council and national Government agencies we interviewed are opting to buy new EVs outright instead of leasing. This is due to three factors:

- The All of government contract has provided discounts when they purchase EVs outright.
- Purchasing EVs allows them to on-sell into the second-hand market, providing cheaper EVs to New Zealanders in the future.
- The low maintenance and fuel costs, higher resale value and availability of capital make purchasing a more cost-effective option than leasing.

Some fleets provide cars for exclusive use to one staff member

Fleet managers we interviewed are often responsible for company cars that are driven by one driver. Some staff require this due to high travel requirements of their jobs, but other fleets provide corporate workers with a car as part of a pay packet arrangement, where company cars act as a status symbol of a higher job.

One driver – one vehicle arrangements tend to increase the number of vehicles in a fleet and reduce the utilisation of those vehicles.

Businesses we interviewed provide shared pool cars in their fleets

Most fleet managers we interviewed operate a shared pool of vehicles for the use of most employees within their organisations. While vehicle utilisation is increased and fleet numbers are decreased, this approach can have an impact on long-term battery health.

Business policies around EV use will have an impact on EV battery life

Most organisations we interviewed have a policy of keeping vehicles for a minimum of between three to five years or 100,000 km before selling them into the second-hand market via an auction. They also had a policy of plugging in the vehicle whenever it is parked at a depot, so that they would be fully charged for the next driver.

Leaving an EV at 100% charge for long periods of time can increase the rate of degradation, depending on the make/model of the EV, its battery chemistry and the quality of its BMS. This policy, plus the expected life in the fleet, could result in prematurely degraded batteries entering the second-hand market.

Non-ownership of EVs impacts on battery life

Staff and fleet managers do not own the fleet vehicles and are focused on getting jobs done with tools available. Maintenance is traditionally not the fleet manager's responsibility and they are not tasked with ensuring long-term battery health is kept high. Battery degradation is also usually covered, to a degree, under warranties.
Conversely, fleet managers we interviewed indicated that plug-in hybrids are seldom plugged in and therefore spend much of their life at low states of charge, which could also have long-term impacts.

Battery degradation is not visible day-to-day, so the impacts of these policies are not likely to be discovered until further down the track, when the vehicles are either brought to market or owned by people who buy from the second-hand market.

Car-share and Transport as a Service

Shared EV services offer very large emissions reductions

The primary environmental goal of shared fleets of vehicles is to replace private car ownership and therefore remove vehicles from the road. The secondary environmental goal is to transition the remaining cars to EVs.
Companies using this business model are either encouraging the public to transition to a shared fleet or are encouraging more car-share within businesses.

Transitioning a centrally owned car-share fleet to EVs is difficult and expensive so these businesses often rely on short-term leases

EVs are more expensive and service-focused fleets must balance depreciation rates and maintenance costs with revenue. Service fleets therefore rely on either buy-backs from manufacturers, or private sales on the second-hand market to achieve this balance, and are unlikely to be the ultimate owner of the battery at the end of its life, despite being the likely first owner in New Zealand.

Vehicles are kept in service fleets for the period of time that this makes financial sense for. Businesses we interviewed indicated that this could be anything from six months to seven years depending on the business case.

Trucks and busses

Businesses are focused on getting EVs into fleets

Switching to a full EV fleet is much harder for trucks. They are not only more expensive, but there are additional charging infrastructure costs and demands.

Vehicle purchasing decisions are based on cost and feasibility and the focus of trucking companies is very much on the current and near-future problem of getting vehicles into fleets, and not on what to do with the vehicles at the end of their lives.

Trucks are often custom made-to-fit

New Zealand trucks are generally either purchased as 'off-the-shelf' trucks or as special, custom 'made-to-fit' orders or conversion kits. Off-the-shelf trucks are cheaper and designed to suit most purposes, while custom orders offer more opportunities to access data from the vehicle and its battery.

Businesses are still in the early stages of exploring EV business models

Businesses we interviewed who are purchasing electric trucks are seeing patterns internationally, particularly in the US, that large, long-haul companies' fleets are looking to install their own charging solutions along routes to support their customers' and drivers' needs.

Most manufacturers are currently using the traditional vehicle sales model and view the battery as being sold part-and-parcel with the vehicle and covered by warranty. Business models such as leasing, battery rental and agency versus distributor outlets are being considered for the financial and risk management benefits, and are being deployed overseas, but are not yet deployed in New Zealand.

Battery lifespan is being considered by manufacturers

One manufacturer we interviewed required that the batteries from their first fleet of electric trucks are to be returned to the manufacturer and would only lease the trucks' batteries to customers with special conditions. The motivation behind this policy was for testing and quality control purposes as they introduced the new technology. The next generation of vehicles available from that manufacturer will likely not come with the same restrictions.

Truck batteries are being imported from a variety of countries

Many, but not all, of the manufacturers we interviewed are obtaining batteries from manufacturers in China. The rest are obtaining batteries from European and North American-based manufacturers.

Electric trucks appear to be lasting longer than expected

Battery health degradation appeared to be very slow in the electric trucks deployed across the businesses we interviewed. Several said they have seen no noticeable degradation over the first five years and are expecting to get between 10 and 20 years of usable life out of their batteries. This is likely due to the large battery size, a lower charge cycle frequency, constant environmental conditions and improved technology. These businesses are expecting their batteries to last up to 50% longer than originally anticipated.

Professionally converted or custom-made EVs tend to have better battery monitoring solutions

Most of the business we interviewed rely on OEM-provided CAN bus scanning tools to obtain information when the vehicles come in to the country or come back to the dealer for servicing.

Businesses we interviewed that do their own conversions or that work closely with suppliers often have much better, more granular data on battery usage and are in a much better position to understand what their battery life and performance profiles look like.

Vehicles that provide this granular data are also often vehicles that allow for individual cell identification and replacement.

Truck batteries are large and will be valuable at the end of their first lives

Electric trucks tend to require 100+ kWh battery packs. Many of the businesses we interviewed consider the end of usable life for a battery in a truck to be at around 70% state of health. While this may no longer be fit-for-purpose for a truck, 70 kWh is an attractively large battery that will likely find many second-life applications.

Plans for truck battery recycling largely rely on OEM buybacks

Recycling has been mentioned by truck manufacturers selling to New Zealand businesses we interviewed, but only insofar as a promises to buy or accept back their batteries back at the end of life. These promises were generally not formalized in contracts. Projected growth in the trucking market implies that there will be significant supply of truck batteries in the future, and without a guaranteed avenue of disposal, overseas manufacturers can't be relied on. Distributing their battery knowledge out to local dealers and agents could be one way of ensuring batteries are handled safely at the end of their lives in New Zealand.

Under the current business model where the vehicles are sold with a warranty, the customer would be more likely to on-sell the vehicle than to return it to the business that sold it to them.

Several businesses we interviewed considered themselves traditional importers who weren't very willing to transition to new business models. While there might be opportunities they can pursue with old batteries, this work is not within their core-competencies, and they would need to partner with other businesses to pursue those opportunities.

Many of the businesses we interviewed have some arrangement in place where the manufacturer will take back their own batteries. Some stated that they will place the batteries into second-life applications, such as on solar farms, while others are partnering with local recyclers in their home countries.
It is worth noting however, that even though manufacturers located in China have said they will take back batteries, the Chinese Government does not allow waste batteries to be shipped to China, making the logistics of fulfilling this promise very difficult.

Aviation

Battery powered aircraft will become much more common

There will likely be a lot of battery aircraft in use over the next 15 years. Any aircraft that offers up to 19 seats will likely be electrified through propellers driven by electric motors, powered by a battery. For example, Sounds Air recently signed an MoU with Hart Aerospace. looking at propellers and battery electric motors.

Energy density and weight are very important for aviation applications

As with maritime applications, power and capacity to weight ratio is very important in an airplane, weight management is so important that systems and behaviour that extend the life of a battery are very much a secondary consideration.

Batteries used in airplanes will have short first-life applications

Commercial airplanes are in almost constant use as when a plane is grounded it is not making any money for the airline or owner. There are also built-in requirements for the aircraft's reserves and countries regulators can impose a service time limit on components. Airline batteries are being designed to be changed every 1000 to 2000 hours in line with engine changes.

This presents a unique challenge for battery-powered aircraft, as they will get through their rated charge cycles much, much faster than batteries in other applications. So swapping out batteries in aircraft while they are still at a relatively high state of health could likely become a common and normal thing to do, rather than waiting for the battery to degrade.

Due to this short life in service and high battery health, battery leasing is a likely solution in the aviation industry. Models similar to how Renault approached leasing the Zoe battery are something that's being looked at by finance companies.

Refurbishing batteries from aviation will make economic sense

At the end of a battery's life, refurbishing makes more sense than complete pack replacement, so that the business does not need to waste money buying the battery management system and pack for the same battery many times over.

There are a very limited number of aviation batteries currently in New Zealand, however the ones that do exist own and are responsible for their batteries and are looking for local partners to handle the end of life reuse and repurposing.

Maritime

Maritime batteries tend to be specialised

Maritime businesses are not buying direct from cell manufacturers, but instead purchase specially made maritime batteries from companies who buy cells from other manufacturers, however some of these maritime battery companies have started their own cell manufacturing.

Typically, battery companies are either entirely in marine/maritime battery application market or not at all, as maritime applications require a large degree of expert knowledge and specialisation.

Maritime batteries cost less compared to the rest of the EV

Batteries aren't a huge piece of the cost of the boats (<10% of value of the boat) and the lighter the battery the better. There is a bottom line on battery safety, but once the required safety standard has been achieved, the focus is on weight reduction. Early products are expensive because they are not being manufactured or sold en-masse but as the industry learns and evolves standardization will bring costs down and significantly increase sales.

Future battery replacement costs will make up a large part of maintenance costs

Battery replacements are a big part of maintenance costs, so reduced battery prices will significantly reduce maintenance bills, which are already significantly reduced from their fossil fuel counterparts, and drive adoption.

Battery leasing will be more feasible in the future

Large batteries in use with the businesses we interviewed were almost always owned by the businesses themselves, with very few examples of leasing. This was mostly due to the high costs of leasing EVs, driven by their high purchase price and the uncertainty over their long-term value. Businesses in the maritime and aviation space are looking into offering batteries on lease to further reduce costs for customers, but to date, customers have not been seen to show too much interest in this split asset-ownership model.

Maritime batteries are being built to last a long time

Businesses in this space are aiming to engineer the longest life products to the extent that they can, and this is reflected in the 10 to 25 year duration of the warranties they are providing, with the aim to extend this to 50 years in some cases. Customers are more likely to replace batteries because they want the capabilities that new batteries offer than due to lost capacity.

Monitoring services for these batteries are important and detailed

Each maritime business we interviewed reported that their vessels were equipped with remote battery monitoring technology via cellular networks. Batteries were monitored extremely well and was able to ensure that the batteries were kept under optimal operating conditions, in some cases within 2 degrees of their optimal temperature.

Monitoring services for the businesses we interviewed tended to be bespoke, and the manufacturers of the batteries are heavily involved in the lifetime monitoring of these products.

Due to lack of reception at sea, some of the vessels we discussed have a small on-board data centre that reports data back to owner, the operator and the manufacturer when it is able. In some cases, live data is a requirement to support and maintain their extended warranty agreement.

Maritime batteries are more likely to be upgraded than replaced

Due to the long warranties and lifespan of these maritime batteries, vessel owners are more likely replace to batteries earlier than 10 years out of a desire for better technology. The second life batteries produced by this industry will therefore have a higher and well recorded state of health.

Old maritime batteries are more likely to find second-life use with the same owners

Batteries in the maritime industry are also very large. Companies we interviewed are using batteries that range from 1 to 3 MWh in capacity and charge at speeds above 2MW. Batteries from the vessels will therefore be more likely to be used in battery supported charging at ports to reduce the burden on network companies and associated power bills for the ports. Again, as technology improves, it is likely that the boat batteries will be accelerated into these second life applications, especially if new batteries offer an improved capacity-to-weight ratio.

8. Life extending applications

Energy as a service

Businesses we interviewed are experimenting with batteries for a wide variety of applications

These applications include

- utility vehicle fleet conversions
- battery storage systems in the field
- small batteries (20kWh+ capacity) for grid balancing
- large batteries (2MWh +) for emergency response services
- standalone power systems for off-grid energy services or in grid-constrained areas
- peak-load reduction for high capacity applications, like farming or tourism attractions (e.g. ski resorts or holiday towns)
- Energy arbitrage (buying and selling electricity for profit)
- Support for EV charging infrastructure
- Portable power supplies for events and businesses
- Enabling microgrids and local / community energy hubs, and
- Research and development.

For example, Auckland Harbour Bridge is a battery solar system. All of the bridge lights are run by solar-powered batteries.

There is a shortage of batteries and small batteries are uneconomical for the large applications that retailers are interested in

Several of the businesses we interviewed that are experimenting with using batteries in second life applications can't reliably purchase the batteries they need to scale these applications. These businesses therefore haven't deployed anything yet and have restricted their research mostly modelling small scale, 5kWh to 40kWh, applications that can be achieved with ex-EV batteries in the future.

Electricity will likely become cheaper with greater battery uptake

One of the key things that drives electricity prices higher is peak demand. Greater battery uptake will reduce the peak demand on networks and generators and create flexibility in the ability to move the electricity around. While there may be a future business model in providing demand flexibility, the need that energy networks have for this business model will not likely be seen until 2030.

Businesses question how lifetime benefits could be used to distribute recycling costs and fees across different battery owners

Innovative battery applications can provide cost savings and revenue streams for businesses. These applications can use both new and second-hand batteries.

Several businesses we interviewed questioned what contribution different owners of the battery would make towards product stewardship during the life of the battery, especially in situations where, for example, the first owner used a battery in a truck for five years and the second owner used the battery as stationary storage for 15 years. While the materials in the battery may not have changed, most of the economic benefit is collected by the second-life owner.

Points of view we encountered during our interviews tended to fall on to one of two sides on the issue of long-term responsibility. Either:

- The battery should be fully paid for up-front, as it is the importer who is bringing the materials in to the country that will eventually be recycled, and there is no guarantee for how long the battery will last, or that it will have a second-life at all.

- The upfront cost should be lower, and an on-going, user-pays cost should be established in the form of an addition to Road User Charges or electricity tariffs. However, as batteries are not exclusively used in vehicles and not all batteries will be able to be metered effectively, targeting a user-pays fee for batteries could be very difficult.

Manufacturer support for second-life applications

Second-hand stationary storage is being rolled out on a residential level in New Zealand

While most solar companies offer energy storage alongside solar options, these systems are still expensive, at around $1,000 per kWh. Several businesses we interviewed are exploring using second-hand EV batteries for more cost-effective storage solutions.

For example, the cheapest EV currently listed on TradeMe (as of 12 November 2022) is LKJ963, a 2011 Nissan Leaf with 57.47% remaining battery capacity for $4,000 ($5,500 buy now).
This is between $330 and $460 per usable kWh.

Community energy projects are increasing around the world in response to rising energy prices and frustration with energy suppliers

Businesses and local organisations are experimenting with funding and creating community energy hubs across New Zealand, often with a focus on supporting low-income communities.
These projects aim to create energy hubs with solar generation capacity of between 20 to 159kW for their communities. This generation will ideally tie in with battery storage and load balancing technology.

Battery stacks will support the system and enable neighbourhoods to use energy as optimally as possible and reduce peak demand. Businesses we interviewed are looking to use second-hand EV batteries to achieve this due to their lower cost and higher energy storage capacities.

Stationary storage is seen as the final step in a battery's lifecycle

EV repair professionals we interviewed have re-homed some EV batteries with less than 50% remaining capacity function effectively under low-stress applications and are observing that they still have quite some life as stationary storage.

Other businesses we interviewed are exploring best practices for using commercial home energy storage. This could mean either using the batteries to their fullest extent to maximise profit over a two to three year period, or taking care of them and extending their life as long as possible.
Several climate-conscious, stationary battery owners we interviewed do not plan on selling their batteries as they want to see batteries recycled and cannot guarantee that the next owner will dispose of them properly. They plan to store these batteries until they know they can be recycled.

OEM support could make second-life stationary storage applications easier, safer and faster to implement.

Businesses we interviewed who were working on second-hand battery storage solutions were looking to create stationary storage units comprised of three or more EV batteries.
A small number of businesses we interviewed were looking to make use of other systems from the car, including the BMS, vehicle computers and CAN bus system, in their stationary storage applications. They regarded these systems as safer and more efficient than other solutions, as they were designed to work with the battery.

However, engineers at these businesses find it difficult to repair or get information out of these devices due to proprietary code and hardware used within the devices.

This lack of access does not dissuade the engineers, or people in the online communities around the world that they are connected to, from experimenting with these devices. Instead, they spend time reverse engineering the technology for use in their applications.

Cooperation between manufacturers and second-life re-purposers could extend the useful battery life

OEM representatives that we interviewed recognised the need to look for better solutions for batteries outside of recycling, and that repair and reuse were effective, environmentally positive solutions.

During our interviews it became clear that while manufacturers want their batteries to last longer, there is a shortfall in technical documentation and information to support the people and small businesses who are creating the second-life applications that prolong the life of these batteries.

Concerns outlined by OEMs around sharing access to data and information included:

- **Health and safety risks**
  Dismantling a battery is dangerous and a manufacturer could be encouraging people to do this by publishing guides and information.
- **Insurance risks**
  Manufacturers could be held liable if a third party used their information to create an application that then failed or caused harm.
- **Responsibility and reputation**
  Manufacturer brand and reputation could be harmed if a third party used their information to create an application that failed or caused harm.

- **Intellectual property**
  The internal workings of vehicles contain trade secrets or proprietary hardware and software that belongs to the manufacturer, its subsidiaries, contractors and partners.
- **After-market**
  If third parties used OEM-published material to create new EV batteries and there is no communication between the OEM and the third-party, the replacement battery may not be compatible and could damage the EV.
- **Carte-blanch approval**
  By publishing data and guides on batteries, an OEM could be seen to be giving permission for anyone to tinker with EV batteries.

Making batteries harder to access or repair also makes them harder to recycle

It was reported that some manufacturers had begun taking technical steps to deter third-party access to batteries in their vehicles. However, batteries need to be dismantled before they can be recycled. Any efforts that inhibit third-party access will therefore also inhibit recycling.

The only way to stop third-parties from using them would be for a government to restrict or ban using batteries outside of manufacturer specified applications. However, this would have a significant impact on innovation, as the businesses who have and need batteries would not be able to buy, sell, use or develop products with them. It would have a significant impact on battery longevity, as EV batteries would not be allowed to be upgraded or swapped or repurposed without manufacturer consent.

Requiring manufacturer consent would also likely place pressure on manufacturers to join or set up their own product stewardship systems to approve, manage and possibly control the extended use of their batteries, as well as to approve and manage third-party recyclers who would require assistance to dismantle and recycle their batteries.

If re-use and recycling solutions are not going to fall 100% on the shoulders of the OEMs and their representatives, then a large degree of support for, and collaboration with, third party technology and capabilities will be required.

Disassembly for small scale use

EV battery modules and cells can be used in consumer electronics

We interviewed a small number of businesses who have used cells and modules from EV batteries to create electric bicycles, wheelbarrows and scooters, and to fix consumer electronics. During the course of this project we even managed to fix a vacuum cleaner using cells from a Tesla Model S!

This practice is most useful for repairing and extending the lifespan of older equipment, especially in cases where the manufacturer has closed down or won't provide repair services or replacement parts.

Figure 35 – Cells being taken out of a Tesla Model S battery module (Left)
The same cells being used to repair a Black + Decker vacuum battery pack (center)
The repaired battery pack being reconnected to the vacuum cleaner (right)

This practice is unlikely to become commercial

Businesses we interviewed, while enthusiastic about using batteries in more applications, were not hopeful that individual cell replacement could become a financially viable business. Reasons for this include:

- Replacement cells would need to be the same age and condition as the cells that already existed within the battery pack, otherwise the new cell could imbalance the pack.
- It requires less labour to re-use modules than cells.
- It is easier to find the module that needs replacing than to find an individual cell that needs replacing.
- It requires two to three days for a person to remove, open and repair a battery pack, while it takes half a day to swap an entire battery pack.

Dismantling batteries creates a grey area in battery stewardship

When large batteries are disaggregated into individual modules or cells, they effectively become small batteries. Individual modules could be used to power e-bikes or e-scooters, while cells can be used to repair vacuum cleaners.

In the case of a Tesla Model S, any product stewardship organisation would lose sight of its large battery if its 7,104 individual cells were re-installed in to 888 vacuum cleaners.

Repairs, refurbishments and replacements

Third parties and home-completed battery replacements and repairs are becoming more common

EV repair and sales businesses we interviewed are already doing refurbishments, replacements and upgrades on old EV batteries. This work has mostly been done on the Nissan Leaf, Toyota Prius and Mitsubishi iMiev and Outlanders, driven in part thanks to enthusiast-driven communities around the world who have reverse-engineered and shared information about the technology within these vehicles. The practice of replacing your own battery is growing and the knowledge of how to do the work is spreading, to the point where individuals are also swapping their own EV batteries.

Figure 36 – A home-completed EV battery swap posted to Facebook on 5/10/2022

New car dealers are receiving qualifications to do this work from the OEMs

Dealer representatives we interviewed shared that their mechanics were becoming EV certified to their parent OEM standards, and that they were acquiring the approved equipment (rubber mats, suits etc.) required by OEMs for work on batteries. However, outside of maintenance work, warranty claims and replacements were handled by the OEM.

OEMs will often handle battery and cell work, while the local servicers handle the vehicle and BMS

The service process, from the perspective of the dealers we interviewed who represent international OEMs, is that they do the paperwork when a vehicle requires repair and pass this on to the country that the car came from. This is then approved and the required part is sent to New Zealand via sea freight. Damaged battery packs and cells are sent back to the country of origin; however this is happening much less now that dealers are becoming set up to do cell and module replacements.

Warranties are void as soon as a third party works on a battery

Battery warranties are currently issued for the life in the car. If a customer removes a battery the warranty is void, regardless of what happens to the battery. Several businesses we interviewed were unsure if the OEMs they represented would take back batteries that had been tampered with.

Often, even if an EV is sold as-new in New Zealand, when it is on-sold in the second hand market, the buyer will likely be seeking a cheaper product, and could be more likely go to an independent, non-OEM-affiliated garage, which could also void the warranty.

Battery certification is more complicated than auto-certification

Cars share many common characteristics and well understood parts and systems, which makes certifications like Warrants of Fitness possible.

Businesses we interviewed agreed that battery packs can vary widely from manufacturer to manufacturer and from year to year within specific vehicle models. Only the OEM or third party technicians that have thoroughly dissected and reverse-engineered particular EVs and battery packs are likely to have the understanding necessary to accurately service and certify them.

As battery technology evolves and changes, and as EVs last longer, the range of battery types on the market will likely make servicing even more complicated.

Battery upgrades and conversions

Batteries and vehicles have different lifespans

The Nissan Leaf is NZ’s most common EV and many earlier models are coming to the end of their battery’s usable life within the vehicle, but the vehicles themselves are still in very good condition.
Several businesses we interviewed are already providing replacements and upgrades for early model Nissan Leafs that will increase the driving range of these vehicles from, in some cases, 60km to 260km.

Cheaper batteries open the EV market to less affluent drivers

Batteries are the biggest part of the cost of an EV. As the battery prices fall, either through cheaper, new batteries or from second-hand batteries, and as businesses become more proficient at performing upgrades and conversions, the price of an upgraded second-hand EV will fall within reach of less affluent drivers.

Petrol and diesel vehicles can be converted to EV using third party batteries

When converting traditional cars to EV, businesses we interviewed would break up the second-hand EV battery packs into modules for use in separate conversions. In some cases, one Tesla Model S battery could convert up to 5 traditional cars to EVs.

Batteries are currently difficult to buy, but this may not last

Businesses doing conversion and upgrade work in New Zealand source their batteries in New Zealand wherever possible, often from vehicles that have been written-off but still have undamaged batteries. However, it's hard to find batteries in New Zealand and there is a lot of competition for them. Most are sourced overseas and shipped to New Zealand from the US, Japan & China.

A small number of companies we interviewed are creating new battery packs for early model Nissan Leafs using cells from other battery manufacturers. This was in-part because they could not obtain cells or replacement battery packs from Nissan directly.

Figure 37 - A battery being re-used from a written-off Tesla

Improving battery technology could make third party battery upgrades less attractive in the future

Most new EVs are released with larger batteries and battery cooling systems. These batteries will have much longer lives due to lower cycling and better

operating conditions, giving them a likely lifespan of 15-20 years, by which stage the owners will be more likely to on-sell the vehicle.
Second-hand dealers are currently finding buyers for EVs with 60 to 80km of range without requiring a battery upgrade. Finding a new home for a 50% degraded 70kWh battery with 150 to 200km of driving range will be more cost-effective than paying to upgrade the battery.

Changing battery technology could make third party battery upgrades more difficult and therefore less financially viable in the future

Official, OEM supported battery replacements are likely to be cheaper and easier to do than battery repairs and 3rd-party replacements due to the proprietary technology that third parties need to reverse-engineer. Businesses we interviewed who have reverse-engineered OEM products predicted that future OEM batteries would be more complex and difficult to deal with in the same ways.

Beyond the battery electronics, fitting new batteries in vehicles requires businesses to design bolts and brackets for the new battery's form and shape. Moving to a different form would require completely new designs and fittings.

9. Shipping and recycling

Shipping

Battery shipping is currently an essential part of recycling in New Zealand

New Zealand does not currently possess onshore battery recycling facilities. This means batteries need to be dismantled, prepared and shipped overseas to facilities like Envirostream in Australia, Hydrovolt in Europe, Redwood Materials in North America or to other facilities in South Korea.

Shipping old battery cells is high risk and high emissions

To be shipped safely, used battery cells must be packaged in a type of sand called vermiculite. Vermiculite reduces the risk of fires by acting as an insulator, which prevents heat from igniting cells and prevents oxygen entering broken cells.

This sand adds a lot of weight and volume, which therefore increases shipping costs and emissions. Recyclers we interviewed do not see shipping as an ideal long-term solution, as costs and emissions will increase as the need to process batteries scales up.

Shipping companies are reluctant to carry old batteries

Waste Management businesses we interviewed have observed an increasing reluctance and much higher insurance costs from shippers to take old batteries as complete battery packs after the Felicity Ace cargo ship caught fire and sank in February 2022. Lithium-ion battery packs were accused of exacerbating and prolonging the fire[16]. If offshore is to remain the main recycling solution for New Zealand, the challenges will be in the form the batteries need to be packaged into for shipping and how shipping can be done across the industry to reduce costs and emissions.

Businesses we interviewed who are importing second hand batteries and electric vehicles have also reported an increased difficulty in shipping products to New Zealand and an increase in the cost of shipping insurance since that event.

Low battery supply means kiwi recyclers are exporting low-grade material

While several businesses we interviewed are stockpiling batteries in anticipation of recycling scaling up, the recycling businesses we interviewed prefer not to

[16] https://www.businessinsider.com/cargo-ship-felicity-ace-fire-electric-vehicle-batteries-luxury-cars-2022-2

stockpile batteries due to the fire risk. They are therefore much more likely to ship a full container of mixed battery chemistries for a lower price, than to wait and ship separate containers of single battery chemistries.

Shipping batteries in mixed containers is also being driven by the difficulty in securing a shipping container, in securing permission to ship batteries to overseas ports, and in restricted choice of countries that they can ship batteries to.
Issues include:

- New Zealand's main export is agricultural products which usually cannot be shipped alongside waste products, like batteries. This reduces the availability of places on ships leaving New Zealand.
- Currently recycling businesses in New Zealand can only ship waste batteries to Australia or South Korea.
- Ships carrying waste batteries are banned from ports in China, and
- Shipping that requires multiple stops along the route can be complicated by the Basel permit.

Shipping is complex and require Basel Permits

New Zealand is a signatory to the 1989 Basel Convention[17]. A Basel import permit is a permit given in accordance with this convention, permitting the import of hazardous or other waste.
A Basel permit is important as it prevents hazardous material from being shipped to countries where it will not be managed or recycled correctly. Historically, some recyclers have simply collected recycling fees and then shipped material (e.g. plastics) overseas to countries where it has not been recycled.

[17] https://www.epa.gov/hwgenerators/international-agreements-transboundary-shipments-hazardous-waste

The recyclers we interviewed all agreed that a Basel permit can be difficult, takes a couple of weeks' worth of time but that it can be worked with. They commented that the people worried about regulation are often the people who are not doing things properly to begin with.

Communication and coordination could make shipping with Basel permits easier

Several businesses we interviewed had the expectation that a business with a Basel permit would emerge to aggregate battery waste and do the shipping for NZ's recycling collectors, or that plants would be created in NZ to do the recycling. This has not happened as yet, and now recyclers are obtaining Basel permits independently. Each recycling business we interviewed seeks to ship batteries as soon as possible due to the fire-risk posed by lithium-ion batteries.

Cost of shipping is pushed on to the product owner

Battery shipping costs facing participants during our interviews in mid-2022 were placed at around $16,000 for a permit to export to Australia and $10,000 for freight costs for a 40ft container. This is roughly $1.20 per kg. These prices are fluctuating significantly due to international destabilisation of shipping routes.

Materials shipped from New Zealand are currently passed on to overseas recycling plants for free and the shipping and handling costs are charged to the battery owners who opt to recycle their batteries.

Recycling

Overview

People want to recycle batteries and it is causing problems

Over the last few years sales of battery-powered devices have grown rapidly, from consumer electronics and power tools to electric vehicles. Recyclers we interviewed noted that some of the smaller devices' batteries, such as those in power tools, are now coming to the end of their lives.

People in New Zealand are becoming more aware that batteries are recyclable, but the facilities to collect batteries and e-waste are either not available, or not accessible.
Lithium batteries are therefore finding their way into different waste streams that they do not belong in like scrap metal and lead-acid battery recycling streams. Existing scrap metal and waste management businesses are reportedly experiencing battery fires across their transport and processing facilities on a regular basis due to lithium-ion batteries being incorrectly disposed of.

This is prompting recycling businesses to explore ways to remove batteries from these waste streams, including education campaigns and battery collection programmes.

The current commercial focus is on business and industrial battery waste, not household battery waste

Business and industrial waste represents the low-hanging fruit for recyclers in New Zealand. Commercial and industrial partnerships provide recyclers with reliable access to a well sorted, concentrated, and high-value source of material to recycle.

Investing in a new processing facility that can deal with a new type of product or waste stream requires a guarantee of supply. For many waste streams, and batteries in particular, this guarantee of supply only comes from partnerships with industrial or corporate businesses.

Businesses we interviewed indicated that this is the approach that is currently being taken for battery recycling in New Zealand.

Recycling for residential waste is much harder to achieve in cost-effective ways. The much wider variety of used products entering the recycling stream makes sorting and processing much more difficult and increases the chances of contamination. Collection of residential recycling is also more difficult, as there are smaller amounts of material spread widely throughout communities.

Only collection and dismantling is currently done in New Zealand

The difficult, manual part of collecting, transporting and sorting the batteries into homogenous waste streams is currently the only part of the recycling process that is done in New Zealand. This is also the most expensive part of the process that produces a revenue stream lower than the costs incurred.

Recyclers want batteries to be correctly disposed of

Incorrect disposal of end-of-life batteries can lead to contamination of the waste and recycling streams that people use to dispose of their batteries. Recycling companies we interviewed are now investing some of their resources into creating battery collection, storage and processing facilities and public awareness campaigns to de-contaminate their existing, profitable, waste streams.

Landfill bans for batteries are not seen as a practical solution

Waste management professionals we interviewed agreed that landfill bans could be very difficult to enforce.

Facility managers regularly see all sorts of things that are banned coming to facilities through wheelie bins or hidden in large deposits like skip bins and their staff are trained to handle this hazardous waste. People want to get rid of all of their waste, and the only options they have that seem responsible and readily available are to either place them in refuse or recycling bins.

Key challenges

A reliable supply of waste batteries is needed to make any operation financially viable

Estimates of the amount of material required to regularly pass through a facility to make onshore processing a financially viable operation were at least 20 tonnes of batteries per month as feedstock. This level of supply would rely on efficient collection of both small batteries and large batteries in New Zealand.

The number of batteries needing to be recycled will increase rapidly

The cost of batteries has fallen over the last years. This falling cost accelerates the volume of material in circulation. This economic availability inevitably means more waste. Recyclers we interviewed have seen this happen over the last two to three years with the increased proliferation of battery-powered tools like mowers and leaf blowers, which are now reaching the end of their useful lives in consumer hands in large quantities.

Few local collection options exist

Motivated by safety concerns, a number of councils have set up household small battery collection systems at participating retailers and transfer stations. They have covered costs themselves and have been successful in collecting waste batteries.

Some Councils have considered setting up battery collections, however they were unable to provide cost-effective services. Other Councils are waiting to see the outcomes of the e-waste product stewardship schemes before investing in collection services.

Recycling industry coordination could support recycling efforts

Our interviews implied that the scrap and recycling industry has limited coordination between businesses. This includes across transport and towing, mechanics, recyclers, and scrap dealers.
Businesses are often known by reputation as either having very good systems in place, or for being "cowboys" who either pick and choose what they recycle, or who don't recycle at all.

During our interviews we received references to batteries being stockpiled in sheds by scrap dealers who see a future value for them and are prepared to wait, or who do not know yet where to send the batteries. Recyclers are wary of investing in recycling equipment or export permits because it is a large sunk cost and if multiple businesses do the same, then they risk competing over waste streams.

Some of the businesses we interviewed offer bounties for specific products, including batteries. However, due to the lack of communication and coordination, setting bounty values is difficult and measuring their impact is even more difficult.

Present and future value of materials impacts on recycling rates

Relying on for-profit recycling means that our current circular economy system relies on there being a market for processed waste streams. This in turn means that recycling businesses rely on the future value of materials staying profitable.

Current research into batteries is seeking to make them out of cheaper, more abundant materials. Using cheaper materials means there will be a lower value for the recycled material. This lower value will lead to lower recycling rates because of the low market value of the recycled material, especially if the process of recycling the batteries costs more than the value of their materials.

For example, LFP battery chemistry is an increasingly popular choice for EV manufacturers, but the recycling value of its materials is much lower than cobalt-rich chemistries like LCO, NMC or NCA.

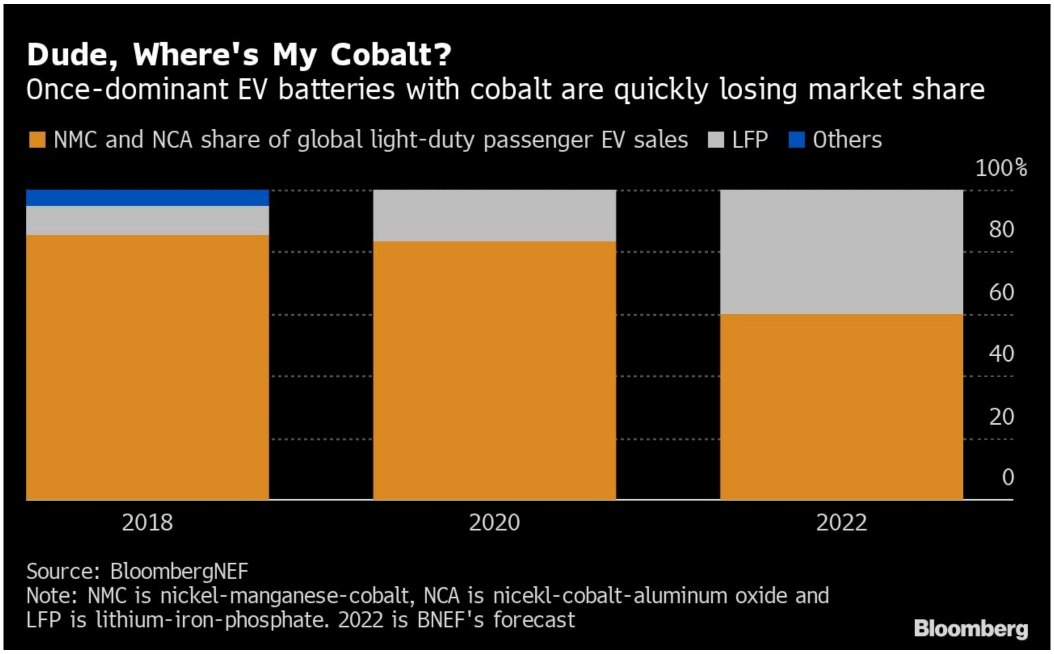

Figure 38 - LFP batteries are growing in market share, but are less valuable to recyclers
Source: Bloomberg

Businesses we interviewed said that overseas battery recycling facilities are still accepting these batteries, but are not actively seeking them out due to the low value in the raw materials.

Some businesses we interviewed shared examples where recycling companies were selecting specific, valuable elements from waste streams for recycling, leaving the rest to either be sent to landfill or to be handled by another recycler. For example, it costs e-waste recyclers more to process simple technology, like alarm clocks, than they generate from the resulting materials, but this cost can be offset or subsidised if enough high-value electronics, like computer circuit boards, are processed alongside them.

Battery recycling has large insurance costs

While businesses we interviewed indicated that some insurance companies are considering ways to provide cheaper insurance to high-risk, yet climate-friendly projects (such as battery recycling facilities), the risk of fire and chemical hazards of recycling lithium batteries pushes insurance costs up. These costs are largely to cover thermal runaway (fire) risks in the specialised storage facilities and collections services which are needed to store batteries until they can be processed, but pose a high fire risk due to the large concentration of flammable materials.

Current business models

Corporate or industrial waste is much easier to recycle than domestic waste

All of the independent recycling companies we interviewed focus on corporate or industrial e-waste because it provides them with a large stream of homogenous, high value items, and because businesses are more willing to pay for recycling. Domestic e-waste is considered difficult to collect and contains a wide variety of items to be able to be sorted, dismantled and processed in a cost effective way.

Costs incurred during recycling are wide ranging

The costs incurred during recycling include:

- Obtaining and concentrating the waste stream to acquire a commercially viable quantity of materials
- Labour costs for sorting and dismantling
- Processing sorted material
- Shipping processed material
- Insurance
- Disposal of non-valuable or non-recyclable parts (e.g. plastic casings)

Fees and subsidies can support recycling, but risk creating incentives

Fees or subsidies can be used to support recycling when the cost to recycle a product is higher than the market value of the materials that result from recycling it.
Where the political, social or environmental importance of recycling is high enough to require recycling, fees or subsidies are more likely to be applied.

While there is value in the materials that result from recycling e-waste and batteries, charging fees or receiving subsidies for recycling can indirectly incentivise inefficient recycling methods. For example, fees can maintain recycling profit margins without the need to invest in expensive, onshore recycling facilities and can encourage inefficient or sometimes unethical practices like shipping waste overseas. Businesses we interviewed indicated that this is what happened with plastic recycling.

Small battery collection services are appearing in city centres

Several waste management businesses we interviewed are rolling out their own collection services for small batteries. These services are either paid for by the businesses that host the collection bins or are offered for free in order to keep batteries out of other waste streams.

Recycling relies on people choosing to do the right thing

Currently, recycling products is much more difficult than simply throwing them in the bin. Small batteries and electronics can currently only be recycled when the owner locates, visits and may pay a fee to a small number of recycling outlets in their area (for example, the Sustainability Trust in Wellington). This is a more complicated and significantly less convenient solution than simply throwing something in the trash or placing it in a drawer and forgetting about it, which are the most common approaches to e-waste recycling.

Opportunities

Higher degradation rates means more materials, faster

Recycling businesses we interviewed agreed that, while longer-lasting batteries provide better environmental outcomes, faster degradation rates would simply mean more material to process. However, some recyclers are expecting that fewer precious metals will be recoverable in successive future iterations of batteries, as technology improves. This and other considerations are currently preventing investment into onshore recycling technology in New Zealand.

Recyclers are considering repurposing waste batteries

Waste management professionals have been looking in to repurposing end-of-use batteries if they receive batteries that are still functioning and serviceable. All waste management businesses we interviewed are starting to get occasional, one-off enquiries from some end-of-use EV owners.

The largest barrier to this solution is currently the knowledge gap as to what they could do with these batteries and how they would do it. This is due to a lack of late-stage second-hand batteries on the market.
Another major challenge is a lack of awareness and coordination across all stakeholders in the EV battery lifecycle around who is doing what and dealing with what.

While the waste management professionals we interviewed agreed that re-circulating second-life batteries is the most practical second-life use, this is currently under early discussions. Significant research still needs to be done on the practicality of assessing batteries, the feasibility of business models, partnerships that will be required, and the timelines in which this could be implemented.

Setting up stage 2 processing, onshore in New Zealand

Setting up a black mass processing facility in New Zealand may allow recyclers to produce a profitable material from the batteries they collect, removing the need to charge fees and supporting the establishment of more battery collection facilities. However, this facility would require consistent supply of waste battery material to be a financially viable investment. Estimates provided to us were in the order of 20 to 80 tonnes per month.

Setting up a processing site also requires specialised expertise and a specialised site to avoid contamination between different battery chemistry types. These, and other issues, make setting up battery processing facilities difficult for a recycler in New Zealand.

While this may make sense in the future, when more, large batteries with higher volumes of valuable materials are reaching the end of their life, a current facility would require collection of small and large batteries, from multiple businesses and collection points to be viable. Any onshore processing facility would therefore need to be established with full recycling industry cooperation.

To achieve this flow of materials, the establishment of a stage-2 processing facility would need to be coordinated with the establishment of battery collection facilities and a public education and marketing campaigns. There would likely be a large, initial clear-out of legacy batteries from consumer electronics.

10. Recommendations

Enable open access to data

Accessible information about battery state of charge, state of health and historical use is essential for enabling second-life applications and transparent battery trading on second-hand markets

Businesses we interviewed that want to create innovative business models like battery financing, leasing and buying/selling second-hand batteries must currently accept or price higher levels of risk into their products because they do not have access to accurate battery health information.

In many electric vehicles, the only information available about the battery comes in the form of estimated remaining range, or a remaining battery percent, shown on the vehicle's dashboard.

Providing greater access to battery data will go a long way to supporting second-hand markets and applications for EV batteries, ensuring they have a longer life and continue to provide valuable services to local communities. Greater access to data will also make battery tracking an easier task across their lifespans.

However, this is much easier said than done. OEMs often cite safety concerns, intellectual property concerns and warranty concerns as reasons for not providing or supporting access to data and specifications about their products. Without regulation or direct engagement with the industry, it is unlikely that this will change.

Working with OEMS and other businesses creating battery powered applications to provide greater data access to third parties, either directly or via a battery

passport platform, and to address OEM liability concerns, will support and optimise second-life battery use in New Zealand.

Create standardised, convenient ways for businesses and consumers to access and update battery passports

Most applications will benefit from a degree of internet connectivity and therefore will be able to automatically update battery passports. However, during our interviews we discussed several first and second-life applications that were not internet connected and did not provide owners with easy access to battery information. These batteries would be much harder to update in the system.

A lack of information about the battery adds risk for both buyers and sellers during second-hand sales. These types of low-data applications are likely to grow in the future, particularly in second-life applications.

Stakeholders we interviewed were unlikely to manually provide detailed battery data to the PSO, especially stakeholders who managed hundreds of vehicles. At best, stakeholders indicated that they would provide annual confirmation of ownership and a description of any changes that may have been made to the battery, such as cell replacements.

Encouraging businesses to provide open-access to this information, educating customers about its importance, and providing convenient, frictionless ways of allowing battery owners to upload, share and benefit from this information via battery passports will help to overcome this connectivity gap.

Making battery passports accessible and transparent will provide benefits to businesses and customers and could improve the resale value of second-life batteries.

Encouraging engagement with battery passports through regular updates to batteries held on the platform, such as ownership changes, will also make tracking batteries throughout their lives easier.

Support the shortcomings of recycling

Early intervention and support for battery recycling may be needed

Operating recycling as a businesses means that recycling a waste stream must generate revenue. Businesses we interviewed obtain this revenue by either being centrally funded, by charging fees, or by selling the products created by recycling.

Establishing onshore processing facilities requires significant investment. We interviewed five businesses who collect batteries for recycling and currently they are not collecting enough material to make investment into onshore recycling a viable option. These businesses estimated that a minimum of 20 tonnes of battery material per month would be required to make this investment worthwhile.

Until this investment is made, New Zealand will have to deal with hundreds of tonnes of battery material, either by paying to ship it overseas for processing, sending it to landfill or stockpiling it.

Without intervention, this problem then risks repeating itself in the future, as battery technology evolves, and expensive upgrades are required to process new types of batteries but are deferred until a sufficient, regular volume of the new battery waste is available.

The Government has made e-waste and large batteries a priority product, that means a product stewardship scheme must be developed. This means producers, brand owners, importers, retailers, or consumers must accept responsibility for reducing a product's environmental impact and to manage environmental harm when it becomes waste.

Shared processing facilities could fill the gap until market solutions take over

While government funding is available to support innovation in waste minimisation[18], funding different facilities for each recycling businesses in New Zealand, in order to maintain a competitive marketplace, is not an optimal solution.

Many businesses we interviewed supported the use of product stewardship funds, in setting up recycling facilities before they are needed to ensure that all of the batteries they are importing will be recycled.

One solution could be to use product stewardship revenue, or the waste minimisation fund, to invest into a centrally owned or shared facility, where recyclers could sort and pool their battery waste for processing and benefit from the sale of the resulting product.

Establishing a central, shared stage two processing facility would allow recyclers to focus their investment on collection and handling of batteries, increasing the amount and types of batteries collected, supporting the case for private investment into private recycling facilities in the future.

If businesses were able to generate reliable revenue from battery collection, it is conceivable that collection facilities would rapidly appear across the country. For example, petrol station forecourts are located in almost every suburb and could supplement their revenue from food and petrol sales with revenue from battery collection, or retailers selling batteries could generate more revenue by taking back and preparing their used batteries for processing.

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[18] https://environment.govt.nz/what-you-can-do/funding/waste-minimisation-fund/

More research into the opportunities for businesses and the case for shared or centrally coordinated facilities, including how the industry can be made resilient to future technologies and price changes in raw materials could significantly support recycling rates in New Zealand.

Coordination between small and large battery product stewardship programmes will be needed

Currently, large batteries are not made of one large, single cell. Instead they are made up of many collections of small batteries organised into groups, modules and packs. While it is not yet common practice, these large batteries can be broken apart into individual modules or cells and repurposed for use in other applications.

Similarly, individual battery cells can be assembled into groups, modules and packs to create new large batteries. While the time and cost of labour required means it is unlikely that large batteries will be assembled or disassembled to avoid the proposed Advanced Stewardship Fees on large batteries, these activities will still likely happen with increasing frequency as batteries become more accessible and as older batteries have their cells replaced.

Coordination of the recording and sharing of information between large and small battery stewardship programmes will help both product stewardship programmes account for batteries that transition between these programmes. Ensuring this data is captured will prevent the large battery stewardship programme from losing track of dismantled batteries and failing to account for the appearance of new, locally assembled large batteries.

Expand the scope of product stewardship

Product stewardship fees could impact on the uptake of green technology

Many businesses we interviewed felt positively towards product stewardship. However, these businesses were also concerned that larger fees could impact on the affordability and competitiveness of battery powered solutions like electric cars, especially when the government is already subsidising them on a large scale[19]. This is because similar fees to account for pollution and waste are not applied to other, more polluting products on the market at a time when the uptake of batteries is essential.

For example, the cost of removing 1kg of CO_2 from the air using Direct Air Capture (DAC) techniques is between $250 and $600 USD per ton[20]. Every litre of petrol burned produces about 2.3kg of CO_2. Using this cost to apply an appropriate product stewardship fee to petrol would increase the price of petrol in New Zealand by between $0.93 and $2.26 NZD per litre.

It is important that fees for end of life management are applied alongside regulation that prices environmental externalities, like air pollution, into other competing products.

Fees for recycling should be lower than fees for landfill

The large battery product stewardship scheme is intended to ensure it is free and convenient to dispose of an end-of-life large battery safely and appropriately. However, several key businesses we interviewed were concerned that the

[19] https://www.nzta.govt.nz/vehicles/clean-car-programme/clean-car-discount
[20] https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal

proposed Advanced Stewardship Fee were too low to adequately support the collection, processing, and handling of large, end-of-life batteries.

We also discussed the application of variable landfill fees and landfill bans with waste management professionals; however, these fees are nearly impossible to enforce. Batteries and other items that should attract high fees are easily hidden in the bottom of skip bins or rubbish bags.

While we don't have the expertise or insights to say whether the proposed advanced stewardship fee is too low or too high, the indications we received during our interviews is that it may be too low. If this is the case, then further fees may need to be applied in the future.

Establishing accessible, convenient pathways for consumers to recycle products alongside higher landfill fees will be essential to achieving high recycling rates and to prevent batteries from being illegally dumped into the environment.

Ensure innovation is not inhibited

Regulation to control batteries could impact small businesses

Innovation with second-life batteries was mostly being done by the small businesses we interviewed. The key concern these businesses had was that regulated product stewardship could restrict their access to second-hand batteries if batteries were required to be returned to manufacturers, or restrict their ability to work with batteries if they had to seek permission from manufacturers before making any modifications (e.g. re-using EV battery pack modules in separate applications).

Restrictions could prevent them from bringing new, innovative products to market. Applications that could be inhibited would include converting petrol cars to EV and creating ex-EV battery home energy storage, which are two of the widely promoted examples of second-life applications for batteries.

Ensuring batteries are used and recycled responsibly is important, but any regulation to that effect should not prevent businesses from using EV batteries in second-life applications.

New Zealand has limited influence on offshore businesses

In general, stakeholders we interviewed believed that, in the future, OEMs would seek to collect their end-of-life batteries back to use as feedstock for battery production. Some OEMs we interviewed were actively engaged in trying to re-obtain the batteries they have sold and create their own recycling and stewardship processes, others were seeking to work with third party recyclers, or to be led by government product stewardship regulation.

One of the goals of product stewardship is to push manufacturers to hold responsibility for the products they create, incentivising them to create products that are easily recycled. For example, in 2018 the Chinese Government made manufacturers responsible for recycling EV batteries[21].

New Zealand is a product-taker. Stakeholders we interviewed agreed that, on the international stage, New Zealand has very little ability to influence what OEMs do.

The best approach New Zealand could take is to support New Zealand's recycling industry and help recycling businesses innovate and keep up with OEM battery technology and international standards, while working with the international community to support product stewardship regulation globally.

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[21] https://www.reuters.com/article/us-china-batteries-recycling-idUSKCN1GA0MG

11. Appendix and core concepts

Battery recycling in general

Only 1% to 30% of batteries are currently recycled

While lithium ion batteries are more than 95% recyclable, if the facilities required to do this are not available, the battery material is simply sent to landfill. Estimates of recycling rates reportedly vary from 1% to 10% across the world. Recycling businesses we interviewed estimated that 30% of lithium batteries disposed of in New Zealand to date have recycled by shipping batteries to recycling facilities located overseas.

The main reasons cited for this are a lack of awareness and education, the lack of collection systems or pathways for batteries to make it to recyclers, and the proliferation of batteries and battery-powered products that are designed to be difficult to repair, and therefore are also difficult and expensive to dismantle and recycle.

A transparent chain of custody across the board for materials right through to reuse or disposal, as well as clear, accessible and affordable pathways to responsible means of disposal, will significantly reduce the impact that these materials can have on the environment.

Recycling is a business model

In New Zealand and across most of the world, recycling and dealing with waste streams in general is run as a for-profit business. Revenue is generated by the sale of recycled material, or from disposal fees paid by companies, governments or individuals.

Recycled material must compete with virgin material

Virgin material is extracted directly from the source (e.g. lithium from a mine, or oil from a well). Virgin material is usually easier to obtain, cheaper and can be more reliably sourced than recycled material. But, the faster virgin material is used up, the harder it becomes to source, and the more competitive recycled material becomes.

Today's battery chemistries rely on rare or difficult to obtain materials

These materials include Lithium, which makes up 0.002% of the earth's surface, Nickel (0.0084%), Cobalt (0.0025%), Manganese (0.095%) and Phosphorous (0.105%). These materials are also only found in high enough concentrations in a small number of areas across the world.

Lithium battery production has scaled up significantly to meet demand

The investment into production will likely ensure that Lithium battery technology remains dominant for at least 5 years, even if new battery technology is developed. However, there is simply not enough of these materials to keep up with the projected growth in demand for batteries.

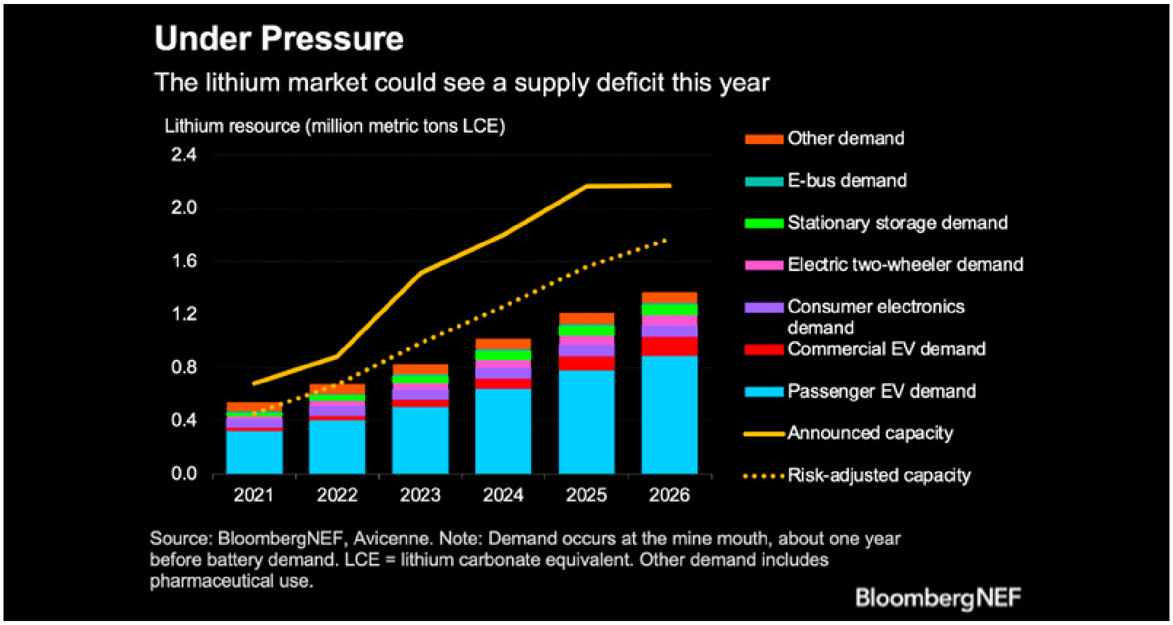


Figure 39 - Lithium supply and demand
source: Bloomberg

This implies that the material that exists in batteries could eventually become easier to access and use than virgin material. Making recycling a critical part of meeting our emissions goals.

Per ton, recycling becomes less profitable as technology improves.

As technology improves, the same devices are made using less of the expensive or rare materials that make recycling a viable business model. This puts pressure on recyclers to seek out more valuable waste streams and to neglect less valuable waste streams.

Recycling businesses we interviewed informed us that, for circuit boards and other e-waste, they have to recycle up to five times more e-waste to obtain the same amount of precious metal than they did ten years ago.

Battery manufacturers are funding research into technologies that aim to remove as much of the rare materials, like cobalt, from batteries as possible. If successful, this could reduce both the production cost, and the recycling value of batteries in the future.

This trend is already underway, as recyclers in Korea have reported that they are obtaining less cobalt from new battery packs than they did from previous generation battery packs. These recyclers have adapted by tying their battery waste purchases to the amount of cobalt they can recover.

Stages of the battery recycling process

Each stage of recycling produces a product that currently has some value

Recycling involves breaking products down into smaller and smaller pieces until they are refined enough to become resources that feed into the creation of new products. The smaller or more pure a waste stream can be made, the more valuable the resulting product usually is.

Each stage has its own expenses, and the resulting products vary in value

The recycling process is completed in stages, from collection through to reintroduction of the materials into the supply chain. Processing materials at each stage has different opex and capex requirements and requires a guaranteed supply of material in order to be financially viable.

This report uses its own naming conventions for the stages

The naming conventions used here (Stage 1, 2 and 3) are unique to this report, we have broken recycling down in to these three stages because we believe they best describe with what New Zealand recyclers are currently capable of, and could become capable of in the future.

Currently, New Zealand recyclers are only capable of State 1 recycling

Stage 2 recycling is being set up world-wide and is being investigated by NZ recyclers, because it produces a high value product that can be shipped safely. Stage 3 recycling is much more expensive to set up, but a number of businesses in Europe, North America and Asia are investing in this.

Collection

Before recycling can begin, batteries need to be collected

Coordination of material collection is a key challenge in recycling. While there is a very large amount of battery material across New Zealand, in cell phones, consumer electronics and power tools, Trying to get product together from lots of people spread across the country is a difficult, expensive exercise, or “like herding cats” according to one of the recyclers we interviewed.

Some businesses are stockpiling batteries in anticipation of recycling value

Spent batteries that are owned by businesses we interviewed are either being stockpiled by those businesses, who anticipate that recyclers will eventually seek them out, or they are being actively sent to recyclers that the businesses have formed partnerships with.

EV batteries are traded in, other batteries are not

When consumers upgrade their EV batteries, the old batteries are currently traded in and kept by the business that does the upgrade. However, stand-alone batteries like home solar storage and other large batteries that are not embedded within another product tend to remain with the owner, who has responsibility for recycling them.

There are limited, publicly available battery collection solutions

In general, consumers are not likely to store their batteries until they can be disposed of properly. There are currently very limited, publicly available solutions for the safe collection of small batteries and very few exist for the collection of large batteries. We could not find are that are easily accessible by the public.

Collecting and storing large batteries is difficult and expensive
The high cost of storing dangerous goods, as well as collecting and couriering the extremely heavy packs (EV batteries usually weigh around 400 to 500kg) also adds to the costs of this stage of the recycling process.

Businesses are investigating the logistics of battery collection

Waste Management's core business is around logistics of collecting and providing a collection and consolidation service for a wide range of materials and then working with a demand or end of market for those products.

Shipping

Stage 1 – Sorting and dismantling

Batteries need to be manually sorted when a recycler receives them

There are three broad groups of batteries that can generally be processed together, Nickel Metal Hydride (NMH), Alkaline batteries and Lithium batteries.

While technologies are being developed to automate waste sorting processes, sorting batteries is currently done manually. This requires trained staff who can identify different battery chemistries of different cells, which is often the most expensive part of the recycling process.

Sorting is particularly challenging for small batteries.
Different brands, battery models and form factors do not always make it clear what chemistry is inside a cell.

NMH, Alkaline and Lithium cells currently available on Alibaba.com

Large batteries require dismantling

The goal of dismantling at stage 1 is to separate the battery cells from the plastic, metals and circuit boards that make up the rest of the battery pack. One of the main concerns the recyclers we interviewed have is what form they will receive the batteries in. It will cost them a lot if they are required to pull batteries out of cars and/or dismantle the battery packs into their base parts like casings, electronics, wires and cells.

Large, high voltage batteries must be discharged before being dismantled

When dismantling an EV battery pack, the pack needs to be discharged before it can be disassembled. If it is not discharged, then the risk of electrocution or ignition is higher. Individual battery cells do not deliver a high enough voltage to be dangerous. However, when cells are connected to form a large battery, the total voltage of the combined pack can be dangerous for people who handle and dismantle them. When individual cells are broken or exposed to air, the materials within them can also become hazardous and difficult to handle safely.

Training is important to ensure safety

Recyclers we interviewed are training their staff to handle hazardous waste. Staff working for recyclers receive specific training for the waste products they are receiving, while staff handling end of life batteries at transfer stations receive hazardous goods training that covers a whole range of different materials, chemicals and products, including batteries and how to handle them if they are broken or exposed to air.

Stage 2 – Producing black mass

Stage 2 involves mechanical recycling to create black mass

Stage 2 processing involves the shredding and processing of battery cells to separate the cells into **black mass**, which contains concentrated amounts of the 'energy metals' (including lithium, manganese, cobalt, graphite and nickel), plastics and other metals (copper, aluminium).

Mechanical recycling must be done in a way that prevents oxygen ingress

There is a high risk of rapid discharging from cells that still contain charge causing fires. Ensuring no oxygen is present when batteries are processed reduces the risk of fires. One method, called Hydrometallurgical processing, achieves this using water, which in turn produces hazardous wastewater and exhaust gasses that must be treated or captured. Another method requires the batteries to be completely (deep) discharged and then processed in an inert environment, for example argon gas.
https://www.duesenfeld.com/comparison_recycling.html

Black mass is more valuable than battery cells and can be shipped safely

Black mass is not a fire hazard, does not require additional packaging to be shipped, and can be sold at a much higher price that makes battery recycling a financially viable, profitable business. As of the end of 2021 one ton of black mass was worth about $5,000 NZD.

Most batteries can be processed this way

The same equipment can be used to process many different battery chemistries into black mass with different chemical compositions. But each chemistry needs to be processed separately and in different ways. This can create a risk of contamination if different battery chemistries are processed together.

The recycling companies we interviewed believe that as battery technology evolves in the future, the recycling technology required to produce black mass should also keep pace and only require tweaks and changes.

Stage 2 recycling facilities require less capital than Stage 3 recycling facilities

Recyclers we interviewed could not share their estimates of the cost of setting up black mass processing in New Zealand, but we determined it would be in the order of millions, to tens-of-millions of dollars. To be commercially viable, a processing facility would require consistent supply of roughly 20 tons of batteries per month. This is the equivalent of around 50 to 100 EV battery packs, or around 440,000 AA batteries per month.

Businesses in New Zealand are considering setting up stage 2 facilities

All of the recyclers we interviewed are exploring the feasibility of setting up stage 2 processing in New Zealand. The main barrier preventing this investment is the lack of a reliable supply of material. The recyclers we interviewed require between 20 and 400 tons per month for this investment to be worthwhile. They also believe that enough material is available in New Zealand in the form of small batteries, but there is no reliable, recognized collection process to supply them.

Stage 3 – Refining black mass

Stage 3 involves refining black mass into its individual elements

The black mass from stage 2 requires further processing to create materials that can be re-used in battery production. Many existing recycling facilities use smelting to recover nickel and cobalt from the black mass, but this process is unable to recover lithium, graphite or manganese. The processes that do recover these and more elements usually involve dissolving and chemically separating black mass by precipitation or various solvents.

Stage 3 recycled products are more difficult to sell

Black mass is a single waste stream that can be relatively easily shipped overseas to stage 3 recycling factories in multiple countries, whereas the products that stage 3 recycling produces are elements that require engagement and sales channels within with multiple, specialised metal markets.

Stage 3 recycling is much more expensive to set up.

According to recycling businesses we interviewed, the US company Li-Cycle are investing $200m USD in a plant that can process black mass into base elements (Lithium, gold etc.) and are expecting a $40m USD return per year by processing 10,000 tons of batteries.

New Zealand does not have the scale or manufacturing for stage 3 recycling

Recyclers we interviewed believe that NZ doesn’t have the scale, or the manufacturing to justify the expense of investing in stage 3 recycling. Many of the companies setting up this process are either located near battery factories (for example Redwood materials are located near Tesla’s California gigafactory.) or have developed proprietary technology that enables them to do cleaner, or more efficient recycling than conventional methods.

Large batteries are small batteries

Large batteries are not one big battery, but many small ones

Despite being called a “large battery”, a large battery pack is not composed of one, single big chunk of lithium. It is a collection of smaller batteries arranged in parallel to create modules, which are then grouped together in series to form a battery pack.

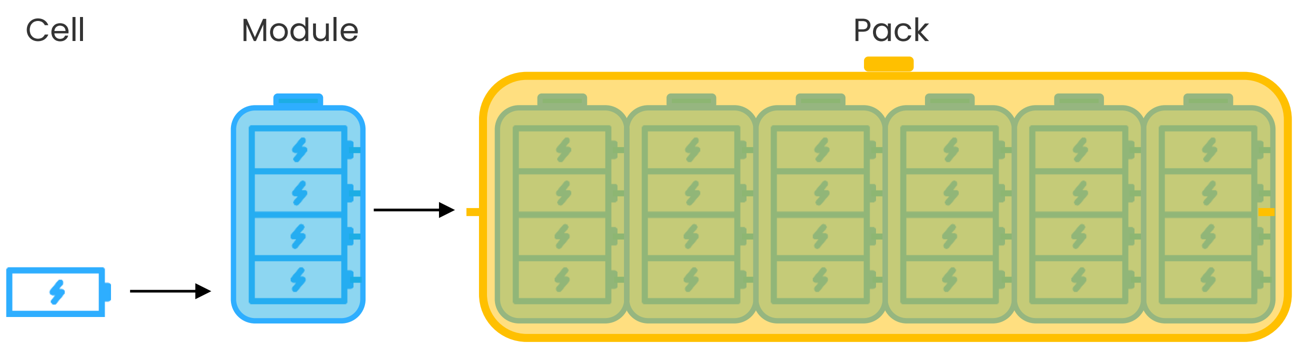


Figure 40 - Battery cell arrangements

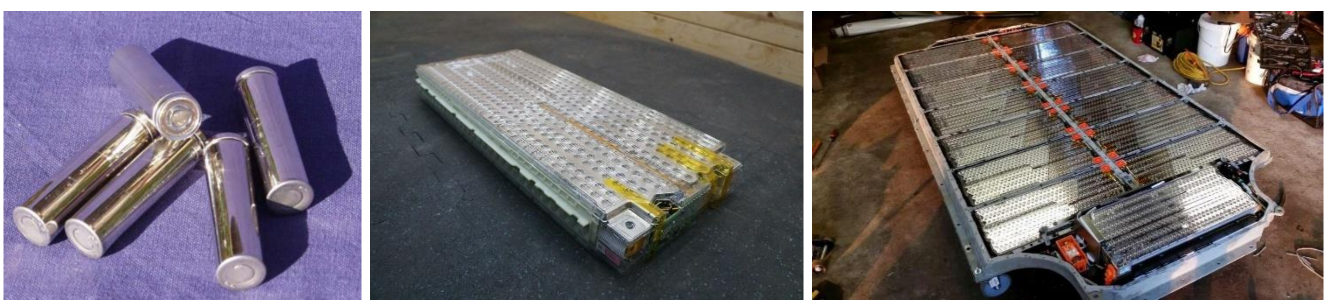


Figure 41 – 5 x 18650 cells from a Tesla Model S battery (Left)
444 x 18650 cells assembled in to a Tesla Model S battery module (center)
16 x Tesla Model S battery modules assembled into the vehicle’s battery pack (right)

Battery cells are used in many applications

The same battery cells used in early Tesla Model S batteries (known as 18650 cells) are also used in battery packs sold by motorcycle manufacturer UBCO, and in many other applications, including consumer electronics (e.g. flashlights, laptops and Dyson vacuum cleaners). The Tesla Model S pack contains 7,104 of these cells arranged into 16 modules of 444 cells each.

Cells don't have unique identification numbers or features

During this project we interviewed OEM representatives and the third parties that are re-using their batteries. It was generally agreed that individual battery cells are currently treated like any other car part and are not uniquely identifiable.

Battery packs have unique IDs and battery modules often, but not always, have unique IDs.

Battery packs rely on the BMS

Depending on how the battery cells are configured, a module or pack will usually only be as effective as its lowest voltage cell. If one cell reaches a lower voltage first, the BMS will prevent the battery from being discharged further, by disconnecting or reducing the performance of whatever the battery is powering.

Battery cells may not degrade at the same rate

People and businesses we interviewed were divided on the opinion of failed cells. It is generally accepted that, when installed inside a well-designed and managed battery pack, cells will degrade at the same rate. However, it is not uncommon for some cells to degrade faster than others.

Examples provided to us included laptop batteries, where often one 'dead' cell affects the rest of the battery, and early cell arrangements where poor spacing and a lack of thermal management led to centrally placed cells overheating and degrading faster than externally placed cells.

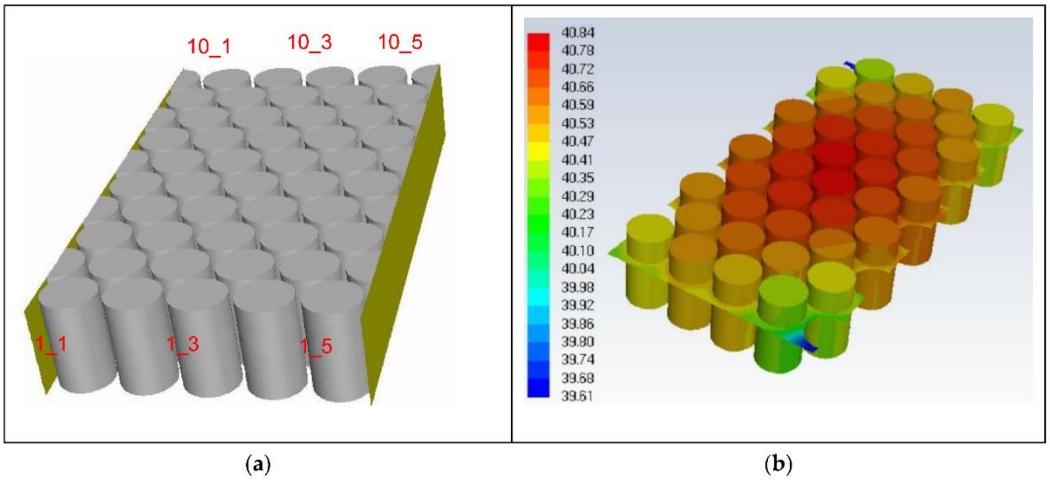


Figure 42 – Temperature differences across cell arrangement within a battery source: https://www.mdpi.com/2313-0105/7/2/27/htm

Cell replacement depends on how the pack is assembled

Some respondents we interviewed viewed cell replacements as a way to maintain customer relationships and extend the life of their vehicles, and had implemented systems in their batteries and vehicles to enable this. Other respondents viewed cell replacements as too labour intensive and instead focused on repairs and replacements at the module level.

Battery chemistry

Different batteries should not be recycled together

Batteries can be made from a wide variety of elements, including lead, sulfuric acid, nickel, cadmium, hydrogen, iron, oxygen, zinc, sulphur, bromide, potassium, silver, sodium and vanadium and more. This broad range of chemistries makes sorting batteries for recycling very difficult, as the chemistry is not always printed on the cells and materials from different batteries can react with each other if they are recycled together.

Lithium batteries can generally be recycled together

Lithium cells are the dominant batteries due to their high energy density. The different types of lithium batteries are named after the chemical composition of their cathode materials, as the cathode has the biggest impact on the abilities of the cell.

Lithium battery chemistries in widespread use today

Battery name and abbreviation	Typical cathode chemistry and application
LCO Lithium cobalt / Lithium cobaltite	$LiCoO_2$ Commercial electronics
LMO Lithium Manganese Oxide	$LiMn_2O5_4$ HEVs, commercial electronics
LFP Lithium Iron Phosphate	$LiFePO_4$ Power tools, BEVs, PHEVs
NMC Lithium nickel manganese cobalt oxide	$LiNiMnCoO_2$ HEVs, commercial electronics
NCA Lithium nickel cobalt aluminium oxide	$LiNiCoAlO_2$ BEVs, PHEVs
LTO Lithium Nickel Titanate	$Li_4Ti_5O_{12}$ Consumer electronics, some EVs

Sourcing batteries

New Zealand is a battery importer

New Zealand does not produce batteries. All batteries that are on New Zealand shores have been imported from manufacturers overseas.

Batteries are imported in different ways, from different places

These batteries are either imported within the applications (e.g. batteries inside EVs),as battery packs imported for a specific use, or as individual battery cells that will be assembled into a new battery pack in New Zealand.
Businesses we interviewed that import batteries were typically sourcing batteries from China, Korea, Norway, Sweden, German, Canada and the USA.

Anyone can import a battery

People and businesses we interviewed indicated that the industry is not requiring special qualifications for people to buy batteries. Price and availability are currently the only factors limiting the proliferation of batteries, and the industry is largely waiting to be led by regulation.

State of charge (SoC)

SoC tells you how full the battery is as a percentage of its total capacity

The SoC of a battery cell is usually reported as the percentage of **usable or accessible** energy a battery contains. A cell can be discharged to below 0% SoC and can be charged above 100% SoC, but this will damage the cell. One of the tasks of the battery management system to prevent this from happening.

There is no direct way to measure the SoC in a lithium-Ion cell.

There is no way of measuring how full a battery is. But there are two indirect ways of estimating it and each method has its limitations so they work best when combined.
These methods are voltage translation and coulomb counting.

Voltage Translation

Voltage Translation uses voltage measurements as a proxy for SoC

Voltage decreases as a battery cell is discharged and increases as it is charged. By understanding and mapping how the voltage changes as the cell charges and discharges, a voltmeter to be calibrated to report SoC based on the voltage level.

Voltage Translation is error-prone and very low resolution.

The voltage translation method is limited because other factors like temperature changes also affect the cells voltage. The voltage of a lithium-Ion cell also remains very consistent for most of the SoC range, increasing sharply at high SoC and decreasing sharply at low SoC. This behaviour means SoC can only be reliably determined at either high or low states of charge.

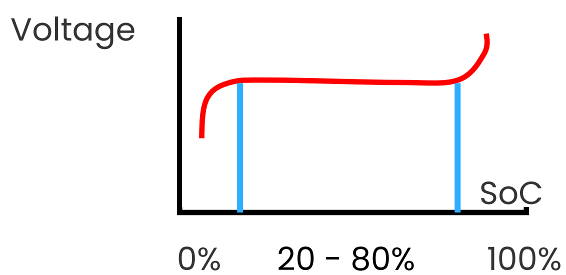


Figure 43 - How voltage changes with state of charge

Coulomb Counting

Coulomb counting treats batteries like energy bank accounts

Constant measurements of the current flowing into or out of a battery cell can be used to calculate the battery's charge by subtracting the energy going out from the energy coming in.
This is similar to guessing the balance in a bank account by only observing the money flowing into and out of the account.

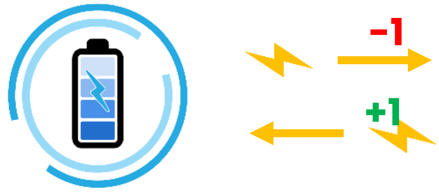


Figure 44 - Representation of coulomb counting

This method only works if the initial SoC is known

If the initial SoC of a battery is known, then coulomb counting can be used to measure the charge going in to and out of the cell, adding and subtracting these values from the starting charge to calculate what the new SoC is likely to be. If the initial SoC is unknown, then coulomb counting cannot accurately provide an estimate of SoC.

This method grows less accurate over time

Energy is lost as heat when the battery is used and inefficiencies in the battery chemistry cause internal energy losses. This causes the estimate of SoC to slowly drift further away from the real SoC value and requires correction.

Figure 45 - Representation of coulomb counting, including energy losses

Combined measurements

Voltage Translation and Coulomb Counting compensate for each other's limits

Battery management systems that report on SoC will usually use the Coulomb Counting method to report on SoC, while relying on the Voltage Translation method to periodically recalibrate the initial SOC whenever the voltage changes are high or low enough. This prevents drift in SoC from becoming a problem, while ensuring SoC is reported in useful detail.

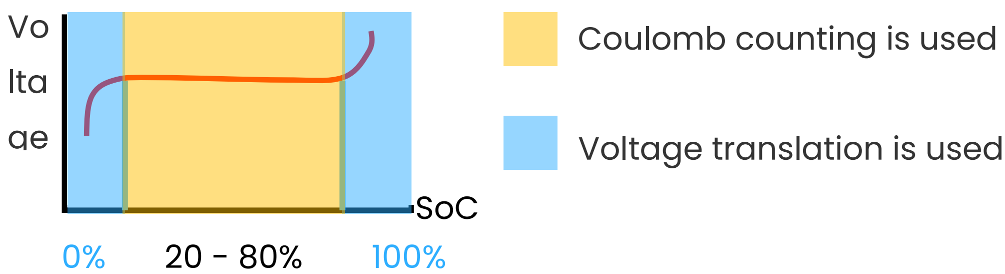


Figure 46 - Representation depicting how coulomb counting and voltage translation are used interchangeably

Calibration is not easy for some applications

Calibration often requires the discharging and recharging to be done in succession without any other small charging and discharging events in between. For applications like EVs, this is not entirely practical, because discharging the battery to a low level requires a significant amount of driving and leaves the driver stranded if they aren't near to a plug.

Recalibration is often recommended by EV manufacturers

OEMs and car dealers often recommend driving close to 0% and then recharging to 100% as a method for recalibrating range calculations, and therefore recovering "lost" driving range.
https://tesla-info.com/guide/tesla-bms-calibration.php

Battery of health (SoH)

Battery health is the current, usable capacity of the battery compared to the usable capacity when the battery was new

Battery health is often called State of health (or SoH) and describes the usable capacity of a battery as a percentage of the usable capacity the battery offered when it was new. This can be derived either as a result of direct measurements over time, choosing the earliest measurement as the original capacity, or by comparing the current capacity to the as-new capacity stated by the manufacturer.

Battery degradation is the opposite of battery health

Battery degradation is also referred to as 'capacity loss', 'capacity fade'. It is defined as the lost, usable capacity as a percentage of the usable capacity the battery offered when it was new. Calculated simply, degradation = 1 - SoH.

Battery degradation does not occur linearly

Lithium-ion batteries lose their ability to hold energy gradually as they are charged and discharged over time. This degradation is typically rapid at first, then very gradual for hundreds of cycles, before falling again as the battery ages.

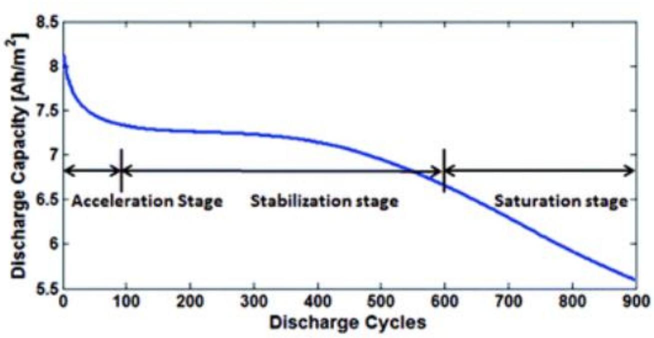


Figure 47 - Typical lithium-ion battery capacity loss over time
Source: Lithium ion battery degradation: what you need to know, DOI: 10.1039/D1CP00359C[22]

[22] https://pubs.rsc.org/en/content/articlehtml/2021/cp/d1cp00359c

Battery health describes the battery's remaining capacity compared to the capacity when the battery was new

The State of Health (SoH) of a battery cell is commonly used to describe the percentage of remaining, usable energy that the cell can contain when fully charged. Usable energy is often limited by the battery management system so actual capacity of the battery and the capacity a battery owner has access to can be different and change over time.

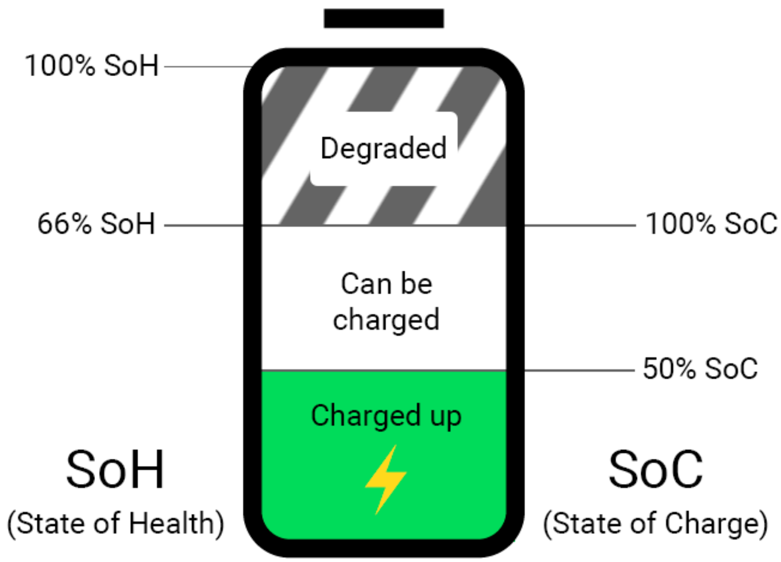


Figure 48 - The difference between state of health and state of charge

Battery health calibration is linked to SoC calibration (see previous section)

Some battery management systems will attempt to predict battery degradation, If the BMS has not been calibrated, it may think that the battery is more degraded than it actually is.
In the context of a vehicle, this would artificially reduce the driving range of that vehicle and prevent the battery from fully discharging.

Battery health cannot be measured directly

Information about the internal state of the battery's cells requires the use of special equipment to measure the voltage and current across each cell during a time in which they are charged and discharged to a good extent. As there are often thousands of cells inside a large battery, direct cell measurements by third parties are virtually impossible without removing the battery pack and accessing the cells directly.

Monitoring battery health must therefore be done by accessing data from the battery management system, or by measuring the battery pack's performance over time.

Battery health is often measured by the battery management system

Measuring battery state of health is usually undertaken by the battery management system, which is not easily accessible without support or information from the Original Equipment Manufacturer (OEM). Direct, independent measurements by third parties are usually not possible and require direct access to the battery pack's individual cells as well as time-consuming charging and discharging cycles to test their performance.

BMS battery health data is difficult to obtain

Measurements of battery health made by the BMS are seldom made available to the owner and are not easily obtained by third parties. For example, an independent app called Leaf Spy is capable of reading battery degradation levels from the Nissan Leaf OBD-II port, yet no similar app exists for the BMW i3 or Hyundai Ioniq. Widely available access to Nissan Lead battery data has created significantly more customer complaints and media publications about degradation for Nissan than BMW received during the same time period, despite early model BMW i3s showing higher than average degradation rates when assessed by independent fleet telematics devices.

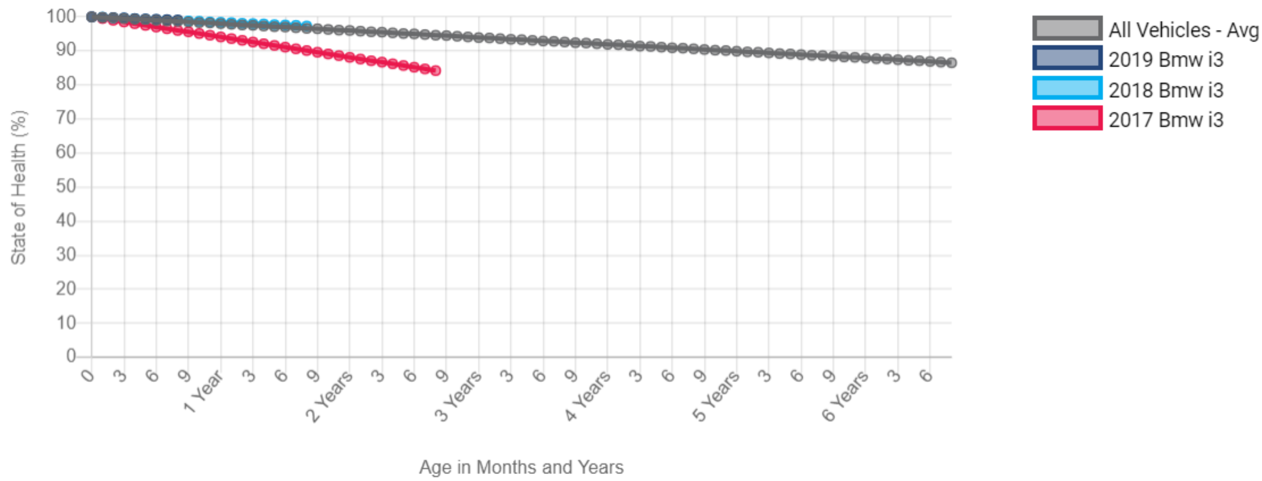


Figure 49 - Independent BMW i3 battery health estimates recorded by Geotab
Source: https://www.geotab.com/fleet-management-solutions/ev-battery-degradation-tool/

Battery health can be estimated when a battery is used

The health of the battery can be estimated from the performance of the battery while it is connected to a load, e.g. by measuring the change in driving range of an EV over time. The drop in benchmarked performance over time is then used a proxy for the drop in battery health over time.

For example, if the driving range of an EV drops by 20% the assumption is that the health of the battery has decreased by 20%.

Companies we interviewed that regularly monitor their vehicle's battery health reported that the SoH was determined by measuring both the level of charge held in the batteries when full and the discharge rates over each day's usage.

Battery health can be estimated when a battery is charged

The health of the battery can be estimated from the performance of the battery while it is being charged. This method is similar to performance-based monitoring, but in reverse.

The energy flowing into the battery is measured at either the charging station or at the battery and is then compared to the relative change in SoC as the battery charges. For example, if adding 10kWh to an 80kWh battery results in a 20% change in SoC, the total capacity of the battery can be assumed to be 50kWh, or 62.5% of its original capacity.

Energy is lost during charging sessions. This means the energy stored in the battery will always be less than the energy that passes through the charging station, its cable and the vehicles on-board charger. The further away from the battery the energy is measured, the higher these losses are and the less accurate the battery health estimates will be.

Battery capacity performance can be changed to mask battery degradation.

The battery management system works to prevent deeper discharging/recharging, which protects a battery from excessive degradation. In some cases, a BMS may allow cells to be charged into higher or lower voltage thresholds over time to maintain the performance of the battery. These actions would mask short-term changes in battery health from the owner but could potentially accelerate the battery's degradation rate in the future. During our interviews we found some evidence of this practice occurring.

Battery health can be inferred from other measurements across each cell

Calibrating a battery (see previous section) can provide battery health measurements indirectly, by measuring changes in voltage and current over time. This process takes time and the battery management system must be capable of performing it.

The general process to obtaining these measurements was described to us as:

1. Charge battery to 100% and then wait for at least half an hour.

2. Discharge the battery to its nominal minimum (0% as reported by the BMS) and then wait for at least half an hour.
3. Recharge the battery to its nominal maximum (100% as reported by the BMS) and wait for at least half an hour.

If the BMS is not capable of calibrating itself, then this method must be performed on the battery directly by removing the battery from the application it is used in. In some OEM applications, like EVs, removing the battery may result in the battery shutting down, preventing access to its systems, reporting itself as broken or inoperable and voiding the warranty.

Causes of battery degradation

Degradation of batteries is already impacting on EV manufacturer and dealer businesses, the factors that accelerate it are essentially - operating at temperature extremes, charging at high rates of current, storage temperature, storage at high state of charge.

Calendar degradation

Like everything else, batteries degrade naturally over time. The main difference is that this degradation is noticeable through lost capacity. Most other products only display degradation when the product breaks completely (e.g. a rusted car stops working).
Advanced battery management systems may contain expected profiles for calendar degradation and may adjust their battery health estimates in accordance with these profiles if they are unable to recalibrate over time.

Environmental degradation

Batteries within applications that don't have active thermal management as it's expensive have batteries that are subject to the user's behaviours. Customers who leave batteries at high charge exposed to hot climates will have more losses than others. There is also an impact on customer experience, and they need to make sure that is kept high.

Extreme heat and cold are two of the main things that contribute to accelerated battery degradation. New EVs coming to the market are increasingly equipped with advanced thermal management systems to maintain the performance and prolong the life of their batteries.

The act of fast charging requires high currents, which don't necessarily directly degrade batteries, but produce more heat during the charging process, which can affect degradation rates.

Degradation from use

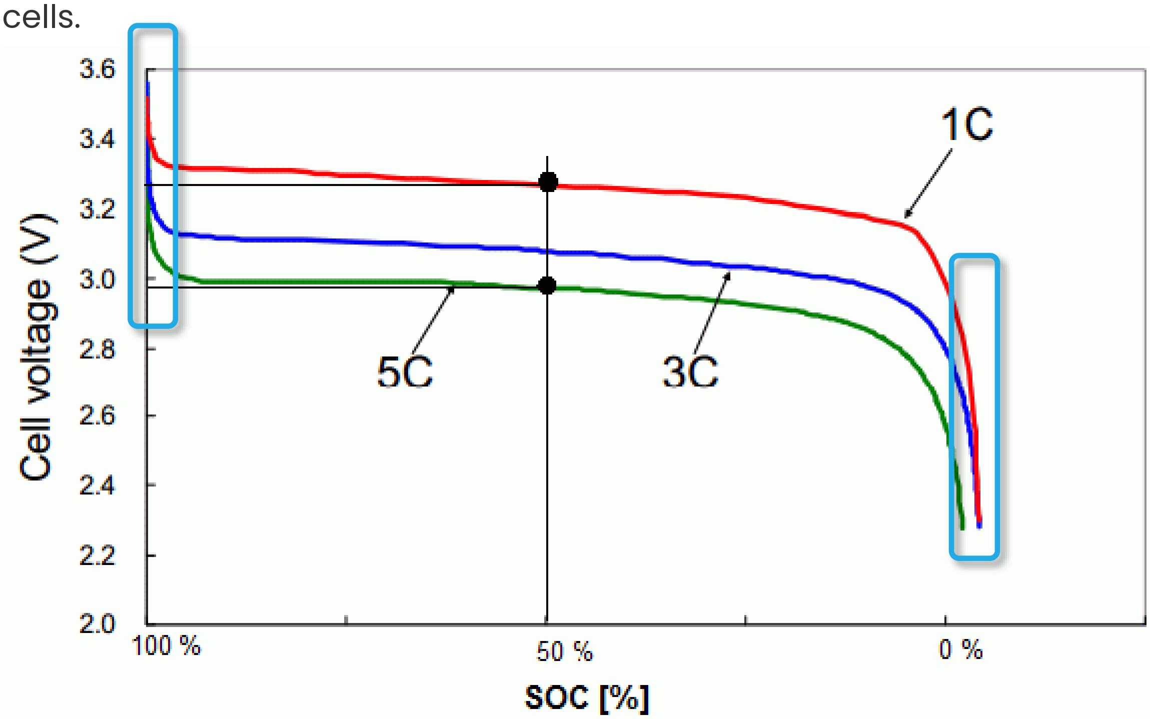
Larger batteries have lower cycle rates, which prolongs the battery life

Bigger batteries experience less stress because the work is distributed across a larger number of high-capacity battery cells. This means each cell is not discharged and recharged as frequently nor as fully as they otherwise would be. This lower stress use maintains the battery's health over time and can extend its usable life to between 15 and 20 years.

However, larger batteries require more resources to produce, cost more and could prevent a larger volume of cheaper cars from being produced. One of the businesses we interviewed suggested that the sale of ten 20kWh vehicles could achieve greater overall carbon reduction than two 100kWh vehicles would.

Fully charging or discharging a battery can damage cells

As the cells in the battery are charged or discharged, their voltages change. At particularly low states of charge the voltage drops rapidly and at particularly high states of charge the voltage increases rapidly. Overcharging or undercharging to reach these extreme voltage levels can do irreversible damage to the battery's cells.



http://liionbms.com/php/wp_short_discharge_time.php

Battery management systems prevent over or under charging

A BMS will monitor the cells in a battery pack and report when a cell's voltage is too low or high. If the BMS is connected to the load (e.g. a vehicle's motor) it will turn off the load, or reduce its output in order to prevent the cells from discharging further. If the BMS is connected to the charger it will stop the cells from charging before they reach the upper limit.

Some battery chemistries are more sensitive to over/under charging

Lithium-ion batteries are particularly sensitive to being over or under charged. Some other battery chemistries, like NiCad and NiMH batteries are able to be fully discharged with a lower risk of permanent damage.

Single cell failures can be misreported as pack degradation

Technical specialists we interviewed had, on several occasions, received EV battery packs where once cell had short circuited and dropped to 0 volts. In these cases, the battery's BMS reported that the entire battery had failed.

Advanced BMS reporting can be used to correct failed cells or modules

OEMS and technical specialists we interviewed that had implemented monitoring of individual cells were able to identify and replace failed cells and restore battery packs to their original SoH value.

Thermal runaway

Thermal runaway leads to battery fires

When the internal contents of a lithium-ion battery cell are exposed to oxygen and subsequently overheat, due to electrical discharge or high ambient temperatures, the flammable materials within the cell can ignite, causing a battery fire.

When a battery cell is pierced or ruptured the metals within the cell absorb oxygen. Both the lithium in the cathode and the cells electrolyte are flammable in the presence of oxygen. Under extreme conditions, such as an electrical short in the cell or extreme high temperatures, an oxygenated cell can ignite.

Thermal runaway is self-oxidising

When air enters a ruptured battery cell the oxygen rapidly combines with metals in the cell to create flammable metal oxides. While the formation of these oxides does not cause the battery to ignite, they provide an internal supply of oxygen that makes a battery fire difficult to extinguish once ignited, even if the battery is placed underwater, in concrete or in a vacuum.

Preventing oxygen ingress is essential

Preventing oxygen from interacting with the metals during battery transport and recycling is important for reducing the risk of thermal runaway. For example, water is used during the recycling process to smother the materials and prevent oxygen ingress as the cells are broken apart. Old batteries must often be packed in vermiculite or sand to reduce the risk of fire when shipped overseas.

New and future battery types

Battery research is accelerating, but lithium-ion is dominant

Research projects into new battery technologies are receiving large amounts of interest and funding, and new technologies are being announced regularly. However, getting a new technology to production scale usually requires five to 10 years. The current lithium batteries are therefore likely to remain the dominant mass-produced technology for the medium term.

Research focuses on better, cheaper technology, not recyclable technology

Research into new battery types is largely driven and funded by commercial goals. These include lower manufacturing costs, higher energy density and longer cell lifespans. These goals do not typically include recyclability. For example, 3D graphite foam cathodes are not recyclable due to the nature of their construction but are a popular area of research due to their ability to extend battery life.

Replacing low voltage battery chemistries makes lithium-ion batteries cheaper

The goal of new battery chemistries for low-voltage devices is displace low-voltage lithium. Chemistries based on aluminium and sodium ion battery development will create inexpensive, small batteries that can displace small lithium batteries. This will leave more rare elements and materials available for high voltage lithium-ion applications like EVs.

Research and development is being done in New Zealand

New Zealand business, TasmanIon[23], is working to produce batteries made of aluminium for lower voltage applications.

Students at GNS have developed a solid-state electrolyte and are working on new battery technologies, including anodes, zinc batteries and redox flow batteries. Most research done in New Zealand is small-scale, PhD-based research.

Aluminium ion batteries

TasmanIon's batteries use an inexpensive, easily recycled aluminium anode and a proprietary cathode made of a very common and known chemical that has recycling methods available.

Supercapacitors

Supercapacitors are cheap, charge and discharge quickly, but have small energy storage capacity. This makes them ideally suited for use in hybrids, in place of the more expensive and difficult to recycle NMH batteries that are currently in use.

Lithium sulphur and solid lithium batteries

Lithium solid (also known as solid state) and lithium sulphur are based on lithium technology, so could likely be compatible with existing recycling processes, however we were unable to confirm this for this report.
Solid lithium-Ion batteries reduce the chances of thermal runaway to almost zero due to the use of polymer gels in place of an electrolyte. Forecasts indicate that they will also be cheaper to manufacture in the long run.

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[23] https://www.tasmanion.com/

Redox flow

Flow batteries use two liquids, an anolyte and a catholyte, instead of a solid anode and cathode. These liquids are pumped past a membrane that facilitates ion transfer from one liquid to the other, releasing energy.

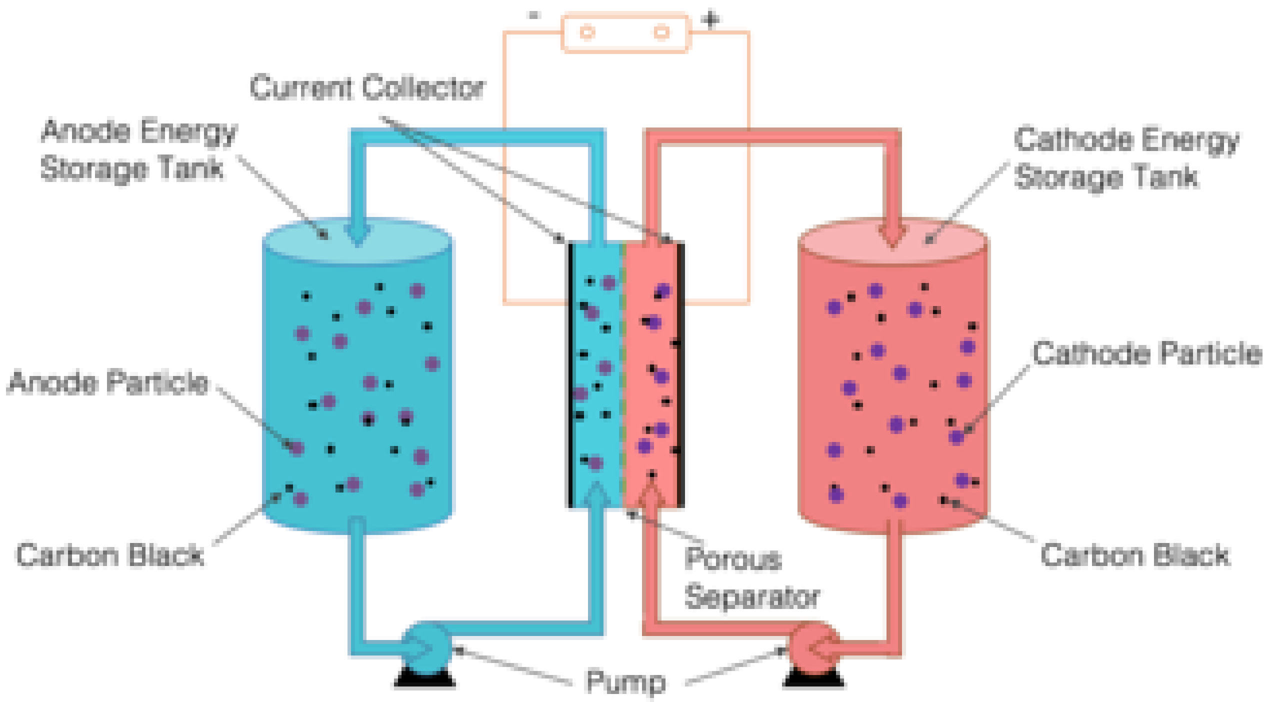

Figure 50 - https://commons.wikimedia.org/wiki/File:Semi-Solid_Flow_Battery.png

Product Stewardship Organisation (PSO)

Regulated product stewardship schemes must be operated by a regulated product stewardship organisation (PSO). The organisation accredited with this role for large batteries in New Zealand is Auto Stewardship New Zealand, their website is https://autostewardship.org.nz/

Battery Passport

Battery passports are digital

Battery passports are also known as 'digital battery passports'. They represent digital 'twins' of their real-life counterparts. Information about a battery is stored in a database and updated throughout the battery's life. There is no official paper version of a battery passport.

Batteries and 'green tech' solutions are held to a high ethical standard

Batteries are widely considered to be green technology, having earned this label by being significantly more environmentally friendly than the fossil fuels they are replacing. However, the general expectation is that green technology should be perfectly environmentally friendly.

While the usable life of a battery is environmentally positive and the overall impact of a battery is far better than the impact of equivalent fossil fuel use, the production and disposal of batteries still carries environmental costs.

Battery passports reduce future environmental impacts

Battery passports work to reduce the environmental impact of the manufacture and disposal of batteries in two ways:

- Providing information on the origin, manufacture, chemistry and materials of the battery they are buying (also known as battery provenance).
- Allowing batteries to be tracked on a digital platform, thereby increasing the likelihood that the battery will be recycled or can be traced back to the owner if it is found in an inappropriate waste stream, or dumped in the environment.

Battery passports support open information sharing

Sharing battery data through a battery passport would provide transparent, verifiable information about a battery's history to owners, recyclers, stakeholders and prospective buyers. It may also be able to track battery state of health, depending on data access permissions. This information would provide a variety of benefits, including:

- Encouraging existing owners to adopt practices that reduce degradation and maintain the capacity, and resale value, of their batteries
- Enabling a robust second-hand battery market by providing buyers with peace of mind and insights into the products they are purchasing
- Providing agencies and battery recyclers with the information they need to prepare their facilities before batteries reach their doors
- Providing manufacturers with data and means of benchmarking, and improving on, their products
- Creating insights to degradation patterns and advice on how to best extend battery life
- Providing insurance and financial institutions with the information they need to price their battery-oriented financial products appropriately, and
- Easier tracking of repairs, cell replacements and therefore easier recovery of materials from individual cells and modules.

Trust in data accuracy is improved using blockchain

Current battery passport platforms and service providers like Everledger provide trust and transparency by recording battery passport information on a blockchain. These services provide immutable (cannot be edited) details about battery provenance as it is recorded during the battery manufacturing process. The nature of a blockchain based system means that, once recorded, this data cannot be easily changed. This provides future owners or buyers with confidence that the information they can access from these platforms is accurate and has not been tampered with.

The Global Battery Alliance (GBA)

The GBA is an international partnership focused on batteries

The GBA (https://www.globalbattery.org/) was founded in 2017 at the World Economic Forum to help establish a sustainable battery value chain by 2030.

The GBA is a membership-based organisation that aims to establish a circular battery value chain platform through battery passports. A full list of its members can be found at https://www.globalbattery.org/about/members/

EverLedger

Everledger provides an industry leading battery passport platform

Everledger (https://everledger.io/) is an Australian-based company and member of the Global Battery Alliance that provide a blockchain based battery passport platform.

Blockchain technology creates an unchangeable record of product history

Everledger uses blockchain to create an immutable (cannot be changed) record of a products history. Their platform is used to provide trusted provenance information for art, diamonds, gemstones, fashion, luxury goods, insurance, wine and spirits, critical minerals and batteries.

Everledger's battery passport platform input requirements were used to develop the software described in Part A of this report.

Battery Management System (BMS)

A BMS monitors battery condition and operation

A BMS is a piece of hardware and software embedded within a battery pack that monitors temperature, voltage and current across all individual cells within the battery pack to ensure the battery pack is maintained at optimal conditions for use.

A BMS works to maintain ideal conditions within the battery pack

In an ideal pack, the voltage across all cells would be perfectly balanced and each cell would contain the same level of charge. As the battery is used, each cell would be discharged and recharged at the same rate, experiencing the same change in voltage.

The battery management system's core function is to ensure that the reality is as close to this ideal situation as possible. It does this by discharging and re-charging individual cells until the voltage across the cells it is responsible for are in balance.

A BMS reports on the condition and operation of the battery

The BMS can also record and report data about the battery state and operation to the application using the battery, such as charge level, state of health and pack, module or cell voltage.

A BMS is often designed for specific batteries with identical cells.

While off-the-shelf BMSs exist, in many applications the BMS and the battery are designed specifically to work with one-another. Because the cells inside a battery need to have identical voltages and capacities to be charged and discharged in-step with each other, batteries that are made up of cells from different sources (e.g. from combining Nissan Leaf cells with Tesla Model 3 cells) would be difficult to create and therefore unlikely to be a viable commercial product.

BMSs in battery upgrades and second-life applications

The battery management systems used by businesses we interviewed who were re-purposing batteries depended on the application the batteries were going to be used in.

For example, replacing or upgrading a battery in an existing EV usually meant that the business would use the vehicle's existing BMS. Using individual modules or cells in new applications, like home storage or ICE car conversions usually used a third-party (or 'off-the-shelf') BMS configured to manage the specific cell or module arrangement created.

In second-life applications that utilise the whole, original EV battery pack, the application can sometimes be best-served with the BMS that the battery pack originally came with. This presents a challenge for engineers working with these batteries, because information about BMSs used by OEMs is not publicly available and the BMS functions must usually be reverse-engineered in order to use the battery effectively in second-life applications.

Application Programming Interface (API)

APIs share data between software programmes

APIs allow for secure, controlled sharing of information with authorised partners. They are a core part of the data monitoring system described in this report.

An API is a way for separate computer programmes to communicate with each other. It is a type of data pipeline between programmes that connects a service provided by a "customer" programme to data or services provided by a "supplier" programme.

APIs restrict communication to specific questions/answer types.

APIs allow for a specific set of "questions" to be asked by the "customer" programme to the "supplier" programme. The allowed questions and expected answer formats are outlined in a specification document or standard that describes how to use the API. These answers can be in the form of data from a database, or a calculated response based in data sent by the "customer" programme.

Ethical materials sourcing

This report does not investigate ethical material sourcing

Encouraging and supporting recycling reduces reliance on trafficked minerals. However, ethical sourcing of battery materials was out of scope for this report, as our intent was to explore opportunities for data collection to support recycling.

Battery Passport platforms already provide insights into battery providence

The platforms this project seeks to support, Everledger and The Global Battery Alliance, already provide information, resources and provenance tracing tools that will give buyers assurance over the origin of their batteries.

New Zealand businesses expressed some concerns about being able to ethically source batteries for their applications

Most of the businesses we interviewed reported several concerns when it came to the ethical sourcing of batteries by New Zealand businesses:

- New Zealand businesses are largely "tech-takers", who can either choose to buy something or choose not to and get left behind.

- Compared to buyers overseas, New Zealand businesses don't have the scale to exert pressure on manufacturers by themselves.
- When asking questions about material origins to suppliers, New Zealand businesses have few opportunities to conduct 'deep-dives' into claims made by suppliers.
- Independent certifications have been seen as getting watered down. New Zealand businesses have, to date, found it very difficult to obtain certificates of material sources.

Battery recycling's impact on supply and demand

Demand for lithium batteries is growing exponentially

Lithium batteries were first researched in 1912, patented in 1976 and commercialized in 1991. The price-per-kWh of lithium batteries has since fallen sharply, and the market is expected to grow to over $130 billion USD by 2030, according to Bloomberg. The impacts of the rapid growth in lithium-ion battery technology, on recycling and availability of materials, will not be seen for several decades.

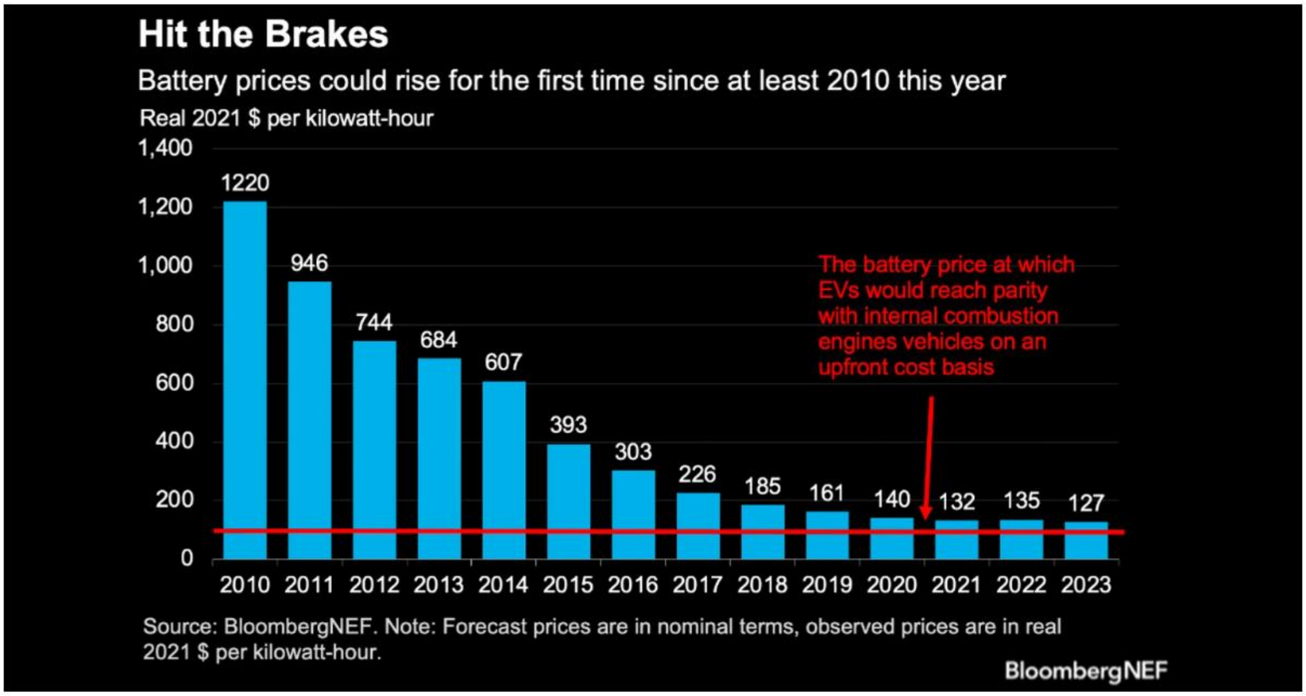

Figure 51 - Lithium-ion battery prices ($USD per kWh)
source: https://www.bloomberg.com/professional/blog/race-to-net-zero-pressures-of-the-battery-boom-in-five-charts/

Recycling is essential to ensure the supply of raw materials for batteries.

Recycling can play an important role in relieving the burden on primary supply from virgin materials at a time when demand starts to surge. For example, the amount of spent EV batteries reaching the end of their first life is expected to grow exponentially after 2030 if the Sustainable Development Goals (SDGs https://sdgs.un.org/goals) are to be achieved, offering the potential to reduce the pressure on investment for primary supply if instead they can be recycled.

Businesses we interviewed cited a range of source, some more positive than others, that show there are not enough raw materials to cater to the projected demand for materials under sustainable development scenarios. This included copper, class 2 nickel, cobalt and lithium. EV battery research currently focuses almost exclusively on lithium and projections show that recycling is essential to even come close to achieve production levels required under these scenarios.[24]

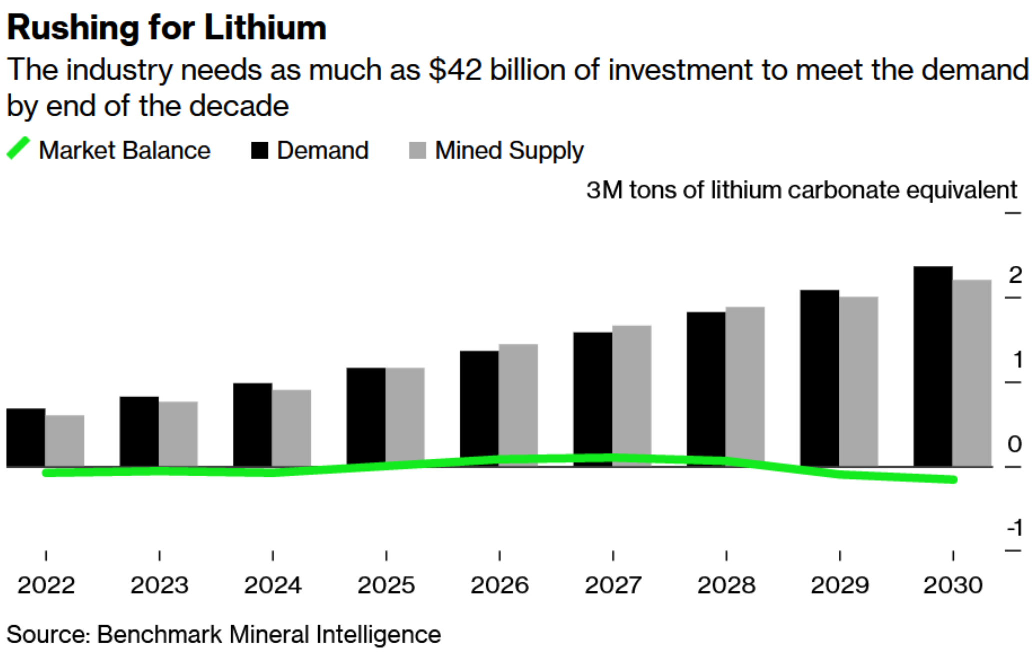

Figure 52 – Predicted lithium supply and demand by Bloomberg
Source: https://www.bloomberg.com/news/features/2022-05-25/lithium-the-hunt-for-the-wonder-metal-fueling-evs?leadSource=uverify%20wall

[24] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/reliable-supply-of-minerals#abstract
https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

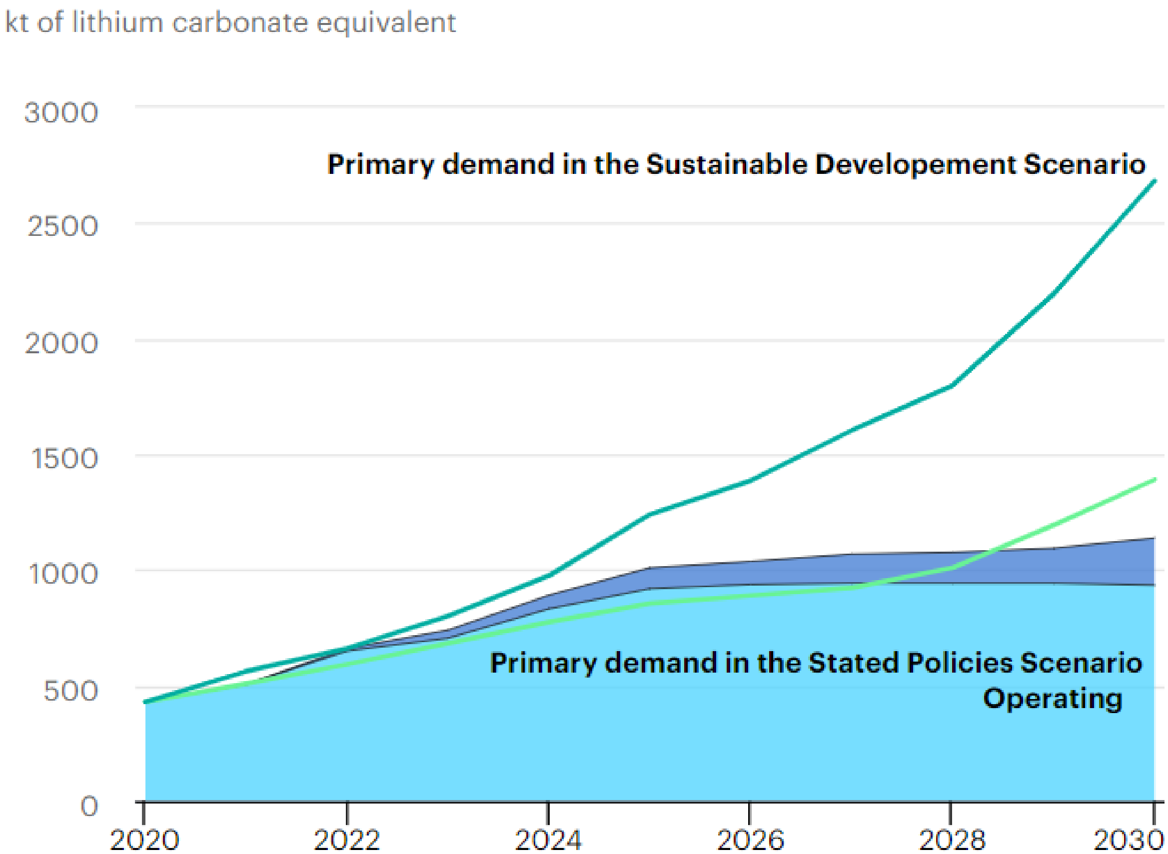

Figure 53 - Predicted lithium supply and demand by the IEA
Source: https://www.iea.org/data-and-statistics/charts/committed-mine-production-and-primary-demand-for-lithium-2020-2030

Vehicle telematics

Many third-party telematics solutions use a '3-wire' solution and do not use CAN bus data to track vehicles

Traditional asset tracking is comprised of an intelligent GPS device (often accompanied by an accelerometer, speedometer or other technology) powered by the vehicle's 12V battery and linked to the vehicle's ignition.

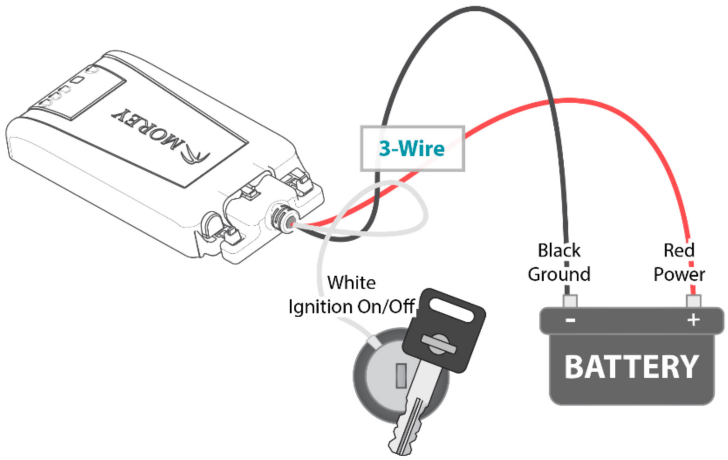

Figure 54 - A basic, non-CAN bus Telematics system

This provides information about the vehicle's location and distance travelled as well as information on driver behaviour, such as driving speed, acceleration and crash detection, which have an impact on the battery health and usability. While this information can be used to infer or predict information about a battery, these solutions are not able to directly collect any information from the battery or the CAN bus.

Telematics solutions are emerging that offer access to some CAN bus data

Battery data is becoming increasingly important and telematics companies are starting to invest in obtaining this information. This is an expensive process, as it requires specialist knowledge and time to analyse and translate signals from the OBD port.

At a minimum, solutions we found offer live state of charge (the current battery level as a percent of total). This is useful, for example, for solutions deployed by some ride share businesses across the world to provide customers with advanced knowledge of a vehicle's remaining driving range.

Advanced solutions, including the Geotab GO9 devices used in this trial and some embedded telematics within vehicles, also provide information about energy flows in and out of the battery while the vehicle is driving or charging and are capable of estimating the battery's state of health over time.

Autonomous vehicles

Autonomous vehicles are driven either in-part, or entirely by a computer

There are six accepted levels of Autonomous driving:

Level 0	No automation at all (e.g. Ford Model T)
Level 1	Driver assistance (e.g. cruise control)
Level 2	Partial automation (e.g. Tesla self-driving today)
Level 3	Conditional automation (e.g. Mercedes-Benz Drive Pilot)
Level 4	High automation (e.g. Google Waymo)
Level 5	Full automation

Autonomous driving could mean more central ownership of batteries

Car-share and sales businesses we interviewed suggested that autonomous or semi-autonomous vehicles would likely remain in a centrally owned fleet for longer. This is because the ability to self-charging, self-drive and self-manage would make transport-as-a-service more profitable. Some OEMs have been structuring parts of their businesses around transport-as-a-service, either by establishing their own services, or by supplying vehicles and software subscriptions to third party car-share organisations.

Eventually, autonomous vehicles would be sold on a second-hand market

Despite having a longer life as a service or rental vehicle, businesses we interviewed believed that autonomous vehicles owned by transport as a service providers would still likely be on-sold into the second-hand market. This would be to provide capital for the fleet owner to buy newer, more modern vehicles. The likely final owners in this case would mostly be private individuals.

One exception to this could be if ownership of the transport as a service fleet is retained by an OEM with an in-house recycling process, or if the fleets were required to return their vehicles to the OEM.