new energy futures paper: batteries & the circular economy

about Vector

Vector is New Zealand's largest energy distribution company, and is creating a new energy future through investigation and investment in new and innovative technologies. This is about unlocking for its customers the benefits of smart meters, solar panels, batteries, electric vehicle charging infrastructure, and energy management services.

This New Energy Futures Paper - Batteries and accompanying Technical Addendum has been made possible thanks to the following people:

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Through its partnership with Ngāti Whātua Ōrākei and its Kupe Street 30-home residential development for first-home buyers, Vector has created a real-world lab enabling observation of how a future community grid might operate, in which access to new technology – specifically networked solar and battery storage - is provided equally amongst all residents.

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What to do with EV batteries: How the problem – and potentially the solutions – will arrive first in New Zealand

By Ariel Muller, Managing Director, Asia Pacific, Forum for the Future

The momentum toward sustainable transport is now undeniable. We just passed the 4 millionth electric vehicle (EV) sold globally. Bloomberg estimates that by 2040, 55% of all new car sales and 33% of the global fleet will be electric. Auto-manufacturers and countries are setting ambitious targets and making measurable progress towards 100% electrification of cars. In New Zealand, the rate of adoption is exponentially rising from just 210 cars in 2013 to 10,000 in 2018.

The benefits of EVs are well understood. They are low carbon, don't produce tailpipe particulate emissions, quiet, and can act as a flexible storage solution for intermittent renewable energy. However, with these benefits come challenges. One of the most pressing challenges faced by this industry is how to treat EV batteries at the end of their useful life in vehicles. An EV battery is the single largest value item in a car and is made with precious resources that are finite. In addition, once EV batteries are no longer fit for purpose in vehicles, they still have approximately 80% of their battery storage capacity left and therefore can operate as small scale, flexible energy storage. In this challenge emerges an opportunity: How might we maximise the life of a battery through reuse and responsible recycling at end of life – and perhaps even more importantly, what will be the business models to enable these solutions?

The need to innovate around this challenge is especially front of mind in New Zealand. The country's current EV uptake programme relies heavily on the import of second hand EVs. This means EVs entering the market come with semi-depleted batteries that are likely to reach end of usable life in the vehicle sooner. Simultaneously, the absence of an indigenous auto-manufacturing sector in New Zealand, coupled with the significant geographical distance to other auto-manufacturing hubs, mean that solutions to maximise the use of EV batteries are likely to come from beyond the automotive sector.

As used EV batteries begin to enter the second-hand market, there is the need for proactive action to build the technical and social infrastructure for reuse, recycling and responsible disposal solutions. Left unchecked, New Zealand runs the risk of facing unintended environmental consequences, as current lithium-ion EV batteries can be highly polluting and pose a fire risk if not disposed of properly. However, if seen as an opportunity to introduce innovative new market offerings, New Zealand could become a leader in approaches demonstrating the new ecosystem of business models that will emerge around the worldwide electrification of vehicle fleets.

Aligning public and private interest to facilitate policy and infrastructure change can be complex and laborious, requiring investment and engagement across multiple stakeholder groups to build consensus. There will also be the need for education and incentives for new behaviour from vehicle owners or users, whose participation would be key for the success of solutions such as battery take-back programmes.

It is in this regard that New Zealand might have an advantage in implementing system-wide change. In short, it is easier to bring the system together here. New Zealand has a relatively small population that prizes its nature and environment as a defining characteristic of its identity. There are a few leading private sector actors with a vested interest in the reuse, recycling and responsible disposal of EV batteries.

The government has also shown interest and willingness to work with industry to introduce enabling policies such as a product stewardship scheme for large batteries. This momentum – and the relative ease of convening all the actors – could allow New Zealand to leap frog other markets in Europe and Asia, when it comes to introducing solutions at the national level.

foreword continued

What to do with EV batteries: How the problem – and potentially the solutions – will arrive first in New Zealand

By Ariel Muller, Managing Director, Asia Pacific, Forum for the Future

We are heartened that Vector, a Partner of Forum for the Future, has taken the lead to catalyse the conversation, acting as a "lighting rod" to attract current and future actors from both the public and private sector, who can present solutions to realise a circular economy for batteries in New Zealand. Last year, we worked with Vector to convene over 30 stakeholders, from EV and battery retailers, users, recycling and waste management solution providers, industry associations and regulators, to innovative start-ups and interest groups.

Through an exploration of future scenarios of the battery value chain in New Zealand, we agreed on three things:

1. The need to solve the problem of EV batteries at end-of-life presents opportunities to create new market offerings and services.
2. Collaboration between private sector and the government is needed, to introduce collective frameworks such as a product stewardship scheme that will enable new market solutions.
3. It is critical to bring consumers along from the start. They can help to shape new markets and finesse new solutions in a rapidly changing landscape.

The challenge is now for those who recognise the opportunities to drive the change we need. Maybe then what is first solved in New Zealand can be shared with the world.

Watch the kiwis.

introduction, purpose & scope of paper

Vector's vision is to Create a New Energy Future. A key part of this future is enabling distributed energy technologies including solar, EVs and batteries.

These technologies are part of Vector's value chain, and batteries are now an essential part of our lives, with the global battery market anticipated to be worth $100 billion by 2025.

> Mobile technology and a low-carbon future are unthinkable without batteries, a core technological enabler of the Fourth Industrial Revolution.
>
> **- World Economic Forum Global Battery Alliance**

Batteries, particularly lithium-ion batteries power everything from toys to cameras, computers, power tools, energy storage, e-scooters and e-bikes, trains and now electric aircraft. The Global Battery Alliance, a World Economic Forum (WEF) initiative, has called batteries a 'backbone technology' in the transition from fossil fuels to a low-carbon future. The Fourth Industrial Revolution, which WEF's Founder and Executive Chairman Klaus Schwab argues we have entered, relies on the hyperconnectivity of products and technologies, and therefore, energy storage solutions.

Thanks to high power and energy densities, lithium-ion batteries are key to the Fourth Industrial Revolution (4IR). One characteristic of 4IR is the electrification of transport (E-mobility).

This Paper focuses on large lithium-ion batteries, such as those used for energy storage or E-mobility which can be repurposed for second-life battery applications such as stationary energy storage for our electricity network, industry and households.

They pose significant sustainability challenges (and by sustainability, we mean interconnected environmental, social and economic issues). As we transition to a low-carbon economy, in which E-mobility plays an increasing role, we all share some responsibility for managing batteries sustainably.

Sustainability challenges include resource extraction which is reportedly responsible for half of the world's carbon emissions and more than 80% of biodiversity loss[1]; unregulated mining of cobalt that uses child labour; and the degradation of the salt flats in Bolivia in the search for plentiful lithium; the potential for thermal runaway fires from used batteries and the current lack of on-shore processing at end-of-life in New Zealand. Add to this rapidly changing battery chemistries and the evolution of other technologies such as hydrogen.

It's a complex, dynamic and rapidly evolving system.

All organisations in the battery value chain need to work together in ways we never have before to get in front of this challenge. We need to innovate to retain the value of the metals we dig out of the earth. We need to invest in facilities to manage our resources if we want a truly circular economy. We need to be flexible in our approach.

> The New Zealand Ministry for the Environment defines a circular economy as an economy "in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life."

Vector has been closely engaging with the Ministry for the Environment and we know that a regulated Product Stewardship Scheme for large batteries including lithium-ion is due to be developed as part of a suite of other schemes (see Technical Addendum for further information).

Vector's focus is on 'large' lithium-ion batteries for mobile (electric vehicle) and stationary battery energy storage. Our view is that, if we as industry proactively address repurposing and end-of-life solutions, we will be well positioned to innovate and shape regulation to avoid a cost-prohibitive model.

[1]https://www.theguardian.com/environment/2019/mar/12/resource-extraction-carbon-emissions-biodiversity-loss?CMP=Share_iOSApp_Other

introduction, purpose & scope of paper continued

Industry needs key insights in order to plan for the future. These include:

- What are the likely volumes of batteries that will be coming to the end of their use / life, given trends and new technologies?
- What is the dollar value of a battery at different points in its lifecycle, particularly end-of-life?
- What is the impact of changing battery technology / chemistry? What about disruptive technologies such as hydrogen? What is the potential or need for standardisation of battery design and battery storage?
- What are the second and third life opportunities?
- How can we safely use, store and transport used batteries?
- Can we have cost-effective on-shore end-of-life solutions in New Zealand?
- Is there a cost to stewardship / end-of-life management? If so, what is the cost, who should pay and by what mechanism?
- How will we need to engage with different stakeholder groups (esp. customers and end users) to prepare them for the transition to a product stewardship scheme? How can we ensure the appropriate plans are in place for this transition?
- If there is to be a Product Stewardship Scheme regulated by Government, to whom should it apply? How could we shape it so that it works for industry and delivers positive environmental and social outcomes?

Purpose of this Paper

We understand that we are not alone in asking these questions and we don't attempt to answer all of these in this Paper, rather these will be addressed by a Battery Industry Group (B.I.G.) focussed on large batteries.

As organisations across the battery value chain, we have a shared need to understand the potential regulatory, volume and market 'scenarios' that we will face over time. We have therefore attempted to pull together all available data on the current battery 'landscape' here in New Zealand and what opportunities are on the horizon.

Our current 'linear' system of extracting materials from the ground to make a battery, using a battery once then putting the 'waste' battery into landfill at end-of-life is simply not sustainable. **A commercially sustainable model will require a shift across the entire system.**

We have a unique opportunity to work together to find the answers, which is why we have commissioned research and engaged stakeholders in thinking about a **circular economy future** for lithium-ion (and other) batteries. In the interest of transparency, and in the hope that it will benefit New Zealand Inc., we are sharing this information publicly in this Paper.

who we talked to

We engaged with a number of stakeholders across the large battery value chain in New Zealand and beyond from the stakeholder groups below. Many thanks to those who contributed advice, data, information and support.

STAKEHOLDERS WE TALKED TO

Battery retailers and organisations such as PowerSmart NZ Ltd (part of the Vector group) New Zealand Battery Leaders Group (which Vector founded and whose members include stakeholders on this list as well as Original Equipment Manufacturers such as Audi, BMW, Toyota and stationary battery manufacturers).

Academic institutions such as Victoria University

Car wrecking individuals or companies

Vehicle industry bodies such as Drive Electric, Electric Vehicles Leadership Group, the Motor Industry Association, Vehicle Import / Industry Association

Sustainability consultants such as Forum for the Future and Eunomia

International battery and product stewardship organisations such as Australian Battery Recycling Initiative (ABRI), Australia New Zealand Recycling Platform (ANZRP), Clean Energy Council, Australia, Envirostream, Equilibrium, University of New South Wales Sustainable Materials Research & Technology Centre, University of Technology Sydney's Institute for Sustainable Futures, ELVES and the Faraday Institution

Charging infrastructure providers e.g. ChargeNet

Circular economy organisations such as the Circular Economy Accelerator, an initiative of the Sustainable Business Network

Electricity distribution bodies, generators and organisations including the BusinessNZ Energy Council (BEC) and Sustainable Energy Association New Zealand (SEANZ)

Government agencies and departments such as the Ministry for the Environment, Callaghan Innovation and the Energy Efficiency and Conservation Authority (EECA)

Innovators in battery technology including circular economy innovators and battery lifecycle management technology innovators

Small businesses who engage with the informal battery economy such as BlueCars

scope: what's in and what's out

This New Energy Futures Paper will:

- Focus on large lithium-ion batteries.
- Identify opportunities for New Zealand in the context of a circular future.
- Highlight environmental, societal and commercial barriers and challenges: by tackling these challenges we will help to enable a new energy future.
- Offer an overview of battery types and technology changes, how this impacts recovery options, key trends and market drivers.
- Introduce the concepts of a circular economy and product stewardship for batteries to ensure we retain a battery's financial and material value over its lifecycle.
- Explain the difference between materials recovery and battery recovery.
- Share industry case studies.

All research supporting each section of this Paper, plus a discussion of battery chemistries and technologies beyond lithium-ion, is presented in a Technical Addendum. This is a compilation and evaluation of available New Zealand data and provides future projections including recovery pathways, markets and trends.

Technology

Development of battery technology is being undertaken by a large number of organisations from major battery manufacturers and auto makers, to research institutions. By the time this Paper is launched or read, new technologies or chemistries may have emerged which will not be reflected in its content: rather, this Paper is a snapshot in time.

There are many possible battery technologies, but one thing that all appear to have in common is that there is a long gestation period between what is theoretically possible in a laboratory and the eventual commercial production of a viable battery. In this Paper, we have focussed on the technologies which, in the literature, appear to be regarded as having the best chance of commercial viability in the next 10 years or so. According to the world's leading climate scientists, this, coincidentally, is approximately how long humans have to keep global warming to a maximum of 1.5oC, beyond which even half a degree will significantly worsen the risks of drought, floods, extreme heat and poverty for hundreds of millions of people.

Lithium-ion vs lead-acid

Given the Government's focus on large batteries including lithium-ion for regulated product stewardship (part of their E-waste commitment), and that lithium-ion batteries are part of Vector's value chain, there is a focus on lithium-ion technologies in this Paper. The Technical Addendum covers all batteries types with the exclusion of lead-acid. Vector currently uses a lot of lead-acid batteries but these batteries are currently considered to have viable end-of-life recovery pathways and mature recycling processes. In this Paper we are also pleased to show case studies from innovators working with various battery chemistries in New Zealand, beyond lithium-ion.

System vs product

Resource use and waste are systems challenges that require systems thinking. This Paper therefore focusses more on the battery 'system' rather than batteries at a product level. Some analysis of the embodied carbon of stationary batteries is provided in the Technical Addendum.

However, one systems area is not covered. This Paper doesn't discuss the carbon associated with the electricity that feeds (or charges) batteries. In New Zealand, while approximately 82% of our electricity is generated from renewable sources[2], so at first sight, electrification of transport (E-mobility) and increased battery use makes sense for our environment, society and economy. However, it must be noted that renewable energy generation mix in New Zealand has associated carbon emissions, and of our energy generation mix, only approximately 60% is low-carbon[2].

Size matters

Although small batteries, such as those found in toys, power tools and electric scooters are a potential fire hazard at end-of-life management, they are not a key part of Vector's value chain.

'Large' batteries are made up of small battery cells and while this Paper focusses on large batteries, we recognise that we must align with any areas of synergy regarding end-of-life management of small batteries in New Zealand.

Vector is interested in large batteries for energy storage on the network, to help even out the 'peaks and troughs' of energy demand and for resilience. In addition, businesses which are part of the Vector group sell large batteries as part of their energy solutions for commercial and household use.

This Paper therefore focusses on large batteries, defined by use to include batteries which are used in:

- Electric vehicles (EVs)
- Stationary energy storage solutions i.e. for
  - The electricity network or 'grid'
  - Commercial or household energy storage
  - Industrial applications

Knowledge sharing and collaboration is key if we are going to get ahead of the impending systemic challenge of battery management in New Zealand. We recognise that while storage, transport and end-of-life management present common challenges / areas of synergy for both large and small batteries, other parts of the value chain such as retail, use and second life opportunities may present very different challenges.

We will therefore seek synergies with small battery management where possible and aim to align with emerging small battery activities such as on-shore collection e.g. through the Australia and New Zealand Recycling Platform[3] (ANZRP) and end-of-life processing which is shortly to be piloted by Waste Management New Zealand – see the case study.

CASE STUDY:

Waste Management New Zealand (WMNZ) Household (Small) Battery Recycling Programme Trial

Waste Management is New Zealand's leading waste and environmental services provider and is committed to finding solutions for problematic waste streams.

Waste Management Technical Services is undertaking a trial to recycle household batteries. Reusable battery material will be used to make new batteries and other components – which means whole batteries will be diverted from landfill.

This trial aligns with Waste Management's sustainability strategy For Future Generations which provides the foundation for our future focus on the sustainability of their company and the communities in which they operate.

The programme will be trialled at various hotels, aged care facilities and Refuse Transfer Stations, and will work in parallel with a wider industry battery recycling working group to develop solutions for rechargeable battery applications such as electric trucks and cars.

Once the trial is proven, this programme will be offered to other Waste Management customers.

Right: The new Battery Recycling Station prototype to be trialled.

[2] Data extrapolated from https://www.mbie.govt.nz/assets/d7c93162b8/energy-in-nz-18.pdf
[3] https://www.anzrp.com.au/

EV vs grid energy storage

For those who know us as an electricity distribution business, some may be surprised that in this Paper we don't talk more about batteries as energy storage solutions for the grid or other applications. Rather, the data focusses on batteries from EVs which can then be given a second life on the grid before being managed at end-of-life as part of a circular economy. This is because in volume terms, most 'end of use' batteries will be coming from increasing use of EVs rather than the currently small proportion of batteries on the electricity network.

The role of the Battery Leaders Group

Businesses involved in the battery value chain in New Zealand share significant common challenges including the rapid uptake of renewable technologies in the context of climate change; the potential expansion of scope of China's National Sword policy to include e-waste; media and public attention on materials and waste management; a lack of on-shore recycling, and Government's new focus on E-waste as a priority issue.

As discussed above, with the convergence of the transport and energy systems, there is also a unique opportunity for businesses from both sectors to collaborate to drive change, support the emerging circular economy, and create the environmental, societal and commercial future we wish to see.

In August 2018, Vector convened the Battery Leaders Group to seek circular solutions for batteries. The Leaders' Group members include Audi, BMW, the Scrap Metal Recycling Association of New Zealand (SMRANZ), Toyota New Zealand, Vector and Waste Management. Members represent different aspects of the battery value chain, from stationary and mobile battery manufacturers and retailers, to end-of-life management.

The aims of the Battery Leaders Group were to:

- Be part of creating a vision for a commercially and environmentally sustainable, circular future for large lithium-ion batteries
- Identify the reuse and end-of-life commercial or financial value of a battery
- Be better placed to advise vehicle leasing companies and second-hand retailers regarding the on-sell of batteries, currently one of the barriers to EV uptake
- Understand the commerciality of battery reuse / recycling and what volumes we can expect
- Understand our roles in product stewardship and shape the upcoming Government Product Stewardship Scheme to avoid onerous, cost-prohibitive regulation which still delivers positive environmental and social outcomes
- Plan for customer and stakeholder engagement regarding battery reuse / end-of-life
- Demonstrate to Government that industry is being proactive and helping to create a circular economy
- Demonstrate to wider stakeholders that work is already underway in New Zealand to help generate momentum
- Ensure clarity in the market regarding messaging around lithium-ion batteries on repurposing options, including safety and financial value
- Keep battery resources out of landfill
- Help to create a New Energy Future

Vector would like to thank the Battery Leaders Group for their contribution to the research and insights in this Paper. The Group is now forming the core of a wider 'Battery Industry Group' (B.I.G.) which will be creating a proposal for a product stewardship scheme for large lithium-ion batteries. This proposal to the New Zealand Ministry for the Environment will be unique in that it aims to:

- Offer a flexible framework able to respond to different battery chemistries, technologies and end-of-life management scenarios.
- In parallel, trial second life and end-of-life management of large lithium-ion batteries to inform the scheme.
- Share practical guidance regarding safe storage and transport of used lithium-ion batteries.

Figure 1. Battery Leaders Group Joint Statement

Working to improve our battery karma

Vector. Audi. BMW. Toyota New Zealand. The Scrap Metal Recycling Association of NZ. Waste Management.

As organisations across the battery value chain, we share common sustainability challenges. Once valuable metals and raw materials have been taken out of the ground, it makes sense to retain their value for as long as possible, rather than returning them to the ground through end-of-life disposal.

The convergence of transport and energy systems means we have a unique opportunity to collaboratively drive change, contribute towards building a more circular economy and create the environmental, societal and commercial future we wish to see. Achieving a shift across the value chain will require pre-competitive collaboration.

That's why we have convened this Battery Leaders Group.

What goes around, comes around

The Battery Leaders Group seeks circular solutions for large batteries with a focus on lithium-ion.

These include both stationary batteries (e.g. used in home energy storage) and mobile batteries (e.g. from electric vehicles) in the context of:

- Climate change and the role of batteries in the decarbonisation of our energy and transport systems
- A rapid uptake of electric vehicles
- Increasing use of battery storage in commercial and residential applications
- Global developments in waste management and recycling, specifically the ongoing impacts following implementation of China's National Sword policy

We are working together to research and evaluate the nascent New Zealand end-of-life battery market. Collaborating now will better prepare us – both as a country and as individual market participants - to find sustainable solutions as the market emerges.

everything you want to know about lithium-ion batteries (and more)

Legislative and Policy Context

The current legislative and policy environment in New Zealand is broadly conducive to the uptake and expansion of battery systems, without there being any strong drivers (such as subsidies to purchase EVs, or emissions standards), or impediments that would unduly limit battery uptake. The New Zealand Productivity Commission 2018 report on the Low-emissions economy recommends a number of minor changes to facilitate the uptake of EVs and battery storage but does not put forward any aggressive measures that would ensure an accelerated uptake. More recently, the Government has indicated that there will be stronger incentives for EVs, by reducing the upfront cost of electric, hybrid and fuel-efficient vehicles when sold in New Zealand for the first time and putting a small fee on the highest polluting vehicles when they are first sold.[4]

The management of end-of-life/end of use batteries is, at present, largely unregulated. At the time of writing, there are no product stewardship schemes in place for large batteries and, beyond the need to comply with export requirements, there are no restrictions around establishing e-waste and battery recycling operations. Other than voluntary codes of practice, there are currently no established procedures or guidelines for how end-of-life batteries should be managed.

However, in May 2019 Hon. Eugenie Sage, the Associate Minister for the Environment, announced "The Ministry for the Environment is developing a mandatory product stewardship scheme for e-waste, starting with lithium-ion batteries, which would make manufacturers responsible for managing the 'end-of-life' aspects of their products."[5]

In August 2019, a consultation document was published by the MfE, Proposed priority products and priority product stewardship scheme guidelines. Electrical and electronic products were identified as one of six priority product groups and the potential scope includes large rechargeable batteries designed for use in electric vehicles, household-scale and industrial renewable energy power systems including but not limited to lithium-ion batteries.[6] The Battery Leaders Group mentioned above undertook research and stakeholder engagement with Ministry support, and MfE representatives will be working closely with the new Battery Industry Group to advise on the development of a new product stewardship scheme for batteries.

Lithium-ion battery chemistries, characteristics and construction

Excluding lead-acid, which is outside the scope of this Paper, there are two main types of large batteries that are most likely to have to be dealt with at end-of-life in New Zealand: lithium-ion and nickel metal hydride (NiMH). This Paper focusses on lithium-ion batteries and this section on their chemistries and characteristics. Nickel metal hydride batteries and detailed information about lithium-ion batteries are discussed in the Technical Addendum to this Paper.

The popularity of lithium-ion batteries is due chiefly to their energy density. Other advantages include:

- Reliability
- They are less likely to suffer from 'memory effect'[7] than other battery types
- They don't contain toxic cadmium
- Use of lithium-ion batteries in transport avoid toxic tailpipe (exhaust) emissions / greenhouse gases which contribute to climate change
- The cost of these batteries has drastically fallen[8]

[4] https://www.newshub.co.nz/home/politics/2018/09/government-promises-decent-incentives-for-electric-cars.html
[5] https://www.beehive.govt.nz/release/funding-e-waste-project-announced
[6] https://www.mfe.govt.nz/publications/waste/proposed-priority-products-and-priority-product-stewardship-scheme-guidelines
[7] https://phys.org/news/2013-04-memory-effect-lithium-ion-batteries.html
[8] Research from BloombergNEF shows that "the benchmark levelized cost of electricity (LCOE) for lithium-ion batteries has fallen 35% to $187 per megawatt-hour since the first half of 2018 and the LCOE per megawatt-hour for lithium-ion battery storage has dropped by 76% since 2012, based on recent project costs and historical battery pack prices"https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/#_ftn1

However, when damaged lithium-ion batteries can cause thermal runaway fires or catastrophic explosions which threaten waste companies' licence to operate. An additional complication is that lithium-ion batteries can be accidentally or purposefully hidden in pallets of used lead-acid batteries, thereby causing a fire hazard. Finally, while lithium is fully recyclable, and reportedly being recycled in China, very little lithium is recycled globally for battery production, as the processing of lithium from used batteries is approximately five times costlier that the virgin material.[9]

Battery characteristics and chemistries

Batteries can have a range of performance characteristics which make them more or less suitable for particular applications. Some types of lithium-ion batteries have special characteristics e.g. Lithium Nickel Manganese Cobalt Oxide (NMC) batteries are well suited to high power applications with many charge/discharge cycles such as home energy storage. See below Table 1 for the main types of lithium-ion battery cell chemistries.

Table 1: Main Types of Lithium-ion Battery Cell Chemistry

Type	Description of power and operating range	Applications
Lithium Manganese Oxide (LMO)	Has a moderate specific power, moderate specific energy and a moderate level of safety compared to other lithium-ion batteries. It is also low cost, but has a poor operating range and short lifespan.	Electric powertrains
Lithium Nickel Manganese Cobalt Oxide (NMC)	High specific energy. Moderate specific power, safety, lifespan and operating range. It can be optimised to have either a high specific power or high specific energy.	EVs, industrial applications
Lithium Iron Phosphate (LFP)	Low specific energy but a high specific power. Moderate operating range. High level of safety and lifespan and low cost	Portable and stationary applications needing high load and endurance
Lithium Nickel Cobalt Aluminium Oxide (NCA)	Very high specific energy. Moderate cost, specific power, operating range and lifespan. Relatively low level of safety	EVs
Lithium Titanate (LTO)	High safety good operating range and long lifespan, but low specific energy, and only moderate specific power. Very fast recharge time. Very high cost	EVs

[9] Source: https://waste-management-world.com/a/1-the-lithium-battery-recycling-challenge

everything you want to know about lithium-ion batteries (and more)

continued

There are other metals used in cathodes apart from lithium, such as cobalt and manganese, and there are concerns about future supply of some minerals such as nickel and copper due to underinvestment in the mining sector[10].

Figure 2 below provides some examples of these other metals and their uses.

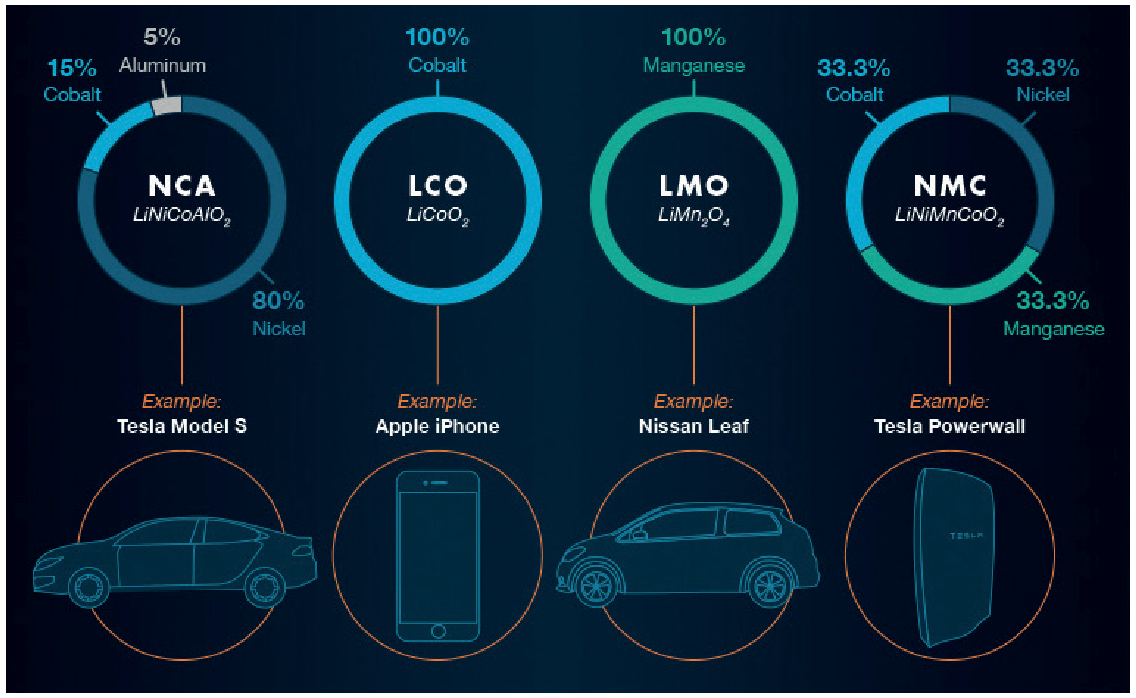
Battery construction

The method of construction varies between manufacturers and depends on the applications for which they are intended.

There may be several different components to a battery. These include:[11] cells (EV battery packs for example may have hundreds of individual cells usually arranged in modules) a battery management system, cooling mechanisms and temperature monitors, relays (which control the distribution of the battery pack's electrical power to the output terminals), temperature, voltage, and current sensors, cabling, contacts, metal and / or plastic casings and other electronics, such as inverters.

While most of the weight of a battery generally consists of the cells, the other materials from a battery can potentially be recovered at end-of-life.

Figure 2: Cathode composition of lithium batteries, excluding lithium. Image reproduced from (Electrek, 2016).



[10] https://www.reuters.com/article/us-usa-lithium-electric-tesla-exclusive-idUSKCN1S81QS
[11] https://en.wikipedia.org/wiki/Electric_vehicle_battery

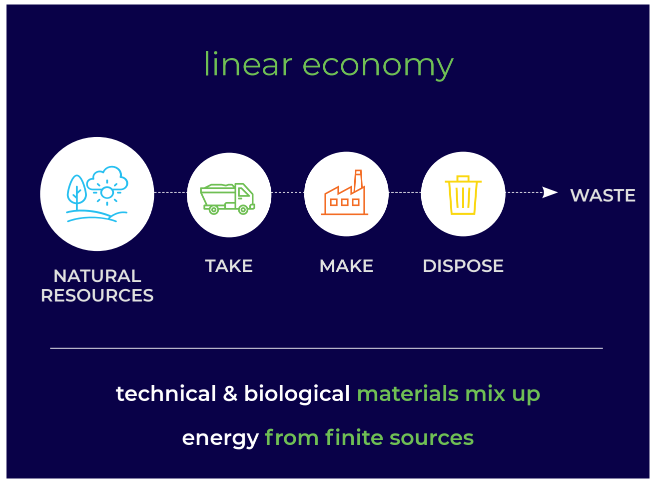
Figure 3: A Nissan Leaf Battery Pack

current state of play: our linear system

What is a linear economy?

Modern economies are based on a linear economy model of 'take make waste' i.e. take resources from the ground, make products, create waste to landfill. Given that we are currently using the Earth's resources 1.7 times faster than they are being replenished[12], our growing populations, the environmental and social impacts mentioned earlier in this Paper plus increased demand for products means that the linear economy is simply unsustainable.

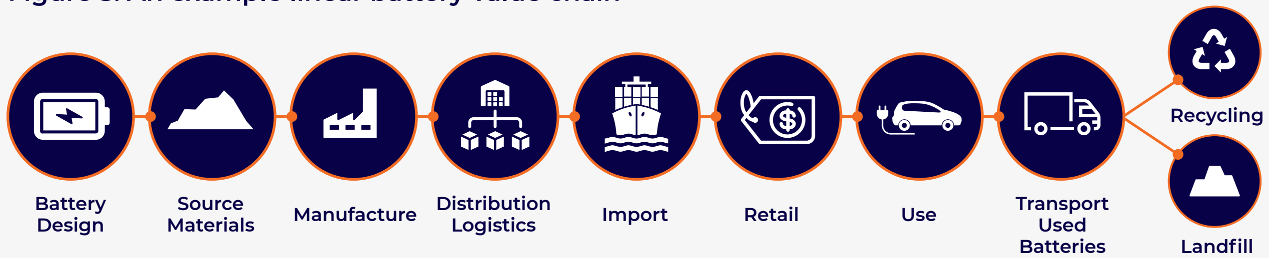
Figure 4: Linear Economy[13]



The linear battery value chain

Figure 5 below provides an example lithium-ion battery value chain. In a typical linear model (business as usual), products end up in landfill, often a cheap alternative to recycling.

Figure 5: An example linear battery value chain



[12] Ecological Footprint Explorer: http://data.footprintnetwork.org/#/
[13] Source: https://www.mfe.govt.nz/waste/circular-economy

Key materials in lithium-ion batteries

Lithium

Lithium, also known as 'white gold', is used as an electrolyte in lithium-ion batteries. Lithium mining, seen as a source of strategic advantage in producer countries from Australia[14] to the 'Lithium Triangle' of Argentina, Chile and Bolivia. In Bolivia[15], where all natural resources have been nationalised, lithium mining has caused water shortages impacting local farmers, and toxic spills. A 2016 toxic chemical leak from the Ganzizhou Rongda lithium mine in the Tibetan plateau damaged the local ecosystem, with dead fish and reportedly, cow and yak carcasses floating downstream, dead from drinking contaminated water[16].

The price of lithium has been climbing and is currently over $12,000 per tonne. However, because lithium is a small fraction of the makeup of a lithium-ion battery (1-2%) the high price of lithium is not expected to significantly impact battery prices. Although production is projected to increase ahead of demand, lithium supply is expected to remain tight as demand continues to grow. Price forecasts suggest that the cost of lithium will drop from recent peaks but is expected to remain high. As mentioned above, lithium is 100% recyclable, but uneconomic to recycle.

Cobalt

Mostly retrieved as a by-product from copper and nickel production, cobalt is often used as a 'safe', stable cathode material in lithium-ion batteries.

Sometimes called the 'blood diamond of batteries' from a conflict supply chain, cobalt is regarded as the most strategic and highest value material in the makeup of batteries. The global market consumes in the order of 110,000 tonnes annually.[18] Supplies of cobalt are dominated internationally by the Democratic Republic of Congo (DRC) where unregulated and dangerous mining takes place, often by children. Despite the 2017 Responsible Cobalt Initiative, long term security of supply, environmental pollution and human rights violations are noted as ongoing concerns.[19] While it is recyclable, it is not routinely recovered at end-of-life. In addition, cobalt tracks copper and nickel prices which can be too volatile to attract investment in safer production. The impact of the high price of cobalt and uncertainties about its supply have led to two key responses by the industry: moving to battery designs that use less cobalt and seeking to recover cobalt from used batteries. Tesla, for example has stated that no cobalt will be used in the next generation of batteries.[20]

Image: Hundreds of trucks drilling under the once-pristine Bolivian salt lake Salar de Uyuni in the quest for lithium[17]

Image: Unregulated 'artisanal' mining of cobalt in the DRC[21]

According to UNICEF and Amnesty International, around 40,000 children are involved in cobalt mining in DRC where they make only $1 – $2 USD per day. DRC's cobalt trade has been the target of criticism for nearly a decade, and the U.S. Labor Department lists Congolese cobalt as a product it has reason to think is produced by child labor. More troubling, cobalt demand has tripled in the past five years and is projected to at least double again by 2020.

Source: Union of Concerned Scientists – Science for a healthy planet and safer world
https://blog.ucsusa.org/josh-goldman/electric-vehicles-batteries-cobalt-and-rare-earth-metals

[14] https://www.csiro.au/~/media/EF/Files/Lithium-battery-recycling-in-Australia.PDF?la=en&hash=924B789725A3B3319BB40FDA20F416EB2FA4F320
[15] https://www.smh.com.au/world/lithium-bolivia-20170523-gwb8me.html
[16] https://www.wired.co.uk/article/lithium-batteries-environment-impact
[17] https://www.smh.com.au/world/lithium-bolivia-20170523-gwb8me.html Photo: Matjaz Krivic, The Sydney Morning Herald
[18] https://investingnews.com/daily/resource-investing/critical-metals-investing/cobalt-investing/top-cobalt-producing-countries-congo-china-canada-russia-australia/
[19] https://www.bloomberg.com/graphics/2018-cobalt-batteries/
[20] Musk, E: Retrieved from Twitter: https://twitter.com/elonmusk/status/1006968985760366592?lang=en
[21] Source: Washington Post, September 30th 2016 – The Cobalt Pipeline Story https://www.washingtonpost.com/graphics/business/batteries/congo-cobalt-mining-for-lithium-ion-battery/?noredirect=on Story by Todd.c. Frankel, Photo: Michael Robinson Chavez, Video editing: Jorge Ribas, Washington Post

current state of play: our linear system continued

Key materials in lithium-ion batteries continued

Graphite

Graphite is the commonly used material for the anode in lithium-ion batteries.

EVs can have in the order of 50kg of graphite in each battery pack. 75% of flake graphite is mined in China. There are concerns over environmental and labour practices, which has China's graphite industry under scrutiny – Chinese mines have even been shut down due to a "government crack down on pollution".[22]

The US, Europe, Japan and South Korea are almost entirely dependent on imported graphite; therefore, the US and the EU have declared graphite a supply-critical mineral. Very little recycling of graphite takes place, and there are almost no substitutes for the material. This has led to an increase in the price of graphite of over 40% in the last 6 months.[23]

One forecast is that the battery anode market for graphite (natural and synthetic) will at least triple in size from 80,000 tonnes in 2015 to at least 250,000 tonnes by the end of 2020.[24]

Image[22]: Graphite miner

Retail & uses of large batteries in New Zealand

Unless sold for network, home or industrial energy storage systems, the retail of batteries takes place when an EV is sold. Given the clear majority of EVs in New Zealand are imported second-hand by a number of organisations (approx. 70% using 2018 import data), this complexity provides a challenge when considering chain of custody issues as batteries move from EVs to second or third life uses.

In New Zealand, large batteries are used in the following broad applications:

- Hybrid, plug-in hybrid and battery EVs
- Stationary storage for local use (such as storage of solar power and for off-grid systems)
- Stationary storage for utilities
- Stationary storage for household use
- Buffer units for fast charging stations
- Industrial applications (such as cellphone towers or data centres)

There are also a range of potential emerging uses. For example, technology start-ups such as Kitty Hawk and Zunum are investing in electric planes, and ships are using large battery power to manoeuvre into port to reduce local emissions.

[22] http://www.energystoragejournal.com/2019/02/21/graphite-production-to-move-west-as-china-supply-chain-to-halve/
[23] https://investorintel.com/sectors/technology-metals/technology-metals-intel/northern-graphite-becoming-an-important-market-player/
[24] http://www.visualcapitalist.com/critical-ingredients-fuel-battery-boom/

Stationary Storage

Stationary storage applications are expected to increase significantly worldwide. Some forecasts suggest that the stationary storage market will grow from approximately U$4 billion in 2017 to US$35 billion by 2030.[25] This is being driven by a shift towards renewable energy generation like wind and solar that requires storage to overcome the disconnect between when power is being generated and when it is being used. Manufacturing costs are expected to continue to fall due to technical advances, economies of scale and efficiencies throughout the supply chain. Distribution costs have the potential to fall if these technologies are integrated and leveraged. Energy companies such as Vector are also installing stationary storage to manage peak loads within networks and to provide backup power in the event of disruption of supply. Finally, a further benefit of the use of stationary energy storage solutions is that it offers a cost-effective alternative to traditional energy infrastructure.

Distributed energy

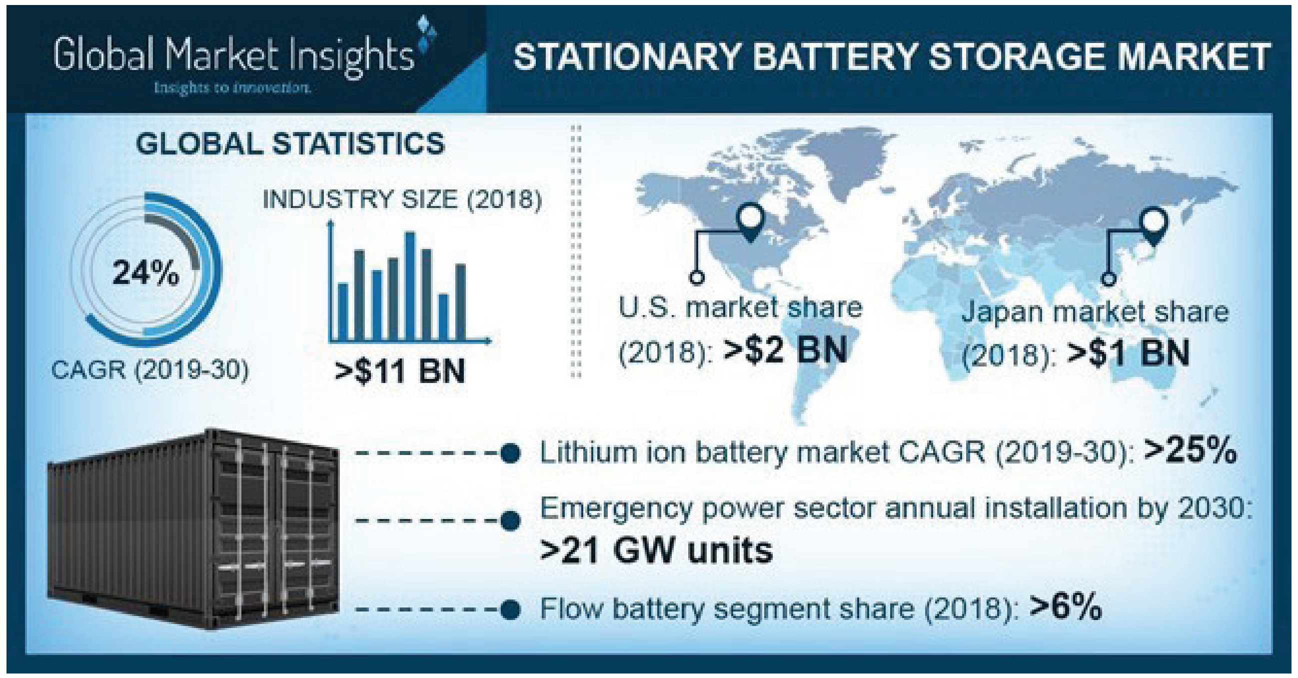
Distributed energy generation and storage refers to systems where electricity is generated and/or stored closer to the point of demand, such as a household with a solar and battery system, or an industrial facility with a wind turbine powering their manufacturing facility. Distributed energy systems can use new or second-life EV batteries as a source of energy during peak demand. Energy companies refer to this as peak shaving.

The uptake of distributed energy systems will take place within a wider context of potential changes to the energy sector as a whole. It is likely that the changes afforded by technology and changing demand profiles will see distributed systems play a larger role in the future.

Applications: Utility and Industrial

There is over 20 MWh of network utility and industrial large battery storage capacity installed or due to come on-line in the near future in New Zealand. Two recent examples of large scale battery storage also used for industrial applications totalling 5MWh are: the Glen Innes substation established by Vector (see case study below), and a second by Mercury Energy in South Auckland, both using Tesla Powerpacks.

Figure 6: Growth of the Stationary Storage Market[26]



[25] https://www.gminsights.com/pressrelease/stationary-battery-storage-market
[26] https://www.prnewswire.com/news-releases/stationary-battery-storage-market-worth-170bn-by-2030-global-market-insights-inc-300803606.html

current state of play: our linear system continued

CASE STUDY:

Vector Glen Innes substation

In 2016, the then Minister of Energy and Resources officially opened Vector's renovated Glen Innes substation, home to Asia Pacific's first grid scale Tesla Powerpack battery storage system to be integrated into a public electricity network. With a storage capacity of 1MW/2.3MWh - the equivalent to powering 450 average homes for 2.3 hours - Tesla Powerpack allows Vector to continue to provide a secure, reliable power supply and defer a conventional upgrade to the substation. This move represented a radical transformation in how Vector manages its electricity network and responds to the need for innovative infrastructure development to support growing communities.

vector

Applications: Household

In household applications, batteries typically support solar photo-voltaic (PV) systems to optimise solar self-consumption, meaning a household consumes most of the solar it generates and only exports a small amount to the grid.

The number of domestic battery storage units installed is currently small with approximately 1-1.5MWh installed per year, however there is potential for growth particularly if adoption of standalone rooftop solar was incentivised by regulation, or the economic case was made more attractive through cheaper storage. This could be provided through new or second-life batteries. There are an estimated 15,000 households in NZ that are generating their own electricity[27], however there is no official data on what proportion of these also have battery storage.

End-of-life collection & disposal

Lead-acid battery recycling is effective for several reasons:

- Standard design and disassembly protocols
- A single chemistry type
- Lead-acid battery recycling generates revenue ie. currently the value exceeds recycling costs
- No need for segregation, plus
- Regulation making it illegal to dispose to landfill.

Unfortunately, each of these factors varies for lithium-ion and other battery types, making them harder to manage at end-of-life. **Notably, at the time of publication, there are no large-scale pre-processing, processing or full recycling facilities for large lithium-ion batteries in New Zealand** although this is being investigated by several organisations. Pre-processing plants break up batteries to be safe for transport by e.g. discharging them or removing cells. The nearest pre-processing facility to New Zealand is Envirostream in Victoria, Australia, which undertakes pre-processing and processing to produce mixed metal dust used in other batteries.

[27] https://www.canstarblue.co.nz/energy/electricity-providers/battery-storage/

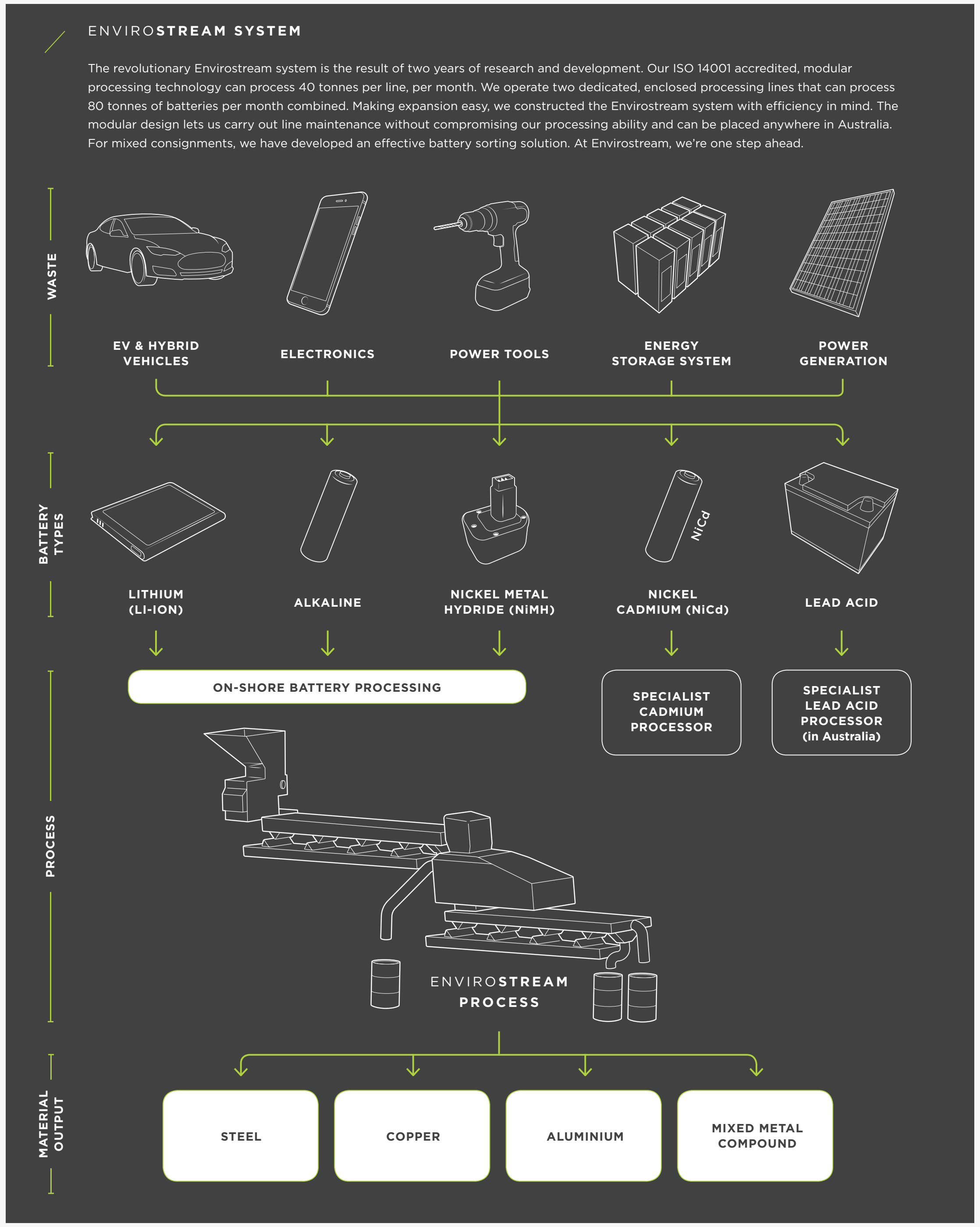
CASE STUDY: Envirostream

ENVIROSTREAM
Innovative Resource Recovery

Around 18,000 tonnes of batteries require disposal each year in Australia and over 95% end up in landfill posing a significant environmental risk. As Australia's first and currently only lithium battery processor, Envirostream is committed to reducing batteries in landfill by recovering the materials onshore and sending them back into the manufacturing sector to be made into new products, including cathode material for new batteries.

This is a true circular business model designed to challenge the last decade of expensive battery recycling that has led to only a 5% recovery rate. Based on over two years' continuous R&D, Envirostream has constructed a commercially viable battery recycling plant that can recover around 95% of the material including the copper, steel, aluminium and a graphene metal oxide which is used as an input material in cathode manufacture.

It's not only Envirostream's material recovery that is circular, the economics are too. By utilising revenue from the recovery of materials, the front-end costs can be reduced to challenge landfill as the cheapest option, in some cases removing the cost to recycle batteries in Australia altogether.



End-of-life EV batteries: Volumes and Approaches

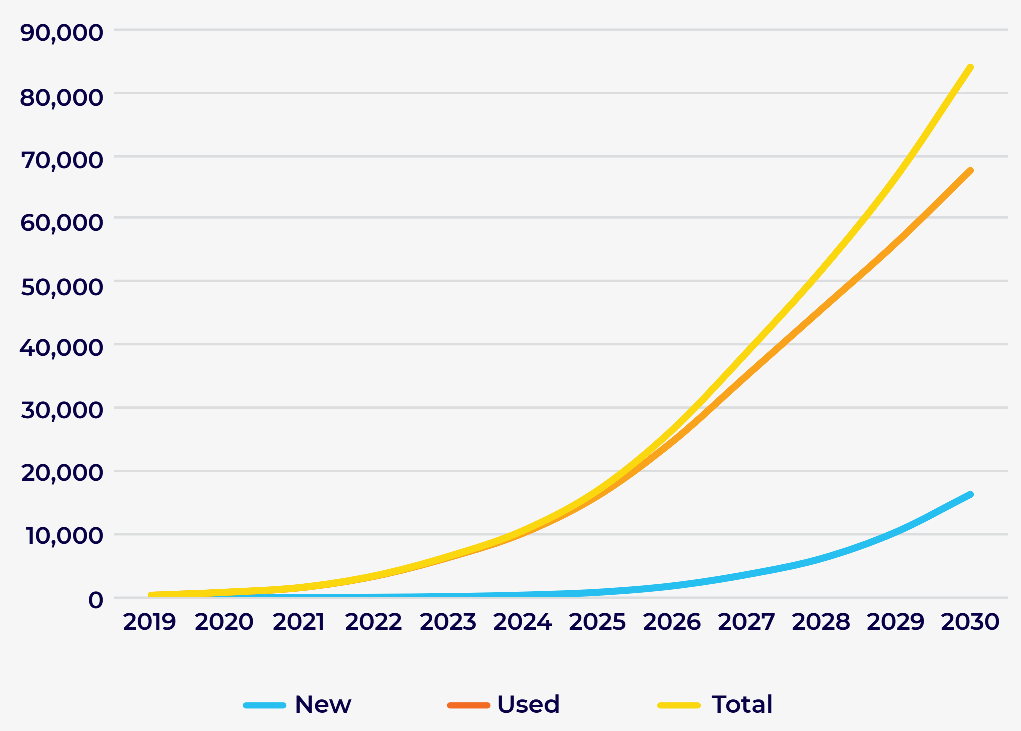
To date, end-of-life electric vehicles have been only a minor issue for New Zealand due to the small numbers involved. Since 2014 only 181 EVs have been scrapped from the fleet in New Zealand although the numbers are rising with 49 scrapped in 2018, and 81 so far in 2019. Over half (101) of the EVs scrapped are Nissan Leafs, with these numbers also rising.[28] It should be noted that the numbers of vehicles scrapped is not the same as the number of end-of-life batteries, as when battery packs reach the end of their life (estimated at 10 - 15 years) they may be replaced in the vehicle, which continues to operate. There is no data available on the numbers of vehicles that have had battery packs replaced.

Modelling by Eunomia commissioned by Vector suggests between 500 and 1,000 EV batteries coming to the end-of-life by 2020 rising to between 9,000 and 17,000 by 2025 and 30,000 to 84,000 by 2030. Because stationary storage applications are still a small (but growing) part of the market and have longer lifespans, the numbers of batteries reaching end-of-life from such uses is expected to remain relatively small between now and 2030.

Assumptions detailed in the Technical Addendum suggest that by 2030 there could be nearly 84,000 end-of-life EV battery packs requiring management each year. The projection is shown in the chart below.

The chart illustrates the potentially steep trajectory that is likely to be facing the industry if the adoption of EVs takes place at forecast rates. The influence of the used car market on the flow of end-of-life EVs is also apparent from the above projection.

Figure 7: Estimates of end-of-life EV Battery Packs 2019-2030



In addition to the above projection Eunomia also modelled a number of alternative scenarios with some varying assumptions including the government targets not being met, a higher proportion of new vehicles and the impact of an assumed longer life for EV batteries. These projections are provided in the Technical Addendum.

In brief, if the adoption of EVs follows a similar profile to global forecasts this would suggest between 880 batteries coming to the end of life by 2020 rising to 9,500 by 2025 and 30,000 per annum by 2030.

In the other alternative scenario, if the vehicle fleet composition targets are met, but the fleet is assumed to have a higher proportion (50%) of NZ new vehicles in its makeup, and a longer average battery life of 12 years is assumed, this would reduce the total number of end of life batteries to 54,000 per annum by 2030.

The approaches taken by manufacturers to end-of-life vary. Two manufacturers offer a take back service for end-of-life vehicles, with one offering a $100 bounty for people to bring them in. This applies to both new and used vehicles imported to New Zealand. The batteries are consolidated and then shipped via a local recycler to South Korea for processing. Other manufacturers have a policy of shipping the batteries back to their factory for disassembly and reuse or recycling of the constituent parts. Tesla, for example, operates a battery recycling programme together with Umicore (pyrometallurgy) in Europe (Tesla, 2011). This programme applies to New Zealand customers but logistics are a challenge: battery shipments need to have proper paperwork complying with the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.

CASE STUDY: Toyota

Toyota has a global commitment to resource efficiency and the recycling of vehicle parts, such as Toyota and Lexus hybrid batteries. This includes investing in battery second-life applications and new recycling facilities.

In New Zealand, Toyota takes a value chain approach to environmental impacts, demonstrated through its nationwide collection of hybrid batteries that have reached their end of their life. The collection takes place through Toyota Stores, and includes a $100 bounty for batteries returned from vehicle dismantlers. Toyota New Zealand (TNZ) corporate and dealer operations and premises are independently audited and certified to Enviro-Mark Diamond or ISO 14001 certification, to ensure customer confidence in Toyota's environmental management processes. Technicians are trained in the safe removal, handling, transport and storage of batteries.

TNZ has partnered with Upcycle Limited to strip the metals and plastics (which are diverted to local recycling systems) and send the cells to Kobar Limited in South Korea (the closest of the few global facilities equipped to recycle cells) for material recovery and re-use. Both Upcycle and Kobar are ISO 14001 certified.

Toyota New Zealand is committed to sustainable business practices, and supportive of the development of battery re-purposing and material re-use in New Zealand.

TOYOTA

[28] https://www.transport.govt.nz/resources/vehicle-fleet-statistics/monthly-electric-and-hybrid-light-vehicle-registrations-2/

current state of play: our linear system continued

A small number of manufacturers will accept New Zealand new battery packs back, but not used imports. The remaining manufacturers do not yet have end-of-life systems in place, and given the low volumes to-date, this has not yet been a vital issue. However, there is anecdotal evidence that small-scale stockpiling is starting to take place in New Zealand and there is a related need for information around safe storage. The approach to end-of-life systems in New Zealand also depends on the global approach of the manufacturer. Where repurposing is seen as a key step, local uses are more likely to be prioritised.

No on-shore solution… yet

The battery recycling industry currently lacks the scale required to make full recycling economically feasible (King, et al., 2018). Pre-processing, or initial recycling, is a more feasible model for New Zealand. Until any onshore pre-processing facility is built in New Zealand, lithium battery cells can either be stockpiled or shipped to e.g. Envirostream in Australia, currently the only facility that offers pre-processing and processing in this region. Envirostream claims it recovers 95% of the battery waste stream. The batteries are sorted by chemistry then are discharged, disassembled and shredded (pre-processing) then further granulated into a 'dust fraction' (processing). The dust containing aluminium, copper and steel is recycled in Australia but the cathodic fraction containing lithium, cobalt, manganese and nickel is currently exported to Korea for hydrometallurgical processing and recovery of the metals for reuse in new batteries. Although in the future this may take place locally, currently the value is realized by other countries. Plastics are sold for reuse.

In New Zealand, local recyclers are investigating options for pre-processing of end-of-life batteries onshore.[29] Onshore pre-processing or processing will come down to economics i.e. the level of cost involved in making end-of-life batteries safe for overseas transport, and whether this makes local pre-processing relatively economic. Discussions with potential service providers indicate these services would create additional employment.

Current estimates indicate that to procure and install a pre-processing plant that could handle up to 40 tonnes of batteries per month, would cost between $180,000-$220,000 NZD plus labour; it is likely that new jobs would be created. An additional processing plant to shred materials to make mixed metal dust would cost approximately a further $475,000 NZD plus labour. Volumes of large batteries would have to be high enough to ensure that this was viable for plant managers.

The possible production of lower-value battery chemistries (e.g. without cobalt) will have a negative impact on the recyclability of the batteries due to the lower-value battery chemistries at end-of-life. It is uncertain whether the recycling of lithium batteries will remain economic with changes in battery composition.

However, there is likely to be high demand internationally for recovery facilities to pre-process batteries (from e.g. the Pacific Islands) which will lead to economies of scale for the major pre-processing, and potentially processing facilities.

With no large-scale on-shore pre-processing or processing of large lithium-ion batteries, in the immediate term they should be safely stored before being shipped overseas (e.g. Australia) to be pre-processed.

The wrecker's yard

Up to this point only small numbers of end-of-life batteries have ended up with auto-wreckers. These are mainly from Hybrid Electric Vehicles (HEVs). There is a second-hand market for some of the newer batteries from the wreckers (possibly for second life applications), and where there is a value these are sold. If there is no value to the battery, car wreckers or owners could simply leave the batteries in the crushed vehicles which are sent to the metal processors for shredding. Anecdotally, there has been at least one major fire at a car shredding plant which is suspected to be from a battery, but it is not known how many vehicles may have been sent through the process without the batteries being removed, and without incident. There is concern in the industry that if there is no value in the battery (it is time consuming to remove) or if there is a cost for disposal, then auto dismantlers will simply leave the batteries in vehicles even if this is not permitted.[30]

Electrical and electronic waste (E-waste)

E-waste refers to all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use (Step Initiative 2014).

Anything with a battery and circuitry (which usually contains gold) is considered E-waste, and with the increase of lithium-ion batteries in everything from toys to power tools, mobile phones, computers and scooters, small lithium-ion batteries are a significant current challenge. In 2016 alone the world generated 44.7 million metric tonnes of E-waste, equal in weight to almost 4,500 Eiffel Towers. At the time of writing, one of the few developed countries to have no E-waste laws, New Zealand is one of the worst E-waste offenders globally, with 20kg of E-waste generated per person per year, projected to reach 27kg by 2030.

It is currently assumed that most E-waste in New Zealand is landfilled: a shocking waste of resources. In a 2017 UN report Global E-Waste Monitor[31], New Zealand was 'named and shamed' for its official E-waste collection rate of… 0%.

End-of-life large lithium-ion batteries are of course considered E-waste and the New Zealand Government aims to tackle these by naming them a 'priority product'. This will enable them to use the lever of product stewardship and supporting regulation to ensure the batteries are collected and recycled.

It is only now that batteries from EVs imported to New Zealand are coming to the end of their use. (see Technical Addendum for data). This means there is a window of opportunity to get ahead of the challenge for large batteries, before they become a legacy issue.

Summary: why the linear economy doesn't work

In addition to a number of system barriers to improvement, there are three key reasons why the linear economy for lithium-ion batteries doesn't work for our environment or society over the long term:

1. Social and environmental impacts of raw materials extraction and processing
   - Lithium and cobalt extraction have high environmental and social impacts
2. A failure to maximise the material and financial value of both batteries and materials
   - Environmental and economic opportunity cost
3. Environmental, safety and health hazards of current disposal methods
   - Loss of resources
   - Piercing batteries can lead to thermal runaway (fires)
   - Toxic and hazardous compounds
   - A growing problem of E-waste

[29] Communication with John Evans, ITERECYCLA, Tim Findlay, Remarkit, and Vernon Sutton, Upcycle.

[30] Communication with Warren Strong, Strong for Honda, 11-09-2018

[31] https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx

the circular economy

What is a circular economy?

The New Zealand Government has identified a 'circular economy' approach as an important principle for addressing resource and waste issues for our country's future. The Ministry for the Environment defines the circular economy as follows:

A circular economy is an alternative to the traditional linear economy in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.[32]

New Zealand's Circular Economy Accelerator (CEA) states:

A circular economy is restorative by design. It is underpinned by the use of renewable energy. It is a sustainable, viable and low carbon alternative to the dominant 'take-make-waste' linear model.[33]

3+3 principles for a circular economy

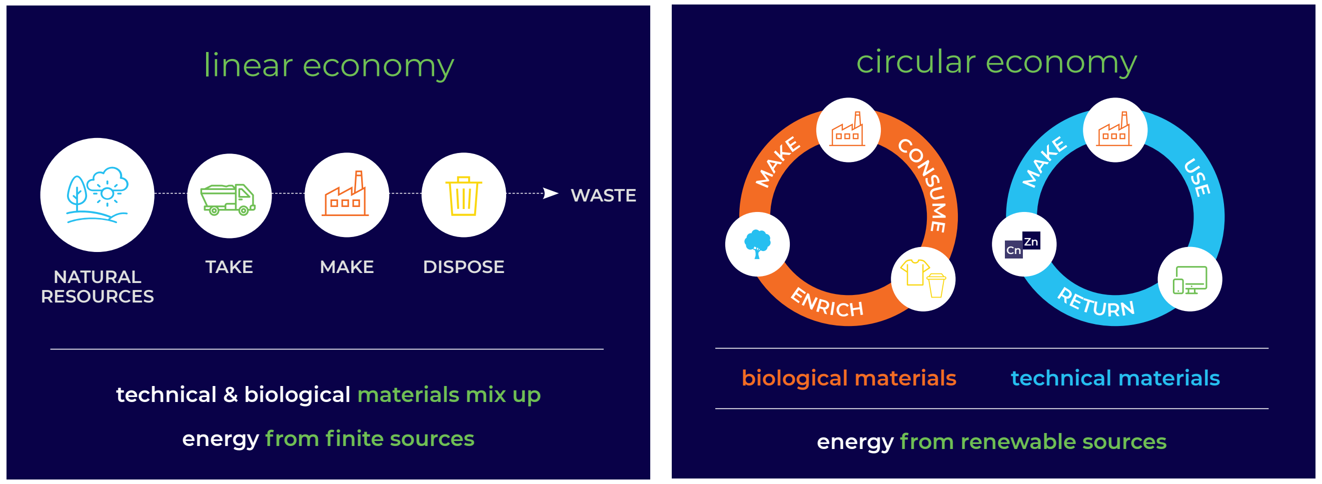
Three key principles of the circular economy are:

1. Design out waste and pollution
2. Keep products and materials in use
3. Regenerate natural systems

A further three principles have been proposed by Alexandre Lemille for the 'Circular Economy 2.0'[34] to ensure our circular future is also socially just, and have been summarised for this Paper:

4. Equality is integral to all services (equality makes business sense; services should be designed to address the needs of all)
5. Ensure access to various means of exchanges, not just currency (to enable more people to access services)
6. Use human labour as a force for regeneration (employing people to regenerate the biosphere).

Figure 8: A linear vs a circular economy

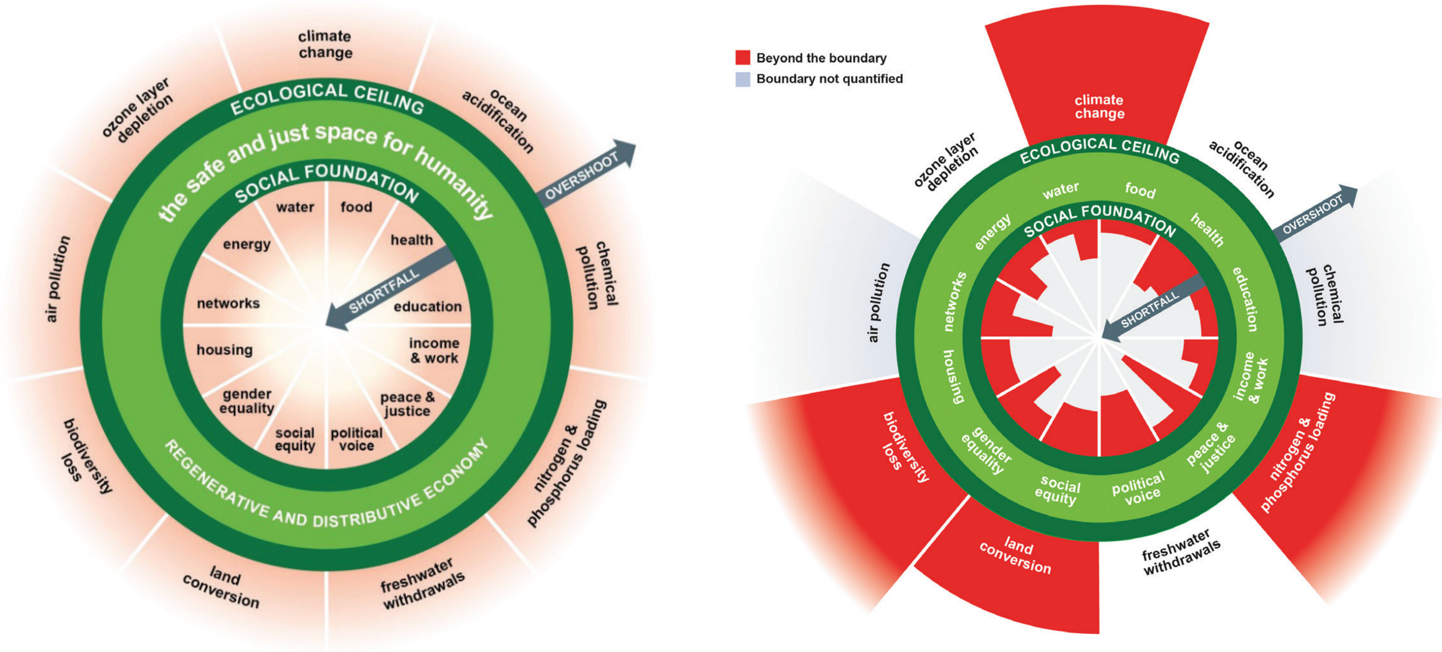


[32] https://www.mfe.govt.nz/waste/circular-economy
[33] Complementary concepts of living within Earth's limits include: blue economy, performance economy, biomimicry, natural capitalism, industrial ecology, regenerative design, zero waste, cradle to cradle™, doughnut economics (Kate Raworth). These concepts are reflected in the the Government's Living Standards Framework, the 2019 Wellbeing Budget and its aim of just transition (fair, equitable and inclusive) to a low emissions economy.
[34] https://www.alexandrelemille.com/circular-economy#!

Circular economy and the Doughnut

Economist Kate Raworth has presented planetary and social boundaries in an iconic 'Doughnut' diagram, which sets the context (a safe and just space for humanity) in which a circular economy should exist. For Raworth, the economy should be 'regenerative' i.e. regenerate our natural systems and 'distributive' i.e. should ensure that energy, production, communications, technology and knowledge are more equitably distributed. Unfortunately, we are currently overshooting many of our planetary boundaries and have a shortfall in our social boundaries. The World Economic Forum has described moving into the Doughnut's safe and just space as "the challenge of our century".[35]

Figure 9: The Doughnut of social and planetary boundaries (2017)[36]



[35] https://www.weforum.org/agenda/2018/01/how-to-do-business-with-doughnuts/
[36] https://www.kateraworth.com/doughnut/

the circular economy continued

Ōhanga Āmiomio: the circular economy in Aotearoa

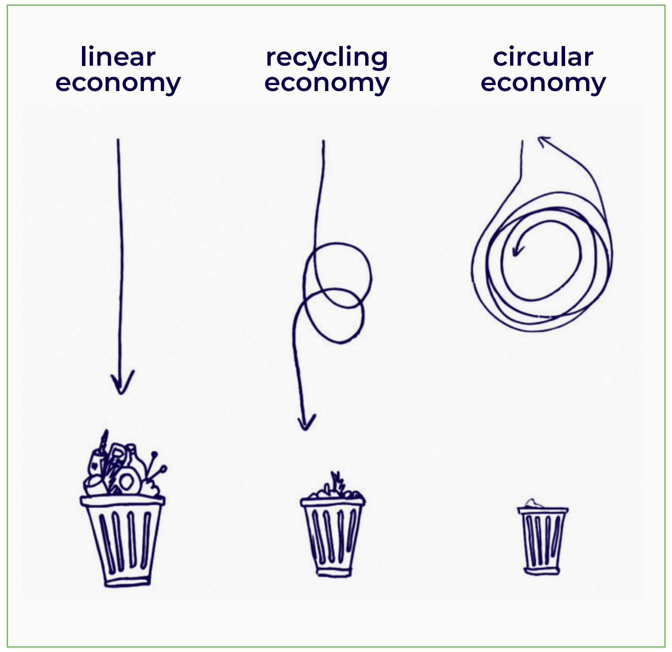
Globally, the circular economy is increasingly seen as the driver to help us reach the United Nations Sustainable Development Goals (particularly Goal 12, Responsible Consumption and Production).

Here in Aotearoa, New Zealand, there is a growing recognition of the role our indigenous Māori and Pacific Island culture can and should play in the emerging circular economy. In the tradition of Aotearoa's tangata whenua (the Māori people), Papatūānuku is the land and ancestral figure who gives birth to all things, including people. Trees, birds and people are born from the land, which in turn nourishes them.

This concept of ōhanga āmiomio, the circular economy, reflects the Kaupapa Māori (knowledge, skills and values of Māori society) and includes the concepts of mātauranga (knowledge and expertise), kaitiakitanga (stewardship) - also one of Vector's sustainability principles - and whakapapa (a consideration of ancestry: human, terrestrial and spiritual).

Māori intergenerational thinking and respect for the natural environment will help the circular economy to take root and flourish in New Zealand.

Figure 10: Linear, recycling and circular economies[37]



A truly circular economy, where one industry's 'waste' is its own feedstock, or feedstock for another industry, requires **a massive system shift across every part of the value chain.** The circular economy requires six enabling factors[38]:

Six enabling factors

The circular economy is often mistaken for 'recycling on steroids', while in fact it is anything but this approach. Recycling can be seen as simply incentivising the current linear system of 'take, make, waste'.

[37] Source: Plan C – empowering circular futures
[38] In British Standard 8001:2017 Circular Economy, these are also known as the six principles of the Circular Economy: https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/BS8001-Circular-Economy/

Table 2: Circular Economy Enabling Factors

six circular economy enabling factors	definition
1 Systems thinking	Organisations take a holistic approach to understand how individual decisions and activities interact within the wider systems they are a part of e.g. our material, operational, financial, social and eco systems.
2 Innovation	Organisations continually innovate to create value by enabling the sustainable management of resources through the design of processes, products/services and business models.
3 Collaboration	Organisations collaborate internally and externally through formal and/or informal arrangements to create mutual value.
4 Value optimisation (retaining value)	Keeping products, components and materials at their highest value and utility at all times.
5 Transparency (open communication)	Organisations are transparent about decisions and activities that affect their ability to transition to a more circular and sustainable mode of operation and are willing to communicate these in a clear, accurate, timely, honest and complete manner.
6 Stewardship	Organisations manage the direct and indirect impacts of their decisions and activities within the wider systems they are part of. This can include product stewardship or Extended Producer Responsibility (EPR), where businesses take back their products to refurbish and resell.

A circular economy for large lithium-ion batteries

A circular economy for batteries is an economically viable battery value loop which aims to optimise the value of the raw materials, negate the environmental impact of batteries and does not push externalities onto those less able to deal with them. In other words, there is no option to dump batteries in a landfill which pollutes the environment and locks away valuable materials. In a truly circular future system, batteries would be redesigned for remanufacture or reuse, are collected and at end-of-life all materials are recovered and, as their material value is optimised (i.e. they are not downcycled), are reused in other batteries or products.

Instead of end-of-life landfill, recovery of end-of-use batteries for refurbishment or reuse is key for the transition to a circular economy. Materials selected for batteries would be able to be separated into benign biological materials (and used to regenerate nature) and technical materials which would be reused. Materials would be recovered at their highest value - i.e. with their 'value optimised' - at end of life.

Of course, the circular economy is not just about material flows. It is vital that the shiny, new value loops we create are, as Kate Raworth and Alexandre Lemille highlight: safe, just / equitable and accessible. This means a circular economy must work for those with few rights and little protection, particular those in developing economies. Consider the start of the supply chain for large batteries: people (often children) working in unregulated, 'artisanal' cobalt mines with no health and safety considerations.

the circular economy continued

While such labour conditions are of course unacceptable, systems thinking teaches us about unintended consequences: removing cobalt from batteries to 'de-risk' the supply chain will remove a valuable source of income from the Democratic Republic of Congo, one of the world's poorest and least stable countries. It will also reduce the material and financial value of a battery, potentially leading to the perverse outcome of less recycling.

Two solutions a circular economy offers are long-term value creation and transparent supply chain management.

Long-term value creation

Keeping materials flowing in biological and technical reuse loops will reduce the need for the extraction of new raw materials and will therefore impact raw material production across every industry. However, this will ensure we are operating within the earth's limits and will create new employment opportunities – e.g. in dismantling and reuse and supporting services such as reverse logistics. E-waste often ends up in developing countries where informal industries have sprung up to reuse and recycle.

As manufacturers reduce demand for raw materials from these countries, they can instead enable their transition to more service-based economies which are regulated for health, safety, fair wages etc. This requires considering value creation over the long-term. Enabling people to lift themselves out of poverty, by working in safe environments with decent pay and dignity, will create more disposable income - and demand for circular products.

Transparent supply chain management

Fourth Industrial Revolution technologies such as the blockchain, artificial intelligence and sensors can help digitally track products from raw materials through to manufacturing, use and end-of-life recycling or disposal. In a circular economy, with transparency a key 'enabling factor', coupled with increasing demand from customers for evidence of circular value optimisation and end-of-life management, it is likely that there will be greater pressure for battery manufacturers or retailers to provide data on the entire battery value chain.

This will change the balance of power in the supply chain, with manufacturers incentivised to treat workers better, and workers more able to complain about working conditions. Companies such as Everledger which supply the technologies that enable this will be well placed to grow with a circular economy.

The Responsible Cobalt Initiative (RCI)

The RCI was formed in 2016 by the Chinese Chamber of Commerce for Metals, Minerals & Chemicals (CCCMC) Importers & Exporters, with support from the Organisation for Economic Co-operation and Development (OECD). It aims to:

- Have downstream and upstream companies recognize and align their supply chain policies with the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas and the Chinese Due Diligence Guidelines for Responsible Mineral Supply Chains in order to increase transparency in the cobalt supply chain and improve supply chain governance.
- Promote cooperation with the Government of the Democratic Republic of the Congo, civil society, and affected local communities to take and/or support actions that address the risks and challenges in the cobalt supply chain.
- Develop a common communication strategy to communicate progress and results effectively to impacted communities, miners, and the public; to harmonize working objectives and plans with other stakeholders.

Source: http://www.respect.international/responsible-cobalt-initiative-rci/

Signals of Change

Throughout this Paper, we share some example case studies which we have identified as signals of change in our transition to a circular economy. These are summarised in Table 3 below and discussed in commercial terms later in this Paper.

Table 3: Signals of Change to a Circular Economy

	Characteristics of current linear system	Characteristics of future circular system	Signals of change
1	Social and environmental impacts of raw materials extraction and processing · Lithium and cobalt extraction have high environmental and social impacts	· Product stewardship / company take-back schemes with supporting reverse logistics · Battery redesign · New chemistries e.g. sodium aluminium · Materials recovery · New materials with positive environmental & social impact	· Tesla's take-back scheme (supporting reverse logistics still required) · Mint Innovation · Micro factories which provide pyrometallurgy services and can accept changing feedstock
2	A failure to maximise the material and financial value of both batteries and materials · Environmental and economic opportunity cost	Market options, policy and protocols for reuse, remanufacturing and recycling of used batteries: · Emergence of second and third life options · Remanufacture · Battery assessment centre · Clear guidance for trialling second life batteries on the electricity network · On-shore pre-processing in short-term · Price-point of second-life batteries below new batteries (otherwise can't compete)	· Relectrify, Australia · Vector to publish guidance to trial second life batteries on electricity network · ReCell, at the Argonne National Laboratory · At least one waste company in New Zealand is seeking investment in a pre-processing facility
3	Environmental, safety and health hazards of current disposal methods · Loss of valuable resources · Piercing batteries can lead to thermal runaway (fires) · A growing problem of E-waste	· Batteries designed to be modular · Easy to assess battery health (battery rating system?) · Safety guidance for use, transport and storage of used batteries · If required, safe to landfill at end-of-life	· The Battery Industry Group will be working with its member Fire & Emergency NZ to develop safety guidance for the use, transport and storage of used large lithium-ion batteries
4	Barriers to improvement: · Opening battery housing can nullify safety warrantees · Lack of regulation around transfer of ownership of batteries · Significant distance between where battery is manufactured and used · Companies that wish to recover and reuse strategically valuable materials (such as cobalt) will be incentivised to take batteries back and recycle them in-house rather than designing their batteries for second-life use and recycling by third parties.	System enablers: · Collaboration across battery value chain · Product stewardship scheme and supporting regulation Innovation: · New digital, supply chain and technical services to support circular economy including tracking chain of custody and providing high quality waste data, also additive manufacturing of new batteries or components near where battery will be used · New technologies e.g. hydrogen, bio-batteries or no longer any need for batteries as energy storage	System enablers: · The Battery Industry Group and their planned proposal for a product stewardship scheme for large batteries · EU considering regulation around transfer of ownership Innovation: · VicLink · Dynantis Aotearoa

transition to the circular economy

Given the significant environmental and economic impacts of the linear economy outlined above, we need to transition to a circular economy for batteries. Some transitional activities are already taking place, albeit in a piecemeal and ad hoc manner.

From business model to product

Below, we discuss opportunities to transition a circular economy for batteries and share examples of systemic challenges which must be addressed to ensure a successful transition.

How existing businesses transition to circular business models (such as products-as-a-service / leasing models) is a challenge and opportunity being faced across the world, and, here in New Zealand, is a particular focus of the Circular Economy Accelerator (CEA)[39].

Rather than starting with changing entire business models and processes, many businesses beginning the journey to a circular economy are often motivated by a particular issue (E-waste, plastic) and focus on the redesign of a product. To support product redesign, the Ellen MacArthur Foundation has published a Circular Design Guide and related resources[40]. In addition, best practice for product circularity is provided by certification by the Cradle to Cradle Product Innovation Institute[41].

The 9R model for products

A useful framework for reviewing products which we reference in the following section of this Paper is the '9R' model conceptualised by Potting et al (2017)[42]. The 9R model helps to show the journey from linear to circular economy for products.

Of the three key principles of the circular economy, the first two are addressed in the 9R model:

1. Design out waste and pollution (R0 to R2: smarter product use and manufacture)
2. Keep products and materials in use (R3 to R7: extend lifespan of product and its parts).

The diagram (figure 11) describes the 9R model.

[39] A Sustainable Business Network initiative, disclaimer: author is the Chair of the CEA Advisory Board
[40] https://www.circulardesignguide.com/
[41] https://www.c2ccertified.org/
[42] https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf

Figure 11: The 9R Framework adapted from Potting et al. (2017)[43]

Circular Economy ↑	Smarter Product Use and Manufacture	R0 Refuse	Make products redundant by choosing circular products that possess some or all of the qualities of the 9R's
		R1 Rethink	Make product use more intensive (e.g. by sharing product)
		R2 Reduce	Increase efficiency in product manufacturing or use by consuming fewer natural resources and materials
	Extend Lifespan of product and its parts	R3 Reuse	Reuse by another consumer a discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective products so it can be used with its original function. Generally has not been tested and may not include a warranty
		R5 Refurbish	Restore a product and bring it up-to-date or restore functionality. Includes testing for defects prior to resell and usually includes a warranty
		R6 Remanufacture	Rebuilding of a product to original specifications by exchanging worn parts with repaired, used or new parts. The product or machine should perform as a new one and includes a warranty
		R7 Repurpose	Use discarded products or its parts in a new product with a different function
	Useful application of materials	R8 Recyclable Resource Recovery	Process materials to obtain the same (high grade) or lower grade quality
Linear Economy		R9 Recover	(1) Recover or 'cannibalise' from damaged products for the reuse of parts in order to facilitate remanufacturing or refurbishing activities. (2) Incineration of material for energy recovery

9R Applied to Batteries

As per figure 11 above, Stages R0 to R2 are in the control of battery manufacturers and the rush to, for example, eliminate the need for cobalt, suggests that manufacturers are very focussed on R2: increased efficiency and consuming fewer natural resources. There are examples of businesses within New Zealand who are seeking straight reuse (R3) of EV batteries with no modification to the battery housing or cells – a 'plug and play' solution.

Some used batteries may have reduced performance due to a small number of weak or faulty cells, rather than the whole battery being degraded. Repair and maintenance of large lithium-ion batteries (R4) could involve a (potentially high risk) replacement of battery cells, a new innovation called 'battery **rejuvenation**' or an adjustment of / by the Battery Management System (BMS).

[43] Source: www.circulareconomyasia.org

Battery rejuvenation (where a cathode is rejuvenated by immersion in a soft chemical solution) is still at an early stage of maturity. This is "more cost effective that battery recycling, as it prevents the cathode from needing to be rebuilt and retains materials in their original form" (King et al, 2018[44], Gies 2015[45]). BMS circuitry and software manages real-time control of each battery cell, communicates with external devices, manages State of Charge (SOC) calculation, measures temperature and voltage, etc. The choice of BMS often determines the quality and lifespan of the final battery pack.

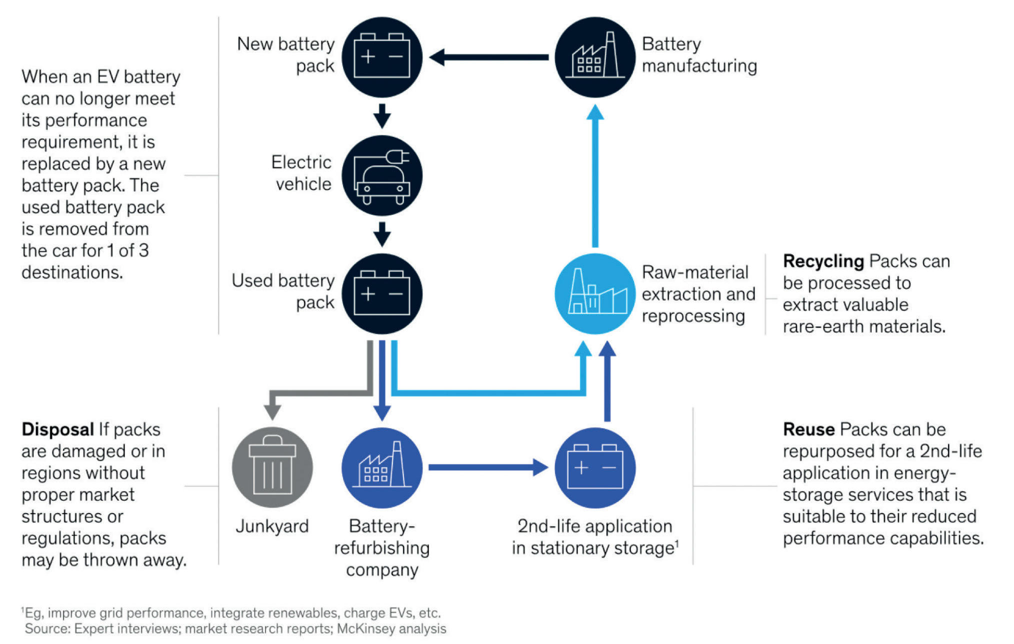
The key transition opportunities identified for New Zealand are the stages from refurbishment (R5) to material recovery (R9) and are described in the following section.

Transition 1: 'Battery karma' - giving batteries a second life

Repurposing batteries (R7) simply means reusing them in another application. Large EV batteries may have in the order of 70% - 80% of their capacity remaining when they reach the end of their useful life in a vehicle after 10-15 years.[46] This presents a significant opportunity to repurpose EV batteries in other applications[47] that do not require such high levels of 'cycling', or capacity. These applications include:

- Replacing less-efficient assets such as old combined-cycle gas turbines[48]
- Use in stationary storage: second-life batteries could have a further 5-10 years of life in a stationary storage application
- Use in mobile applications: these applications, for example in boats, are also being developed by companies such as Renault

Figure 12: Example EV battery lifecycle. Source: McKinsey & Company[45]



[44] https://www.csiro.au/~/media/EF/Files/Lithium-battery-recycling-in-Australia.pdf?la=en&hash=924B789725A3B3319BB40FDA20F416EB2FA4F320
[45] https://www.nature.com/articles/526S100a.pdf
[46] https://www.energywise.govt.nz/assets/Resources-Energywise/on-the-road/ev-battery-report.pdf
[47] https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire https://www.telegraph.co.uk/cars/advice/happens-used-lithium-ion-battery-packs-electric-cars/
[48] https://www.mckinsey.com/Industries/Automotive-and-Assembly/Our-Insights/Second-life-EV-batteries-The-newest-value-pool-in-energy-storage?cid=other-eml-alt-mip-mck&hlkid=5cb696dd6a9a488497d5062cbd91f206&hctky=10410888&hdpid=1d168e3c-8cf9-4d2e-928b-4e4dc441ffdc

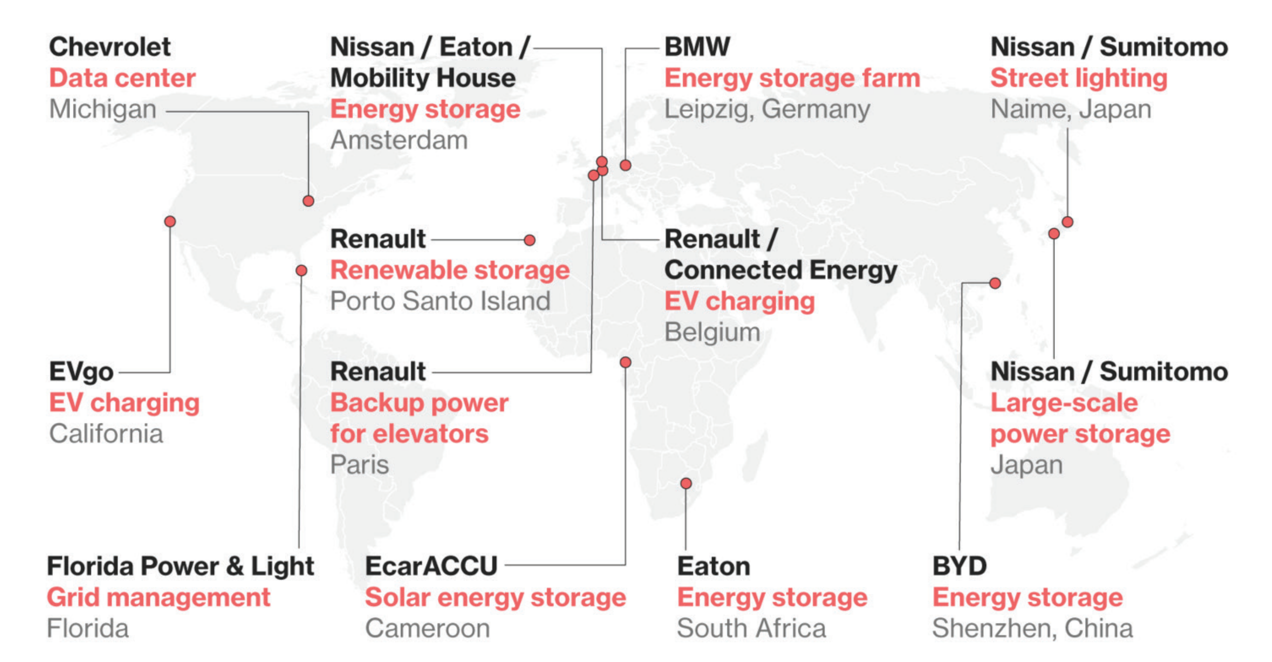
There is rising demand for energy storage systems as there is a shift to renewables which only supply power at certain times (and not necessarily when it is needed). Repurposing is one way in which demand for these systems could be met as well as finding a home for a potential growing stockpile of end-of-life EV batteries. Examples include:[49]

- Buffers for multi-unit fast charging stations
- Domestic energy storage (e.g. for solar energy)
- Management of network and peak loads
- Emergency back-up power
- Mobile applications such as caravans and forklift trucks

Reuse may become more common as car manufacturers (also known as Original Equipment Manufacturers or OEMs)[50] shift to a battery leasing model to retain the material value of a battery.

A range of automakers are working on reuse applications. By taking the product back and repurposing it, they can, in effect, sell it twice.[51] There are many instances worldwide where batteries are being repurposed.[52] Examples include: Nissan UK offering an energy storage product that utilises re-used Nissan Leaf batteries[53], the Johan Cruyff ArenA in Amsterdam uses 63 used and 85 new EV battery packs, which stores the energy from 4,200 solar panels on the stadium roof. In partnership with Eaton, used Nissan Leaf batteries are also used to power The Reborn Lights in Japan. BMW, in cooperation with Bosch built a 2.8 MW energy storage facility in Germany utilising re-used EV batteries, see figure 13 below.[54]

Figure 13: Where electric vehicle batteries are being used and tested for new roles. Source: Bloomberg, company filings



[49] Natkunarajah et al, Scenarios for the return of lithium-ion batteries out of electric cars for recycling. Procedia CIRP 29 (2015), 740-745
[50] OEMs make equipment from component parts bought from other organisations
[51] Automakers involved in developing repurposing include General Motors Co., BMW AG, Toyota, Renault-Nissan, Volvo and Porsche. https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire
[52] https://www.idtechex.com/research/reports/second-life-electric-vehicle-batteries-2019-2029-000626.asp
[53] https://www.cips.org/supply-management/news/2017/may/nissan-launches-home-battery-in-the-uk-to-rival-teslas-powerwall/
[54] https://electrek.co/2016/09/22/bmw-bosch-energy-storage-facility-built-from-batteries-from-over-100-electric-cars/

transition to the circular economy

continued

CASE STUDY:

BMW

BMW Group New Zealand is an active member of the Battery Leaders Group, seeking circular solutions and end-of-life management for all large lithium-ion batteries.

In Europe, the BMW Group, Northvolt and Umicore have formed a joint technology consortium in order to work closely together on the continued development of a complete and sustainable value chain for battery cells for electrified vehicles in Europe that will help to create high-tech jobs. The chief objective is to make battery cells sustainable by establishing a closed life cycle loop. This starts with a recyclable cell design and continues with a manufacturing process that mostly uses renewable energy. The next step is a long period of primary use as a drive battery, possibly followed by another phase of secondary use as a stationary energy storage device. At the end of its life cycle, the cell is recycled and the raw materials reused, thereby completing the loop.

In view of the growing numbers of electrified vehicles, establishing a broad basis for procuring battery cells is becoming a matter of greater strategic significance for manufacturers. With Northvolt as a partner focused on sustainable production and the BMW Group in its capacity as a carmaker that is already developing its own battery cells today, this can be achieved to great effect. Because battery cells contain essential resources and materials, feeding these back into the loop becomes more and more important as electric vehicles multiply in number. As Umicore is a global leader in the development and production of active materials for battery cells and resource recycling and the BMW Group boasts tremendous expertise in material and cell design, there are high hopes for some major achievements in this area too. Sustainability and efficiency are both crucial factors for Umicore.

The collaboration

When it comes to key technologies of the future, the BMW Group often works together with established specialists and suppliers, young companies and start-ups. This enables faster access to specific solutions. The BMW Group, Northvolt and Umicore are laying the basis for a sustainable value chain for automotive battery cells in Europe, from development and production right through to recycling.

The BMW Group is already demonstrating now how batteries can be used as energy storage devices in both domestic and industrial applications once the battery cells reach the end of their vehicle life cycle.

Umicore has recently announced it will soon start building a cathode material manufacturing facility in Europe and already runs a recycling plant for lithium-ion batteries in Europe. Umicore is advancing the technology for recycling battery cells and returning the recycled resources to the material production cycle, thereby making a vital contribution to the future of sustainable mobility.

CASE STUDY:

Second-Life EV Battery Project

Strategic Lift Ltd (SLL) and Winstone Wallboards Ltd (WWL)

In 2018 SLL carried out an analysis of the make, model, and age of EVs being imported into New Zealand. There is substantial complexity with 21 different manufacturers, and 134 different make/model/year combinations, of which 70% were used imports. With the majority of the imports having lithium-ion batteries, even if new battery technologies emerge, New Zealand will have a complex end-of-EV-life lithium-ion battery disposal issue to grapple with.

Further to this New Energy Futures Paper, SLL and WWL are working together to define a New Zealand strategy for second-life batteries. This will include relevant built-environment regulatory issues and a database of second-life projects around the world.

Trialling second-life batteries in New Zealand

Once second-life batteries have been successfully prototyped, the next step is usually to undertake a larger-scale trial. In order for second-life batteries to be trialled in New Zealand, they are at an advantage if they are:

- Commercially viable
- Safe (there is no fire hazard or the hazard is managed)
- ‘Plug and play’ (there is little or no need for modification)
- New Zealand-certified (noting this can be costly and time-consuming process)

Trialling second-life and new technology batteries on the network

Vector supports the emerging circular economy and recognises that battery technology is advancing at speed. We are happy to trial second-life batteries or new battery technologies on the Auckland electricity network provided that a) such a trial aligns with our project planning and b) that the batteries meet the technical and safety specifications we have developed. Please see the Technical Addendum for these specifications.

CASE STUDY: Renault

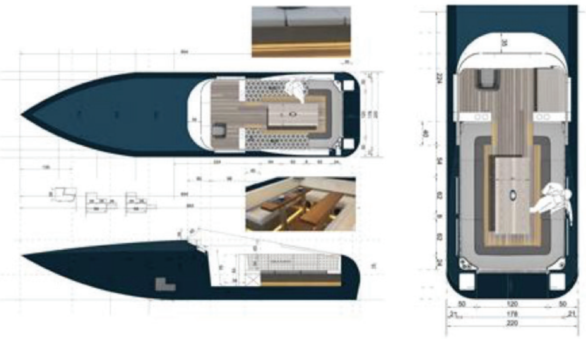
Renault’s ‘Second Life’ Batteries Power All-Electric Passenger Boat in Paris

Renault, French specialist maritime company Seine Alliance and electric propulsion experts Green-Vision have developed the first all-electric passenger boat powered by ‘second life’ batteries. Due to go into service in 2020 on the River Seine in Paris, the boat can carry up to eight passengers and pioneers the use of lithium-ion batteries that have already had their ‘first car life’ in Renault Z.E. vehicles.

Named Black Swan, the zero-emissions (in operation) boat is powered by two electric motors and needs no generator or back-up internal combustion engine. It is a voluntary, circular economy transformation approach to reduce the impact of river activities on the environment.

Gilles Normand, Senior Vice President, Electric Vehicle at Groupe Renault, said: “We are proud of having contributed to the Black Swan project alongside Seine Alliance and Green-Vision. Once again, this approach has shown that, used in a second life as energy storage units, the batteries from our electric vehicles represent an essential lever for the acceleration of the energy transition.”

Lithium-ion batteries taken from Renault electric vehicles once they have reached the end of their ‘first car life’ are re-conditioned and re-purposed, thus avoiding the energy and raw materials required to produce new batteries. They are then installed beneath the boat’s side bench seats in 4 battery stainless steel housings that have been specially designed to ensure safe, water-tight operating conditions.



Sources:
https://media.group.renault.com/global/en-gb/groupe-renault/media/pressreleases/21235734/le-black-swan-premier-bateau-a-passagers-equipe-de-batteries-de-seconde-vie-et-100-electrique-a-pari
https://www.autofutures.tv/2019/11/06/renaults-second-life-batteries/

CASE STUDY:

End-of-life electric vehicle batteries could power homes and businesses

Vector, New Zealand's leading distributor of electricity and gas, is exploring the possibility of turning end-of-life Electric Vehicle (EV) batteries into affordable power storage for homes and businesses. In collaboration with Relectrify, an Australian battery control technology growth firm, the trial is testing the capability of EV batteries to be converted into electricity storage batteries.

End-of-life battery packs from New Zealand's most common EV, the Nissan Leaf, were retrofitted with a battery management system developed by Relectrify, and connected to the grid via a standard hybrid inverter.

At the end of their life, when batteries can no longer provide the driving range and acceleration required to power EVs, they still hold up to 80 percent of their storage capability. During the trial, Nissan Leaf battery packs were repurposed to supply est. 15kWh of usable energy at power levels up to 10kW – or enough electricity to power a standard New Zealand solar home for 1-2 nights.

Cristiano Marantes, Head of Engineering at Vector, says the trial's results open up significant possibilities. "As electric vehicles become more and more popular in New Zealand, they bring with them an increasing supply of lithium-ion batteries. Once these batteries reach the end-of-life, they provide no further use in a car." We have successfully proven that with Relectrify control technology, these batteries can be kept out of landfill and hold significant value for further use. This is fantastic from both a business opportunity and sustainability point of view.

The results open up an opportunity to build affordable power storage for our distribution network here in Auckland to help solidify its resiliency. While this requires some further development towards scaling, the possibility of what we could achieve is really exciting."

Relectrify's co-founder and CEO, Valentin Muenzel, says the company is seeing significant interest in its control technology across geographies and applications. "Vector brings extensive insight into distribution requirements and storage opportunities, alongside an interest in solutions that solve the key problems of tomorrow. Relectrify is positioned to enable collaborators such as Vector to build uniquely affordable and capable battery storage products, including for households, businesses, and the power grid."

Vector is New Zealand's largest energy distribution company, and is creating a new energy future through investigation and investment in new and innovative technologies. This allows it to unlock for its customers the benefits of smart meters, solar panels, batteries, electric vehicle charging infrastructure, and energy management services.

Relectrify is a developer of advanced battery control solutions. Based in Melbourne, Australia and working with collaborators around the world, Relectrify's technologies demonstrably increase the lifetime and decrease the cost of battery storage systems in homes, industry, the power grid, and beyond. Relectrify's work on this innovative project has received support by the Australian Government Department of Industry, Innovation and Science under the Entrepreneurs' Programme.

vector

RELECTRIFY

MAKING ENERGY STORAGE AFFORDABLE

Challenges

Complexity of design and technology

It is worth noting that present efforts to repurpose batteries are reliant on battery designs that are around 10 years old. Battery technology has advanced significantly in this time and it is unclear to what extent newer designs will lend themselves to repurposing. As automakers race to develop battery performance for EVs, the products are becoming more complex and highly engineered for a specific purpose. A 2019 McKinsey & Company report[55] states: "Up to 250 new EV models will exist by 2025, featuring batteries from more than 15 manufacturers." This could add to the challenge of reconfiguring battery packs for stationary storage applications, particularly if the packs come from a range of manufacturers. As with lead-acid batteries, standardised design would greatly support second-life innovation, however industry experts feel this is unlikely. There is also a reluctance from manufacturers to share battery chemistries, seen as critical intellectual property which leads to challenges for end-of-life management. However, issues such as the predicted decrease in the supply of raw materials such as nickel and cobalt could incentivise manufacturers to absorb end-of-life batteries back into their supply chain.

Lack of infrastructure for battery assessment

The first step required for recovery is infrastructure to safely receive, store, assess and transport batteries to where they may be further processed (and discharged if necessary). Currently no such assessment centre exists on-shore in New Zealand, however businesses which service and import EVs will likely be key to assessment. Assessment could include early identification of battery issues / opportunities as well as finding appropriate process or technological solutions to ensure that end-of-use / life batteries are appropriately repurposed or recycled.

While assessment of any electrochemical product presents its own challenges (trying to identify the lifecycle stage of a battery), the facilities would also need to be appropriately designed, and staff trained to ensure safe handling.

Safe and effective reverse logistics

New Zealand's reverse logistics capabilities are widely acknowledged to be immature. In addition, there are not yet many established pathways for the collection of large batteries. Some manufacturers have processes to take batteries back, but batteries can also end up in car wreckers and scrapyards.

Batteries present a number of hazards including electric shock, the potential for corrosive material to leak, and for combustion, or gasses to be given off. Transporting and storage of lithium-ion batteries for example requires the terminals to be insulated to avoid accidental discharge and the potential for fires. The hazards involved in transporting of lithium-ion batteries may place constraints on logistics.[56] Note: the Technical Addendum provides some further information about transporting of waste lithium-ion batteries.

The pathways for large batteries are likely to be different than for small consumer batteries. Most large batteries will come from vehicles and these will enter the return system either via car wreckers, mechanics, or brand dealerships and service centres.

Devising return systems to accommodate industry players is likely to be less complex than for consumers directly. There may be greater challenges for other battery applications which may require consumer engagement programmes.

Chain of custody

Currently there is no widely-used chain of custody tracking mechanism for batteries although companies such as Everledger are developing such a mechanism. Ensuring chain of custody of a battery through its uses to ensure correct end-of-life management will be key.

[55] https://www.mckinsey.com/Industries/Automotive-and-Assembly/Our-Insights/Second-life-EV-batteries-The-newest-value-pool-in-energy-storage?cid=other-eml-alt-mip-mck&hlkid=5cb696dd6a9a488497d5062cbd91f206&hctky=10410888&hdpid=1d168e3c-8cf9-4d2e-928b-4e4dc441ffdc

[56] https://www.packsend.co.nz/clarifying-lithium-battery-sending/
https://www.dhl.co.nz/en/express/shipping/shipping_advice/lithium_batteries.html#overviewAnecdotally there is currently only one shipping company willing to transport used lithium ion batteries.

transition to the circular economy

continued

Transition 2: Remanufacture

Battery **remanufacture** (R6, also known as 'refurbishment') involves rebalancing or replacing cells or modules, swapping out damaged cells to extend the life of the battery. This is being done in New Zealand[57] and can reportedly extend the life of existing packs for two to four years. Nissan for example has announced that, internationally, it will offer refurbished battery packs for Nissan Leafs at approximately half the cost of a new battery pack.[58] (Note: In the near term, Nissan is not offering this product in New Zealand; we would expect this to change over time when more vehicle manufacturers are selling directly to the New Zealand market). It is expected that, particularly with the large number of second hand EVs that make up the New Zealand EV fleet, the demand for refurbishing and replacement battery packs will increase.[59]

Challenges

Design for disassembly

Large battery packs in EVs are built to withstand high-impact collisions which can make them difficult and dangerous to open. They are also complex, with 100-5,000 individual cells, comprised as modules within a pack, connected to a circuit panel. As such, the removal and discharge process is also complicated, requiring trained professionals and a high level of manual handling to correctly and safely disassemble the battery from the car.[60] Some people are already buying used EV batteries from the informal battery economy (e.g. TradeMe) to repurpose them in their garage or backyard. While this ingenuity is admirable, it is also risky given the potential for thermal runaway fires.

Although highly feasible, any activity that involves removing or damaging the battery housing carries a fire risk. The deployment of used batteries in new applications needs to meet standards of safety and performance. Each battery needs to be evaluated individually because each one has been exposed to different charging and discharging conditions during its use in a vehicle.

The remanufacturing process may include partial disassembly of the battery pack or module, removal and replacement of substandard cells, and reassembly of the module and pack. The process involves diagnostics, screening and selecting used EV batteries, following safe, reliable, and efficient methodologies. There are currently no widely-accepted standards for battery reuse in initial design or at end-of-life. It is vital that any standards created are proportionate otherwise they could depress a market for new or second-life batteries e.g. for storage on the electricity network. Those seeking commercial opportunities in second-life batteries may find it difficult to achieve costly certification (to meet New Zealand-specific electrical safety standards).

The lack of uniformity in cell and pack designs across EV models may also increase the challenge in transitioning an EV battery pack, module, or cells into a second-life application.[61]

Transition 3: Material recovery

When 'thinking circular', there is an enormous opportunity to **recover and reuse** the materials in a battery at end of life (R8). Value optimisation for materials means circulating materials so they maintain their highest quality and utility at all times.

The 9R framework clarifies that 'recyclable resource recovery' is when materials are processed to obtain the same (high grade) or lower grade quality. The first option is a value optimisation approach and the second, commonly known as 'recycling', is in fact 'downcycling' - where the value of materials deteriorates with each round of recycling.

[57] http://evtalk.co.nz/where-do-dead-batteries-go/
[58] https://www.youtube.com/watch?v=w93QF1ZCoiU
[59] Personal communication with Carl Barlev, Blue Cars
[60] King S, Boxall NJ, Bhatt AI (2018) Australian Status and Opportunities for Lithium Battery Recycling. CSIRO, Australia.
[61] https://www.nrc-cnrc.gc.ca/eng/publications/nrc_pubs/energy_storage/2016/summer_main_article2016.html

Batteries of course are made up of more than strategically-important metals: plastic in the housing and more common metals such as copper, aluminium and steel. Plastics can be recovered at the mechanical processing stage, where plastics, copper, aluminium and steel can be selectively removed during crushing and sieving.

Currently options for New Zealand for recycling large lithium-ion batteries mean that used batteries have to face customs and shipping challenges to be safely transported to a pre-processing plant where the resulting lithium-ion 'dust' is shipped to e.g. Korea to be used in other products, or batteries are shipped to their manufacturers for recycling through their partners, or batteries are shipped directly to e.g. Korea for full recycling.

Recycling is at the low end of the 'waste hierarchy' whereas reuse of entire products, ideally with high value material recovery at the end, is a more 'circular' solution. See the below 'butterfly diagram' from the Ellen MacArthur Foundation who spearhead circular economy thinking, where the aim is to keep technical materials cycling in the smallest loops (reuse of materials vs recycling).

Material recovery (R9) and recycling (R8) should not be confused with the recovery of the product (e.g. EV batteries) through reverse logistics and for reuse (R3) in a circular, second life application. Reuse of batteries such as on the grid to even out 'peaks and troughs' of energy demand, to power EV chargers, as energy storage for home or industrial use etc should ideally happen before any material recovery and recycling.

As can be seen from the 9R model, battery reuse is a clearer signal of the shift towards a circular economy than material recovery. Material recovery risks being the 'ambulance at the bottom of the cliff' and an extension of the 'take-make-waste' linear system unless the materials are recovered in a manner that retains their value. Value optimisation is a core concept of the circular economy.

CASE STUDY: Audi

Prior to 2018, Audi had analysed the batteries in the A3 e-tron plug-in hybrid car and defined ways of recycling. Audi together with material technology experts, then determined the possible recycling rates for battery components such as cobalt, nickel and copper. The result: in-laboratory tests found **more than 95 percent of these elements can be recovered and reused.**

With the future movements in e-mobility and a focus on sustainability, Audi then partnered with Umicore (Global technology and recycling group) in June 2018 and have successfully completed phase one of their strategic research cooperation for battery recycling. The two partners are developing a closed loop for components of high-voltage batteries that can be used again and again.

Audi

transition to the circular economy

continued

CASE STUDY: ReCell (USA)

In February 2019, the U.S. Department of Energy launched a research centre, ReCell, at the Argonne National Laboratory to further its goal of closed-loop recycling for lithium-ion batteries, help the US grow a globally-competitive recycling industry and reduce reliance on foreign sources of battery materials. This collaboration between laboratories, the private sector and universities aims to develop advanced technologies that safely and cost effectively recycle lithium-ion batteries. ReCell hopes to create jobs and create a national supply of lithium-based battery materials and accelerate an 'affordable electric vehicle economy.' ReCell's four key research areas are:

- A direct cathode recycling focus will develop recycling processes that generate products that go directly back into new batteries without the need for costly reprocessing;
- A focus to recover other materials will work to create technologies that cost effectively recycle other battery materials, providing additional revenue streams;
- Design for recycling will develop new battery designs optimized to make future batteries easier to recycle; and
- Modelling and analysis tools will be developed and utilized to help direct an efficient path of R&D and to validate the work performed within ReCell.

Source: Waste Management World "DoE Launches US's First Lithium-Ion Battery Recycling R&D Center", Ben Messenger

CASE STUDY: The Faraday Institution (UK)

The Faraday Institution is the UK's independent institute for electrochemical energy storage research and skills development, and the research vehicle for the ISCF Faraday Battery Challenge.
The Institution brings together scientists and industry partners on research projects to reduce battery cost, weight and volume; to improve performance and reliability; and to develop whole-life strategies including recycling and reuse.

"Through the Faraday Battery Challenge, we are cementing the UK's position as the 'go-to' destination for battery technology so we can exploit the global transition to a low carbon economy."

- GREG CLARK, UK SECRETARY OF STATE FOR BUSINESS, ENERGY AND INDUSTRIAL STRATEGY

The Institute's first four research projects include 30 industry partners and 20 universities that are passionate about leading Britain's energy future.

Battery Degradation

Led by the University of Cambridge, this project is examining how environmental and internal battery stresses (such as high temperatures, charging and discharging rates) damage electric vehicle (EV) batteries over time.

Multi-Scale Modelling

Imperial College London (ICL) is leading a consortium to equip industry and academia with new software tools to understand and predict battery performance, by connecting understanding of battery materials at the atomic level all the way up to an assembled battery pack.

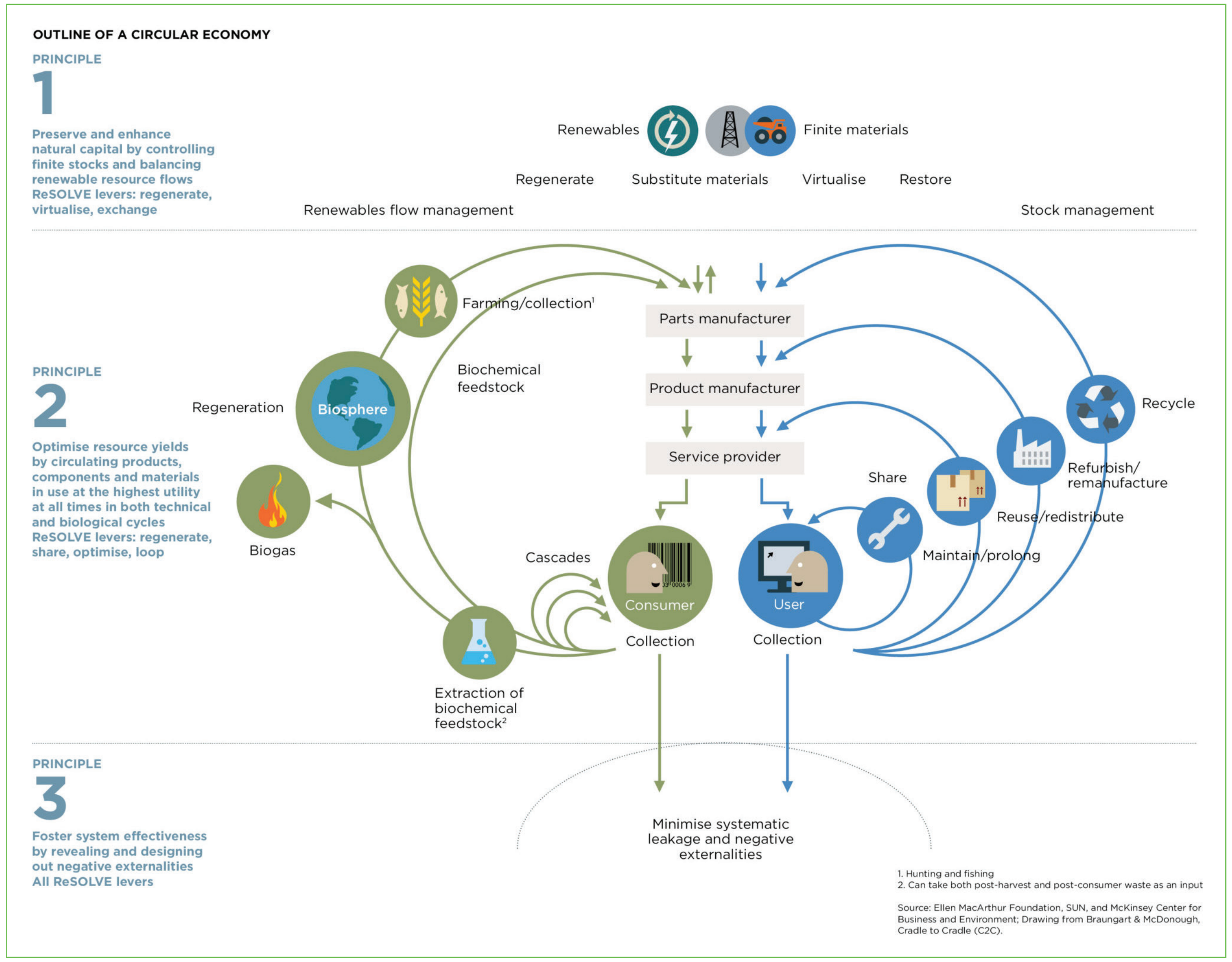
Recycling and Reuse

A project led by the University of Birmingham is determining the ways in which spent lithium batteries can be recycled. With the aim to recycle 100% of the battery, the project is looking at how to reuse the batteries and their materials, to make better use of global resources.

Next Generation Solid State Batteries

The University of Oxford is leading an effort to break down the barriers that are preventing the progression to market of solid-state batteries, that should be lighter and safer, meaning cost savings and less reliance on cooling systems.

Figure 14: Outline of a circular economy. Source: Ellen MacArthur Foundation, SUN and McKinsey Centre for Business and Environment. Drawing from: Braungart & McDonough, Cradle to Cradle (C2C).



A circular economy seeks to rebuild capital, whether this is financial, manufactured, human, social or natural. This ensures enhanced flows of goods and services. This system 'butterfly diagram' illustrates the continuous flow of technical and biological materials through the value chain.

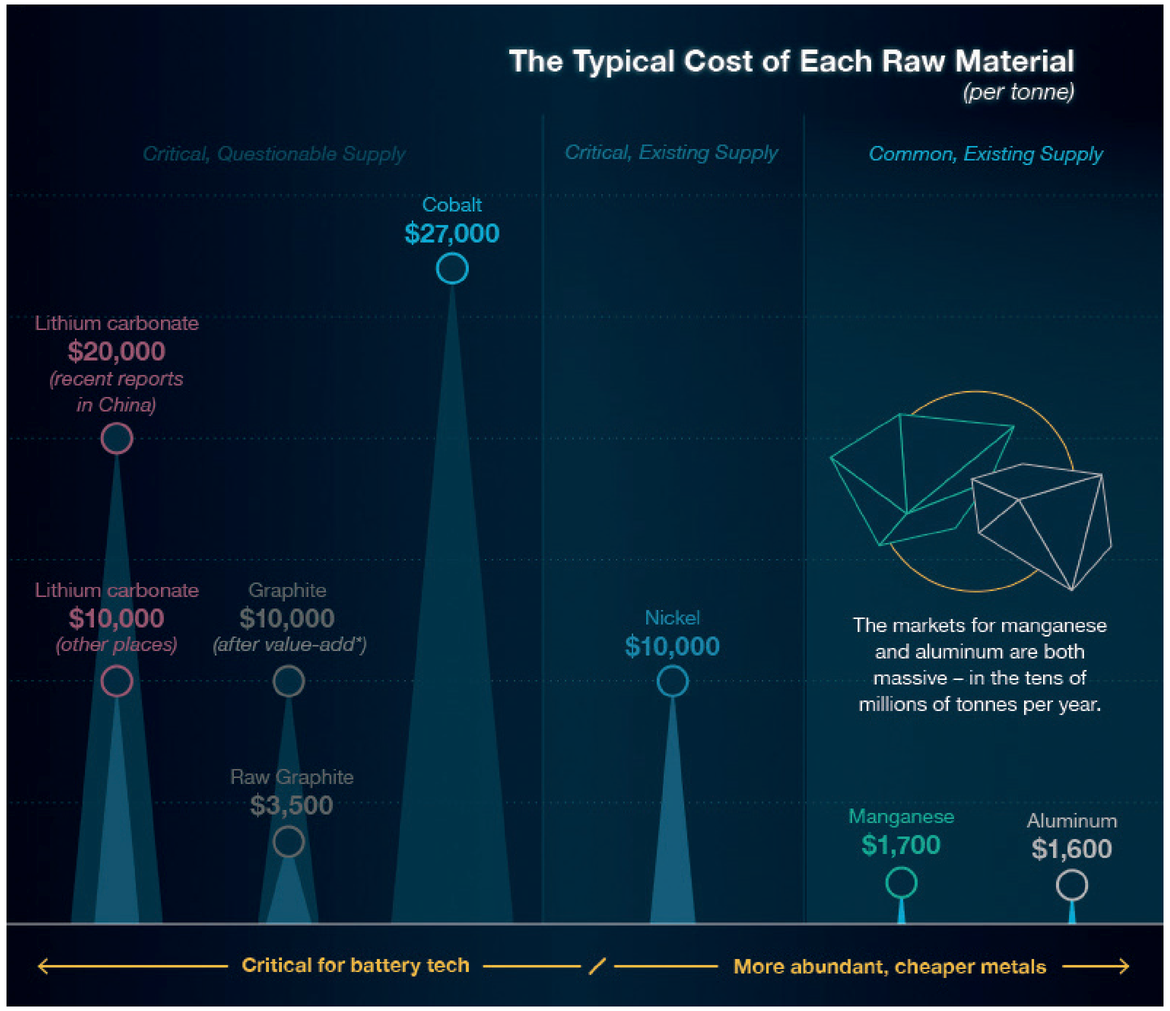
transition to the circular economy

continued

Battery chemistry

The recycling of batteries is highly dependent on the battery chemistry in terms of ease of recycling and value of recovered materials. This is a challenge as, in addition to the current variety of chemistries, the same manufacturer may change battery chemistries over time. Key materials in the recyclability of lithium batteries are cobalt and nickel. Cobalt has a very high material value due to its critical supply chain, originating mainly from the Democratic Republic of Congo. Recycling of lithium batteries currently focuses on the recovery of cobalt and nickel, as the other metals are uneconomic to recover (WMW, 2011). Almost no lithium is recycled for battery production, as the processing of lithium from used batteries is five times costlier than the virgin material (WMW, 2011). Some lithium is recovered as slag mixtures and used in lower value applications such as cement production.

Figure 15: Cost of raw materials used in batteries. Image reproduced from (Electrek, 2016)



Plants capable of recycling lithium-ion batteries exist in Europe, the USA, Korea and Japan (Elibama, 2014). Retriev Technology in Canada was one of the first commercial lithium-ion battery recycling plants in the world. It is increasingly likely that China will become a major recycler due to its large battery and electric vehicle markets. Key technologies include the two main established processes for recovery of materials from batteries: hydrometallurgy and pyrometallurgy (Elibama, 2014).

Hydrometallurgy

This is a lower temperature process where materials are converted into an aqueous solution and then valuable fractions are extracted using processes such as electrolysis, pressure precipitation and crystallisation. The consultancy Circular Energy Storage was commissioned by the Swedish Energy Agency to analyse 312 peer-reviewed research papers on recycling processes for lithium-ion batteries. The analysis of the research papers – mostly from China and South Korea – was published in April 2019 and identified more than 70% of the recycling processes were primarily hydrometallurgical.[62]

Hydrometallurgy involves the use of acids or alkalis to dissolve the metals. In theory, this process can recovery all the metal and non-metal components including lithium. However, a significant amount of pre-treatment, including sorting, is required. This makes the process difficult and expensive for waste streams with mixed and/or variable composition.[63] However there is some investigation into reducing the environmental footprint of hydrometallurgical processes such as bioleaching (Kaksonen et al. 2004).

CASE STUDY: Increasing the recycling rate of electric vehicle batteries

Source: Amanda Doyle, The Chemical Engineer
https://www.thechemicalengineer.com/news/increasing-the-recycling-rate-of-electric-vehicle-batteries/

A partnership between Nordic clean energy company Fortum, and Finnish speciality recycling company Crisolteq will make over 80% of an electric vehicle (EV) battery recyclable.

According to the International Energy Agency, electric vehicle numbers will increase from 3m globally in 2017 to 125m by 2030, making it crucial to have efficient recycling processes for the batteries. The current recycling rate for EV batteries is around 50%, but a new process by Fortum and Crisolteq will increase this to 80%.

The batteries are first made safe for mechanical treatment by Fortum, and the plastics, aluminium, and copper are separated and recycled in their own processes.

Fortum has announced that it will be able to recycle over 80% of an EV battery, putting the metals back into circulation and reducing the need to mine cobalt, nickel, and other scarce metals. The remaining material, known as "black mass" is a mixture of lithium, manganese, and cobalt, and is then set for chemical processing at Crisolteq's facility in Harjavalta, Finland. Crisolteq has developed a low-CO2 hydrometallurgical recycling process which is already operating on an industrial scale.

"Crisolteq has for several years developed technologies and capabilities to recover metals from industrial side-streams," said Kenneth Ekman, CEO of Crisolteq. "Our partnership allows us to expand the use of this knowledge to process the black mass and recover metals for new batteries."

The recovered metals can be sent to battery manufacturers for use in new batteries, reducing the need to mine for these scarce metals.

"Circular economy in its strictest sense means recycling an element to its original function or purpose," said Kalle Saarimaa, Vice President, Fortum Recycling and Waste. "When we discuss the recycling of lithium-ion batteries, the ultimate aim is for the majority of the battery's components to be recycled to new batteries."

"There are very few working, economically-viable technologies for recycling the majority of materials in lithium-ion batteries. We saw a challenge that was not yet solved and developed a scalable recycling solution for all industries using batteries."

Fortum is also piloting "second-life" applications for EV batteries that are no longer fit for their original purpose by using them for stationary energy storage.

[62] http://www.energimyndigheten.se/globalassets/forskning--innovation/overgripande/forskningsoversikt-om-atervinning-och-aterbruk-av-litiumjonbatterier-2019.pdf
[63] King S, Boxall NJ, Bhatt AI (2018) Australian Status and Opportunities for Lithium Battery Recycling. CSIRO, Australia.

Pyrometallurgy

An established and robust technology, pyrometallurgy involves the smelting of wastes at high temperatures and typically has high recovery of valuable metals, such as cobalt, copper, and nickel, from battery waste. Although the process is energy-intensive, it is generally robust and does not need to be specifically tailored for the treatment of a waste with specific composition, which is an advantage for inputs with a variable composition like e-wastes and battery waste.

However, apart from examples such Umicore's Ultra High Temperature (UHT) recycling technology, the process usually only aims to recover the most valuable and noble metals such as cobalt, nickel and sometimes copper. Less valuable metals or compounds such as lithium, manganese, iron, aluminium and plastics are not usually recovered.

However, the process does not usually recover metals and materials such as lithium, manganese, iron or aluminium and plastics, which are difficult or not practical/economically viable to recover. These end up in the slag or are volatilised (given off as gasses). Slag may be used as aggregate (for example in roading).[64] Pyrometallurgy typically recycles around 40% of the battery by weight excluding the slag.[65]

The high capital and operating costs mean that there are few facilities in the world capable of recovering the high-value metal fractions from lithium batteries. However there are new, more cost-effective innovations, such as 'micro-factories', which are currently at prototype stage in Australia, to recover valuable oxides through thermal processes.[66]

Biometallurgy and other processes

Biometallurgy is an emerging (and not fully developed) technology using microbe biosorption to extract valuable materials. Examples include Mint Innovation in New Zealand who use proprietary microorganisms to bind and concentrate specific metals under environmentally benign conditions (this process can operate in small footprint, but it is not yet commercially tested[67]).

Mechanical recycling has not been discussed as it is often a precursor to the processes described above. Additional processes which promise to economically recover a higher proportion of the materials from batteries are in development, but the timelines to commercial application are uncertain e.g. Li-cycle based in Canada aspires to recover up to 100% of lithium-ion batteries through a 'proprietary arrangement of existing technologies'.[68]

It is estimated that recycling NMC lithium-ion cells could reduce the carbon footprint and human toxicity potential from their manufacture by 15% and 10% respectively using a combination of hydrometallurgy and pyrometallurgy (EPA, 2013).

Commonwealth Scientific and Industrial Research Organisation (CSIRO) research has shown that, while in 2018 only 2% of Australia's annual 3,300 tonnes of lithium-ion battery waste was recycled, this is growing by 20% per year. Therefore sufficient volumes of batteries will be generated by approximately 2036 for viable recycling programmes to exist (King, et al., 2018)[69]. New Zealand is expected to be able to export used batteries for recycling in Australia therefore on-shore pre-processing is needed to avoid export / shipping challenges. Pyrometallurgy or biometallurgy may be the only feasible recycling method for lithium batteries within New Zealand, as other recycling methods would be economically unfeasible at lower volumes.

Emerging transition opportunities: beyond lithium-ion

Innovators in New Zealand and abroad are already looking at a 'post-lithium' world, avoiding the use of materials with a high sustainability impact (and, in the case of cobalt, cost). This relates to the 9R model smarter product use and manufacture section, namely R0, R1 and R2. As discussed, lower value materials could be a disincentive to invest in recycling infrastructure. While arguably a pre-processing facility is already needed in New Zealand, it would be wise to consider disruptive chemistries and technologies such as hydrogen or bio-batteries (e.g. made from wood fibre or sugar or microbial respiration[70]) before investing in costly, long-term infrastructure projects. Smaller, modular facilities designed to last for e.g. a 20-year time horizon may be prudent.

[64] https://www.li-cycle.com/blog
[65] Richa et al al, A future perspective on lithium-ion battery waste flows from electric vehicles. Resources, Conservation and Recycling 83 (2014), 63-76
[66] http://smart.unsw.edu.au/
[67] https://www.mintinnovation.co/news
[68] For example: https://www.li-cycle.com/
[69] https://www.csiro.au/~/media/EF/Files/Lithium-battery-recycling-in-Australia.PDF?la=en&hash=924B789725A3B3319BB40FDA20F416EB2FA4F320

CASE STUDY:

New Zealand Product Accelerator (NZPA) - Sustainable Energy Storage Group

An initiative of the New Zealand Product Accelerator (NZPA) and a member of the B.I.G. Battery Innovation Hub, the Sustainable Energy Storage Group (SES) is an alliance between Callaghan Innovation, GNS Science, Auckland University of Technology, University of Canterbury, Massey University, University of Otago, Victoria University of Wellington, University of Waikato and University of Auckland. It aims to build a bridge between battery researchers and market needs for battery technologies in New Zealand. This platform is expected to spark more ideas to improve battery technologies through collaboration in applied research between industry partners and researchers. In this group battery research groups are working on projects relating to Li-ion batteries, Magnesium batteries, Al-ion batteries, Redox flow batteries, Na-Al batteries, battery upcycling, battery material/metal recycling and others.

NZ Product Accelerator

[70] https://www.triplepundit.com/story/2015/biodegradable-batteries-real/32756

CASE STUDY:

Victoria University, Wellington

Researchers at VUW are working on aluminium ion batteries that are safer, more sustainable and better performing than lithium ion batteries. Aluminium is the third most common element in the Earth's crust and offers a higher theoretical energy density. In the past, the challenge in getting a commercially viable aluminium battery has been the lack of suitable cathode and electrolyte materials. This has changed – VUW researchers have identified new possible materials that could bring a commercially viable aluminium battery within arm's reach. The motivation for this work was to look at reducing the reliance on costly raw materials (e.g. lithium), reducing the use of unethical materials (e.g. cobalt) and also to improve the safety profile of batteries in the future. VUW is now actively looking to commercialise this technology and is currently in the process of protecting the IP and engaging the market.

viclink

CASE STUDY:

Dynantis Aotearoa – Researching the sodium aluminium battery

"Dynantis Aotearoa is developing electricity energy storage solutions that will change the way electric grids are operated worldwide. We are developing — the sodium aluminium battery. Research and development of the battery has continued under contract at the University of Auckland Light Metals Research Centre last year.

The battery is focussed on making the cost of energy storage cheap by using chemistry based on some of the most abundant elements available on the earth crust – sodium and aluminium.

We are at the beginning of a revolution in decarbonising the global energy system and to do it we need energy storage solutions that are cheap, environmentally friendly and are easy to manufacture, maintain and recycle. The sodium aluminium cell is such a solution."

What does all this tell us about the future value chain of lithium-ion batteries in New Zealand?

There are some clear opportunities to transition to a circular economy for large batteries. However, a complex, uncertain and fast-changing landscape makes it highly risky for businesses to make strategic decisions and investments. Public sector local and central government will also have difficulty justifying hefty infrastructure investments and policy mechanisms that risk becoming quickly irrelevant. Rather, anticipating changing technologies, investment in smaller-scale, modular solutions may be more appropriate.

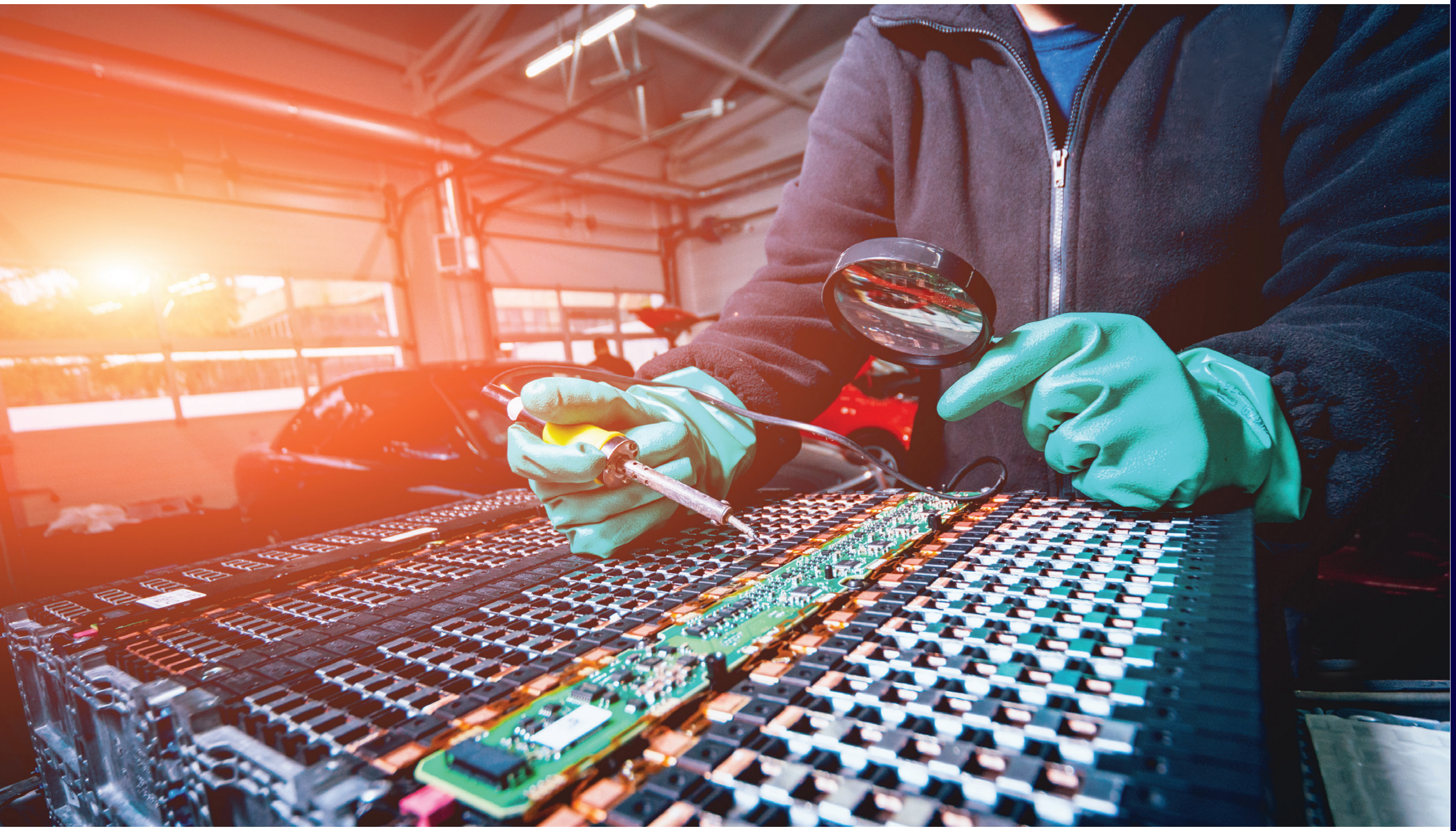
Future scenarios are a useful tool for navigating such an uncertain future. Scenarios serve to play out key uncertainties, and allow decision makers to generate a range of opportunities in response to each scenario, thereby identifying areas of opportunity common across, or unique to, distinct scenarios.

Vector worked with international sustainability non-profit Forum for the Future to engage with stakeholders across the batteries ecosystem, arriving at three 2030 batteries scenarios for New Zealand, explored in this section.

Key uncertainties influencing the future value chain of large batteries in NZ

There are two key uncertainties which influence the future value chain of large batteries:

1. Battery recovery and reuse vs materials recovery
2. Local vs global solutions



Analysis: battery recovery and reuse vs materials recovery

In theory, both options of battery and materials recovery should occur in series – batteries are given an extended life through secondary applications, and then recycled at the end of this time to recover valuable materials.

In practice, the two options are likely to (at least partially) compete due to several factors which include the fact that EV battery pack designs are becoming more complex and engineered for specific performance. Adapting these specific designs for secondary applications may create challenges in the future unless they are designed with secondary uses in mind, and manufacturers may also have reputational concerns with the use of battery packs or components by third parties. There is an opportunity, therefore, to feed back a second life 'battery design wish list' to battery designers.

The high price of raw materials drives the recycling market and may incentivise EV manufacturers to keep the batteries within their supply chains. In addition, second life applications will have to compete with dedicated storage technologies and designs. It will come down to the economics of the options. It is likely that repurposed batteries will find a niche in certain applications.

There may be a divergence of approaches by different manufacturers depending on the corporate philosophy globally.

With higher commodity prices, recycling technologies such as pyro or hydrometallurgy, or newer processes that can recover a higher proportion of the valuable metals, are likely to be more economic. Innovation in these technologies mean they may be able to take changing feedstocks i.e. materials and chemistries.

The development of onshore processing or pre-processing depends on the economics. There is likely to be high demand internationally for recovery facilities to process batteries. This will lead to economies of scale for the major processing facilities. The economics will likely be driven by the level of cost involved in making end-of-life batteries safe for overseas transport, and whether this makes local processing relatively economic.

Regulations surrounding product stewardship and take-back programmes for batteries seem likely to be enforced in future as the amount of waste grows. Examples includes Australia's Product Stewardship Act 2011 and New Zealand's Waste Minimisation Act 2008. Recycling schemes would be easily implemented for EV and household/commercial energy storage batteries (such as the Tesla Powerwall and Powerpack) due to their size and value.

However, there is uncertainty and challenges facing lithium battery recyclers. Battery suppliers, such as Tesla, are focusing on reducing their dependence on high value materials such as cobalt to reduce the cost of manufacture, instead exploring phosphate and manganese-based chemistries. Tesla has stated that no cobalt will be used in the next generation of batteries (Musk, 2018). This means newer, lower-value battery chemistries are less attractive for recycling by current methods (Gies 2015). It is uncertain whether recycling of lithium batteries will remain economic with changes in battery composition.

1. Battery recovery and reuse vs materials recovery

While reuse and recovery of batteries is preferred to materials recovery from a waste perspective, whether New Zealand moves towards (i) advancing second-life solutions for batteries, or (ii) recycling batteries for materials recovery, depends to a large extent on the value of recovered materials.

Where the value of recovered materials is high, companies and governments will be incentivised to build infrastructure and supply chains that favour materials recovery over battery reuse.

In turn, the value of recovered materials is dependent on technological developments and global market conditions for batteries:

Demand for new lithium-ion batteries:

a. Uncertainty around growth in demand for lithium-ion; market prediction that it will dominate; but already talk of a post-lithium era with carbon-based or compostable batteries.

b. If demand for new lithium-ion batteries continues to grow, the value of recovered materials will be high.

Technological reliance on strategic / rare materials (e.g. lithium, cobalt, graphite):

a. Uncertainty around current reliance on lithium and cobalt for batteries; signs that new batteries might use less of these strategic materials.

b. If the reliance continues to be high, the value of recovered materials will be high.

Availability and cost of raw materials for batteries:

a. Uncertainty in the supply and price of lithium, cobalt, etc.

b. If availability is low or inconsistent, the value of recovered materials will be high.

2. Local vs global solutions

The key consideration for New Zealand is whether to (i) build local infrastructure and capacity to reuse, repurpose and recycle batteries at the end-of-life or (ii) plug into global infrastructure. A number of factors will influence this – in particular, the cost and viability of international transport of batteries.

Cost & viability of international transport for batteries:

a. Uncertainty in the cost of international trade and transport, considering safety requirements as well as potential climate change risks – this includes physical disruptions to transport, but also increased prices as costs of carbon emissions start being built into all transportation modes.

b. If the cost of trade and transport increases, the incentive for local solutions will increase, given the geographical distance of New Zealand from most major global production locations. It is possible that New Zealand could establish itself as a regional recycling hub including, for example, the Pacific Islands.

Complexity of battery design and ease of disassembly:

a. Uncertainty around whether battery manufacturers will design batteries for disassembly, especially if they deem that there is competitive advantage in designing unique batteries.

b. If batteries are not designed for easy disassembly, the incentive for local solutions will decrease, as the batteries will need to be transported to manufacturer-appointed recovery facilities that have the requisite capabilities.

Local demand for second-life applications:

a. Uncertainty around the market size of the potential second-life applications for batteries in New Zealand; questions around whether repurposing EV batteries for stationary energy storage will truly be more cost-effective than dedicated storage technologies and designs.

b. If there is not sufficient local demand for second-life applications, New Zealand will be pushed to plug into the global market and infrastructure to achieve a circular value chain for batteries.

Three 2030 scenarios

Below we describe three potential 2030 scenarios for circular value chains for lithium-ion batteries in NZ.

What are future scenarios?

Scenarios are not predictions. Nor do they represent a utopic or dystopic vision of the future. Instead, they serve as intentionally distinct versions of the future by playing out different outcomes that might result from the trajectories of today's key uncertainties.

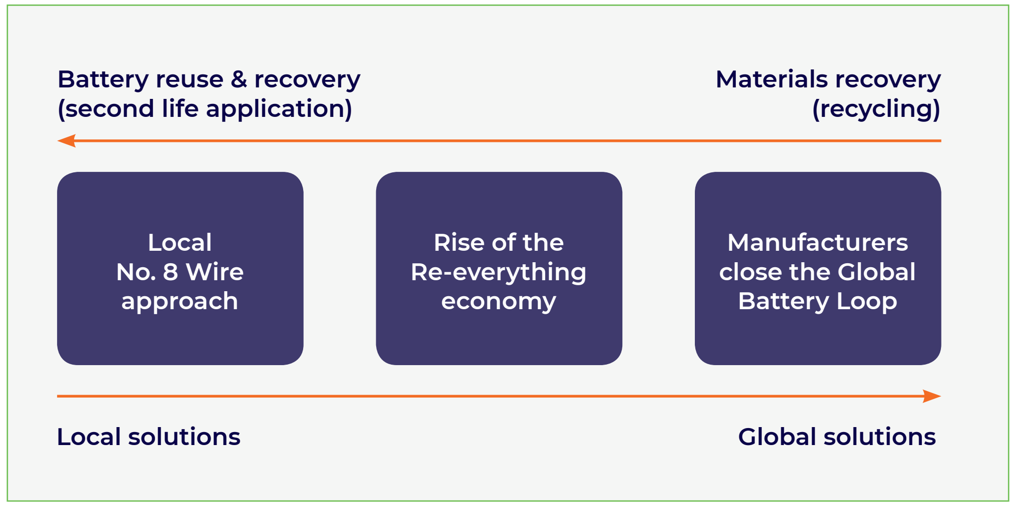
Scenarios provide enough detail to allow for constructive conversations that further deepen understanding of the issues from different perspectives. By immersing in future scenarios and building out how these future worlds operate (i.e. new rules, new players), stakeholders from diverse backgrounds can generate a range of opportunities in response to each scenario, thereby identifying areas of opportunity common across, or unique to distinct scenarios.

Ultimately, scenarios allow decision-makers to prioritise actions that can pre-empt risks or result in positive outcomes across most or all scenarios. They provide a structured means for a group to agree on a way forward, in the face of uncertainty.

How did we arrive at the three 2030 scenarios?

As summarised in the section above, two critical uncertainties are likely to pull the future value chain of large batteries in New Zealand in opposing directions: materials recovery vs battery recovery and reuse, and local vs global solutions, seen in figure 16 below.

Figure 16: critical uncertainties and three 2030 circular scenarios for large batteries



our circular future continued

We started by combining the two ends of the uncertainties, and begin to picture how New Zealand economy and society interacts with large batteries in 2030.

For example, looking at the far-left segment of the diagram above, what would a world look like where battery reuse & recovery (i.e. second or third life applications of batteries) is prioritised over materials recovery (i.e. recycling of raw materials), and New Zealand chooses to make significant investment into localised solutions, rather than plugging into global infrastructure?

We arrived at three plausible combinations of the two critical uncertainties: **Local No. 8 Wire approach, Rise of the Re-everything Economy, and Manufacturers close the Global Battery Loop.** By applying a reverse 'STEEP analysis' (Social, Technological, Economic, Environmental and Political) we then fleshed out each of the 2030 future scenarios. For example, what is the political and social backdrop against which such policy and business decisions are made? What are the expectations from users of the large batteries? What types of technological developments are being favoured in this world and how have environmental impacts affected the NZ economy or society?

In building out this future world, we reference stakeholder insights, market research conducted by Eunomia Consulting, as well as "signals of change" – new ideas or innovations that are early signs of this potential future in terms of the sustainable production, use and disposal of batteries.

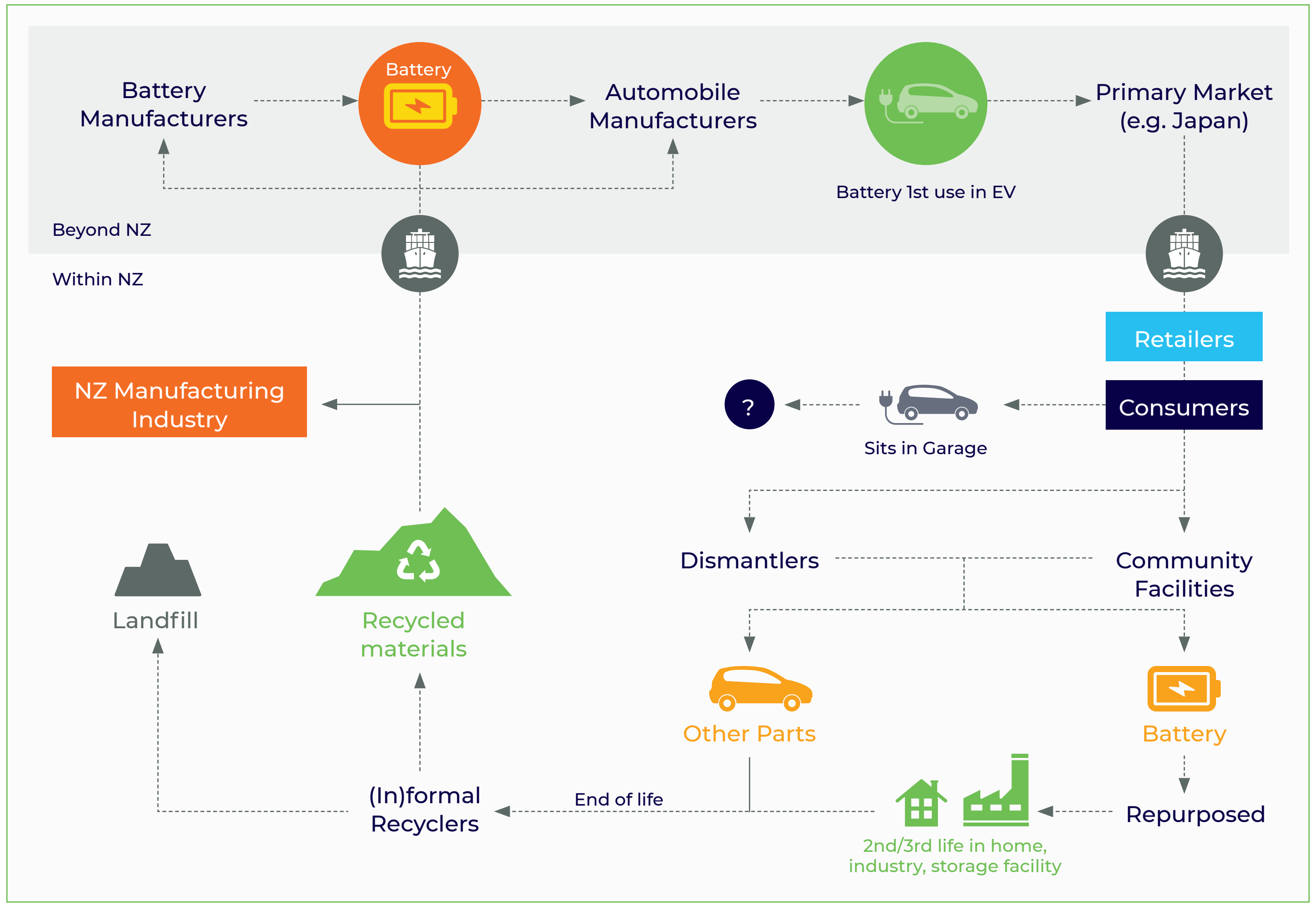
In the context of designing a tool that stakeholders across the batteries ecosystem could engage with, we opted to visually present each scenario by illustrating the hypothetical journey that large lithium-ion batteries would take through the value chain, in each scenario. These infographics are included below, with full descriptions of the three scenarios in the Technical Addendum.

Assumptions

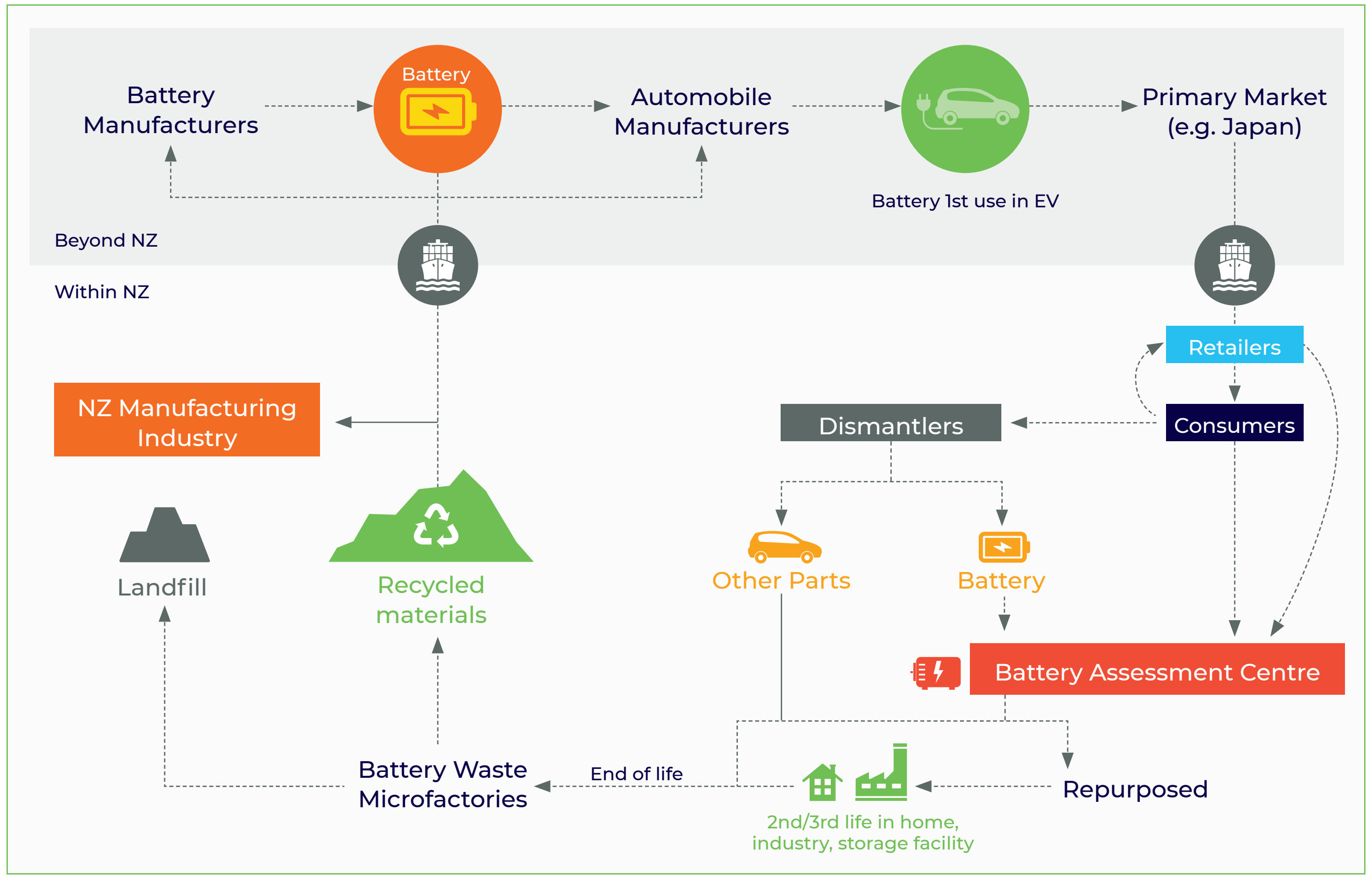
This set of scenarios makes three important assumptions that we recognise are up for debate. This was done to support the scope of the conversation we were seeking to have with stakeholders. Vector and Forum for the Future recognise that, to varying extents, these assumptions represent a limitation to the options generated using these 2030 scenarios.

- Firstly, we make the bold assumption in all scenarios that an economically viable circular battery value chain has been achieved, largely negating the environmental impact of batteries.
- Secondly, we assume that between now and 2030, New Zealand maintains a relatively stable political environment, and that population demographics do not change significantly from 2018.
- Lastly, we assume that based on current market predictions, in 2030, large batteries enter the New Zealand market largely via EVs and lithium-ion technology remains dominant.

Local No. 8 Wire Approach
"We support local solutions designed with Kiwi ingenuity."[71]



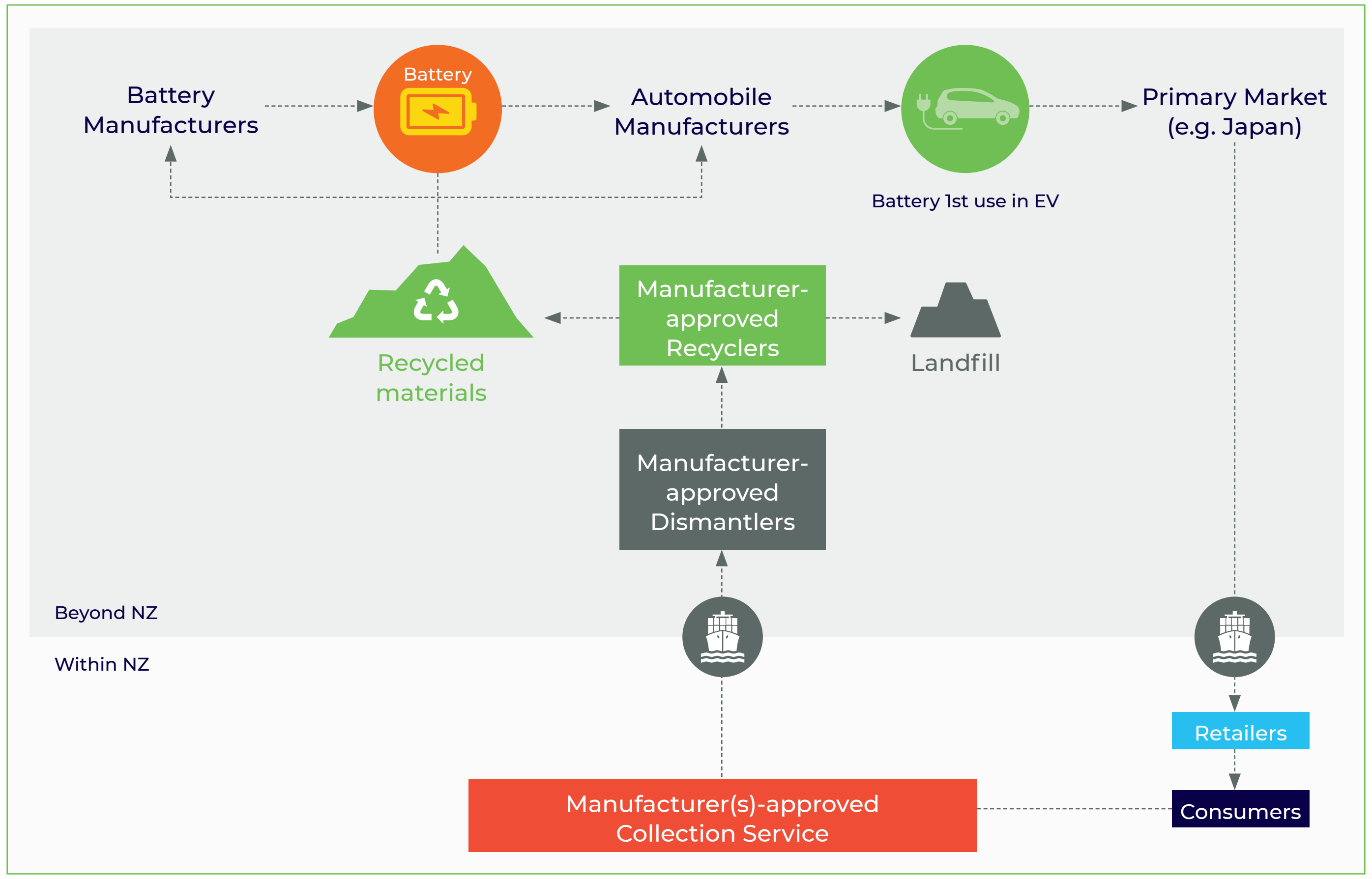
Global Rise Of Re-Everything
"Being part of the circular economy is convenient, socially rewarding and makes economic sense."



[71] To learn more about what No. 8 Wire means, see: https://en.wikipedia.org/wiki/Number_8_wire and https://www.motovated.co.nz/genesis-kiwi-ingenuity/

our circular future continued

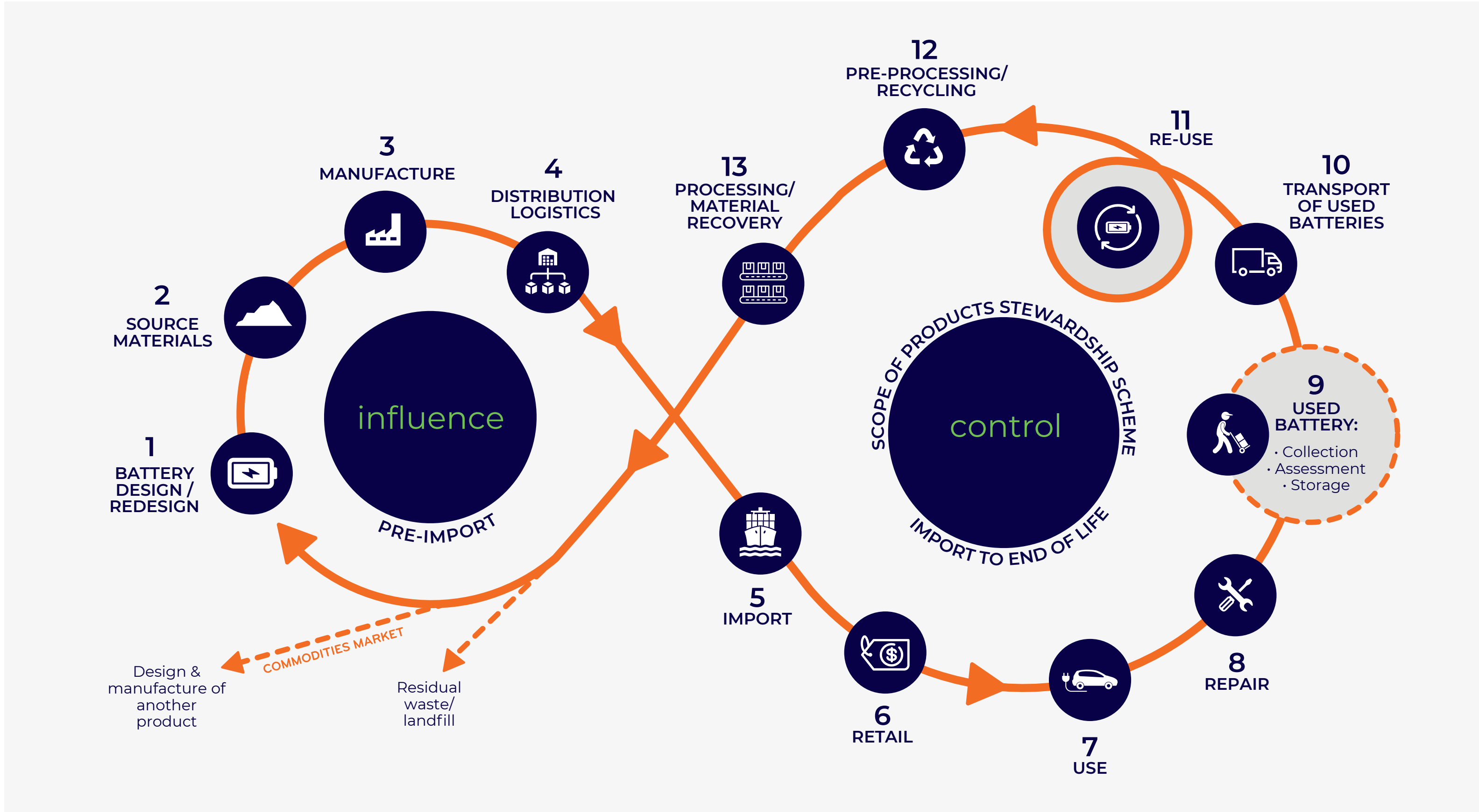
Manufacturers Close The Loop
“Please take care of it. Waste is a problem that companies can deal with better than I can.”



opportunities in the new battery ecosystem

There are many opportunities for battery innovation in New Zealand which arise from considering a circular battery ‘value loop’ rather than a linear value chain.

Figure 17: An example circular ‘value loop’ for large batteries



If the circular economy principle of equality being integral to all services is adhered to, a key commercial benefit of a circular system is that will provide a level playing field for all involved. The opportunities arising from a circular system can, and should, also include benefits for environment or society. For example, creating standards for second life of batteries has no immediate commercial benefit but could help support a safer industry and better environmental outcomes.

New Zealand faces a ‘tyranny of distance’ from other countries, challenging geography, lack of scale and a distributed population. However, if New Zealand can innovate and incubate smaller-scale, on-shore solutions, it could benefit from positive outcomes such as upskilling of the workforce, increased employment and lower environmental impact.

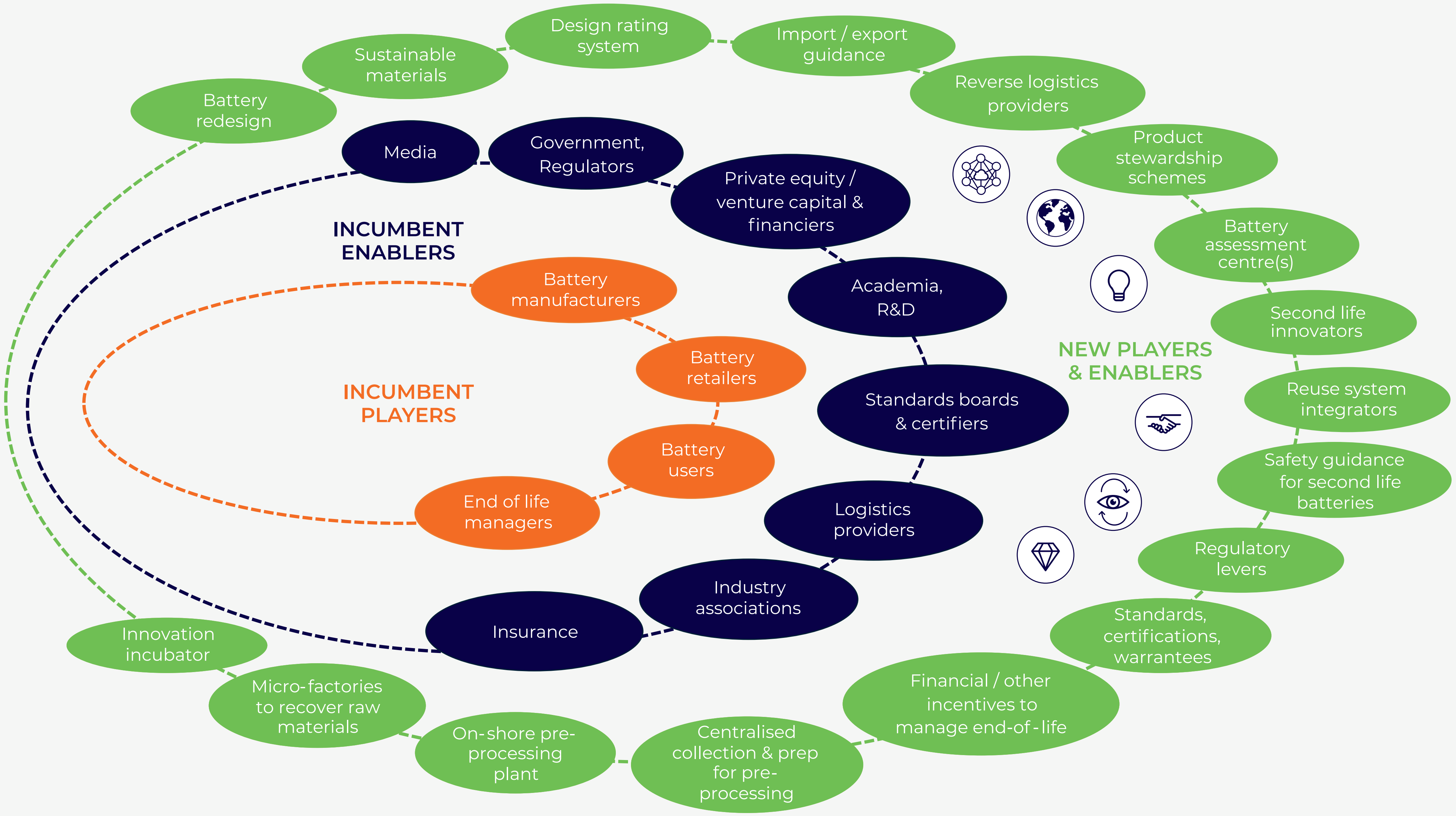
A new, circular ecosystem needs to emerge in the next five years to make the 2030 scenarios plausible. This ecosystem is made up of incumbent players such as battery manufacturers; incumbent enablers such as industry associations and new players and enablers, such as battery redesign for second-life or more sustainable materials, second-life innovators, new battery standards etc. See figure 18.

The circular economy enabling factors, discussed earlier in this paper, will also need to underpin all activities to ensure a true systems-shift from a linear to a circular economy:

opportunities in the new battery ecosystem continued

The new battery ecosystem

Figure 18: the new Battery Ecosystem in a new circular economy



opportunities in the new battery ecosystem continued

New players & enablers: Innovation opportunities for NZ

As discussed, the three circular economy scenarios shared above are not predictions. It is therefore possible that the battery ecosystem in 2030 will comprise elements of all three. The following section describes the new players and enablers (shown in green in figure 18) which need to exist in order to support any of the three circular economy scenarios.

Whether these new players and enablers exist in New Zealand or as part of a global infrastructure is to be determined, but there is evidence they are already emerging. **There is therefore a window of opportunity for New Zealand industry, innovators and Government to take a leadership role to enable positive commercial, environmental and social outcomes – such as new employment opportunities – for Aotearoa.**

Battery redesign

EV batteries that are now coming to the end of use were designed at least a decade ago. Battery design is changing; while this is a highly competitive area, there is an opportunity to engage with battery manufacturers to improve the design to enable rejuvenation or remanufacture e.g. through designing for safe disassembly or modular design. Battery design may become less relevant with the increasing sophistication of Battery Management Systems, however design provides the biggest opportunity for circularity and battery design is an ongoing area of focus for the Global Battery Alliance, a World Economic Forum project. To this end, standardised signage on batteries which are designed for repair and reuse would be helpful (see Battery rating system / passport section).

Sustainable materials

New, sustainable materials should be trialled and tracked by chain-of-custody technologies such as blockchain to ensure recovery at end-of-life. As discussed earlier in this Paper, manufacturers are already seeking ways to avoid materials with high ethical / environmental risk supply chains such as cobalt. A materials database for battery manufacturers has been suggested.

Renewable energy in manufacture

Life Cycle Assessment (LCA) analysis shows that batteries which are produced in factories using renewable energy will carry significantly lower embodied carbon and the 'carbon payback' period for a customer will be reduced.

Battery rating system / passport

A rating system (e.g. A-G) or passport for new batteries based on sustainable design or the recyclability of a battery e.g. that considers materials used, the manufacturing process, ease of disassembly for reuse and recycling and end-of-life environmental impact) may incentivise manufacturers to improve battery design. Such a 'Battery Passport' is being developed by the Global Battery Alliance.

Import/export guidance

Consistent guidance for shippers will be required, currently shipping companies have different policies for shipping used batteries. This would enable short-term shipping of used batteries for regional recycling until a long-term on-shore pre-processing facility has been built.

Reverse logistics for battery recovery

New actors in the product stewardship space could include transport and freight providers who offer, or are part of, a product stewardship scheme(s) to collect used batteries from users, bring them to assessment/ testing centres, then to the relevant locations (either locally or globally) to be refurbished, reused or recycled.

Use

Clear instructions and communications are needed to ensure that customers know how to use their cars / stationary energy storage solutions in a way that maximises battery life. It is also key that customers know where and how to get their batteries safely repaired, and how repair will affect their warranty and financial value of the battery.

Repair

Batteries could be safely refurbished / remanufactured as discussed above, either by trained staff at dealerships or at an Assessment centre below. Particularly given the fire risks with lithium-ion batteries is important to understand the safety, technical, liability and sustainability implications in New Zealand of the global trends towards 'right to repair', increase of community repair schemes and the mainstreaming of repair in general (see www.ifixit.com and www.fairphone.com).

Collection, Assessment, Storage

Although collection, assessment and storage could be undertaken by different service providers, synergies between them may mean it is most efficient for one business to provide all three services. In the short term, a centralised point of collection and pre-processing of used batteries for discharging and export to either second-life markets or markets with refurbishing/ recycling capabilities may be helpful to manage the small stockpiles currently building up in New Zealand.

There is a greater fire risk for used than for new batteries, and the collection, dismantling and assessment of used batteries should be undertaken by trained professionals. Clear guidance about safe use, handling, transportation and storage of used batteries is vital at this stage to help avoid / minimise the fire risk. Evidence-based and proportionate guidance is an intended outcome of a battery Product Stewardship Scheme discussed in this Paper.

Assessment could take place at either:

- An adaptation of current repair infrastructure (garages, dealerships etc)
- A battery assessment centre
- A network of battery assessment businesses

See below commercial opportunities section.

opportunities in the new battery ecosystem continued

Informal reuse economy

Reuse presents an opportunity for innovators, many of whom form part of an informal reuse economy. Safety guidance is required to minimise risk while encouraging innovation. Chain of custody technologies such as blockchain and sensors could help to track batteries as they pass from owner to owner.

Reuse system integrators

Beyond the reconditioning of used batteries, there will be a market for reuse 'system integrators' who specialise in repurposing used batteries (e.g. turning batches of used EV batteries into fixed industrial energy storage at scale).

Regulatory levers

The uptake of repurposing will come down to economics and regulatory levers. If the level of demand for stationary storage is in line with the number of end of use EV batteries coming on stream, and the cost per kWh over their remaining life is competitive with dedicated designs, then there could be pull through of EV batteries into stationary storage applications. It is likely that repurposed batteries will find a niche in certain applications where the price and performance metrics align.

Current regulation is immature and inconsistent. A 2019 McKinsey & Company report[72] states: "Today, while most markets have some form of regulation requiring the recycling or remanufacturing of consumer electronics in general, most markets do not have EV-battery-specific requirements or delineations of responsibility between the producer and the consumer, save a few examples where goals have been set (such as in California and China). The lack of regulation creates uncertainties for OEMs, second-life-battery companies, and potential customers. The lack of regulation also gives rise to regional differences regarding whether recycling or reuse is the dominant pathway."

Regulation to ensure transfer of producer responsibility is currently under consideration by the EU. When a battery is sold for repurpose/second life purpose it will be helpful to regulate for transfer of ownership for a) reuse (e.g. vehicle to vehicle) and b) second life (vehicle to another application such as home energy storage).

Standards, certification and warrantees for battery reuse

Standards for battery quality, performance, battery management systems, state of charge and performance would help to ensure safe reuse of batteries and a standardisation of approach. Standards, such as safety standards, should be robust but proportionate and evidence-based to ensure a healthy market for new and used batteries and a better social and environmental outcome. Certification is another area which should be simplified so that innovators aren't faced with costly and time-consuming bureaucracy. This could be e.g. through alignment with EU or Japanese certification.

Some battery manufacturers are starting to provide warranties for secondary uses of large batteries; this must be more consistent to encourage market innovation (understanding that in some cases, manufacturers want to take back and recycle their batteries to retain the materials rather than encourage second-life options).

Financial or other incentives

Similar to Container Deposit Schemes, a levy or other mechanisms will help to ensure the value of batteries is captured and they are appropriately managed through to end-of-life.

There are various market incentives and technologies which could encourage return of batteries at end-of-life.

[72] https://www.mckinsey.com/Industries/Automotive-and-Assembly/Our-Insights/Second-life-EV-batteries-The-newest-value-pool-in-energy-storage?cid=other-eml-alt-mip-mck&hlkid=5cb696dd6a9a488497d5062cbd91f206&hctky=10410888&hdpid=1d168e3c-8cf9-4d2e-928b-4e4dc441ffdc

End of life: pre-processing and processing

A circular economy presupposes that batteries will not be landfilled. Cradle to Cradle™ certification for batteries would be an example of best circular practice, which would ensure that all materials are safe to be returned to technical and biological nutrient cycles.

In the short term, regional pre-processing and processing facilities exist (e.g. Envirostream in Australia). As discussed in this Paper, the resulting mixed metal dust is reused in other batteries.

In the medium term, an on-shore pre-processing solution is required. Some facilities for small batteries are, at the time of writing this paper, about to launch in New Zealand. However, battery (EV) retailers have stated that there is a clear need for an on-shore pre-processing facility for large batteries; such a facility could also create employment at the plant and via supporting services. New Zealand may never have the scale required for a full processing facility (unless we also start processing Pacific Island batteries), and mindful of an uncertain future, any infrastructure should be built in a small-scale, modular way to future-proof against disruptive technologies such as hydrogen.

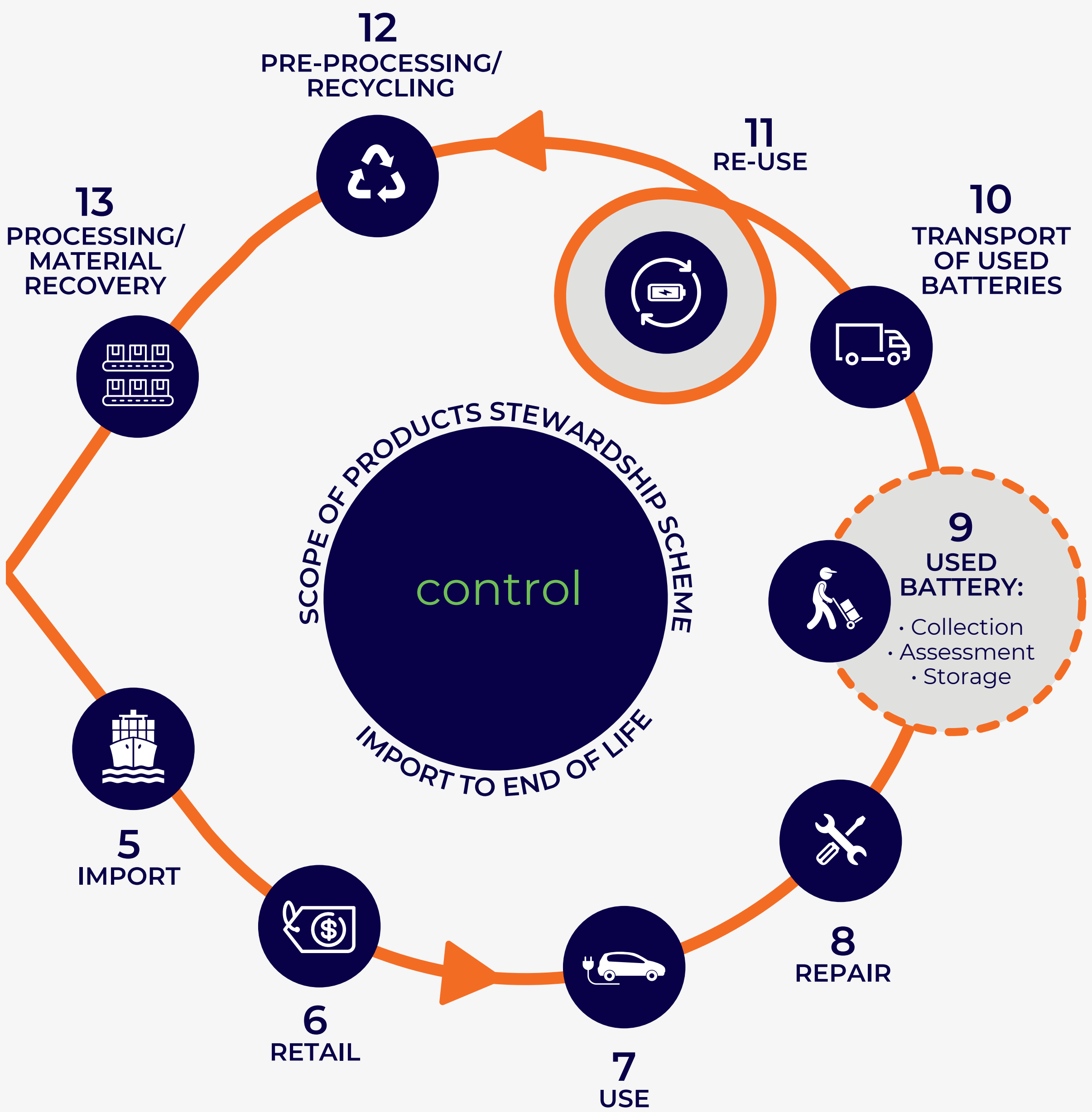
End of life: micro-factories for material recovery

In the longer term, small-scale micro-factories may be able to process and extract almost pure raw materials, see below commercial opportunities section.

Innovation incubator

Innovation incubators could provide mentorship, networks, access to market and other basic business and management services to start-up companies. An incubator focussed on sustainable innovation could support the network of new companies that will service a decentralised, renewable energy system that encompasses a circular economy for batteries. New chemistries of batteries such as sodium-aluminium and new technologies such as hydrogen may disrupt the lithium-ion battery market.

Figure 19: Product Stewardship Scheme Scope



Product stewardship schemes

An overarching industry product stewardship scheme (co-designed with, and regulated by, Government) or specific company product stewardship schemes should include companies which retail and lease batteries and should incentivise the collection/ transportation of used batteries. Such a scheme could be integrated into battery manufacturer's after-sales offering, or provided as an independent service. A product stewardship scheme is likely to require a digital (web or app-based) user interface. This could be supported by new digital-physical solutions using e.g. blockchain and the Internet of Things to ensure chain of custody tracking and efficient reverse logistics. Examples include blockchain solutions offered by Everledger and a digital battery materials passport being developed by the Global Battery Alliance. Ease of use will be key.

To ensure that batteries are returned to the correct places for end-of-life management, recovery needs to ideally be free to the end-user, or there needs to be some form of incentive such as a bounty.[73] There also needs to be a good level of clear and consistent consumer and industry information about how batteries should be returned at end of use.[74]

Such a scheme for large batteries is currently being designed by the NZ Battery Industry Group (B.I.G.).

[73] International examples include the European WEEE directive, BEBAT (Belgium), ElektroG (Germany), INOBAT (Switzerland) Call2Recycle (North America). Refer to: MS2 (2013) Business and Public Policy Case for Battery Stewardship – BACKGROUND PAPER AND REPORT Prepared for Sustainability Victoria
[74] https://www.productstewardship.us/page/Batteries

opportunities in the new battery ecosystem continued

Commercial opportunities for NZ

Six areas of commercial opportunity have emerged from the Battery Leaders Group research and industry 'New Energy Futures Lab' workshop. These also respond to the challenges identified in the 'Transition to a Circular economy' Section.

1. Second-life applications of batteries: Energy grid
2. Second-life applications of batteries: Home energy storage
3. Raw material recovery (e.g. nickel, cobalt, lithium)
4. Battery assessment platforms and services
5. Collection platforms and matching services
6. Battery chain of custody solutions (e.g. blockchain and IoT-based)

Second-life applications of batteries:

1. Energy grid and

2. Home energy storage

COMMERCIAL OPPORTUNITY:

Reconditioning of used batteries for resale as home energy storage solutions, or to be used in bulk in decentralised energy grids. There will also be a market for system integrators who specialise in repurposing used batteries (e.g. turning batches of used EV batteries into fixed industrial energy storage at scale)

BMW & Bosch In 2016, BMW started testing, in partnership with Bosch, a new utility-scale energy storage facility in Hamburg, Germany. It uses 2,600 battery modules from more than 100 electric vehicles for a total power capacity of 2 MW and a storage capacity of 2.8 MWh.

Relectrify has developed a "plug and play" system that enables and facilitates the transition of batteries from EVs into a second life in residential solar storage, commercial peak-shaving, grid support and beyond. It does so through an intelligent monitoring and electronic control technology that delivers personalised health care to battery cells within large battery packs.

3. Raw material recovery (e.g. nickel, cobalt, lithium)

COMMERCIAL OPPORTUNITY:

Either a franchise chain, or locally/ community-run micro-factories with the capabilities to dismantle and process a whole range of used electronic products, including batteries, in small batches. They would operate according to nationally approved, open-source safety guidelines and best practices. They would provide an opportunity for local employment and upskilling as well as a solution to E-waste, currently estimated at approx. 20kg per person in New Zealand[75].

Mint Innovation is developing recovery processes that use inexpensive chemicals and proprietary microorganisms to bind and concentrate specific metals such as gold under environmentally benign conditions.

"Our platform aims to be modular and adaptable to input applications such as low-grade ores, tailings and electronic wastes. It may also be tailored to help remediate environments contaminated with toxic metals."

[75] https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx

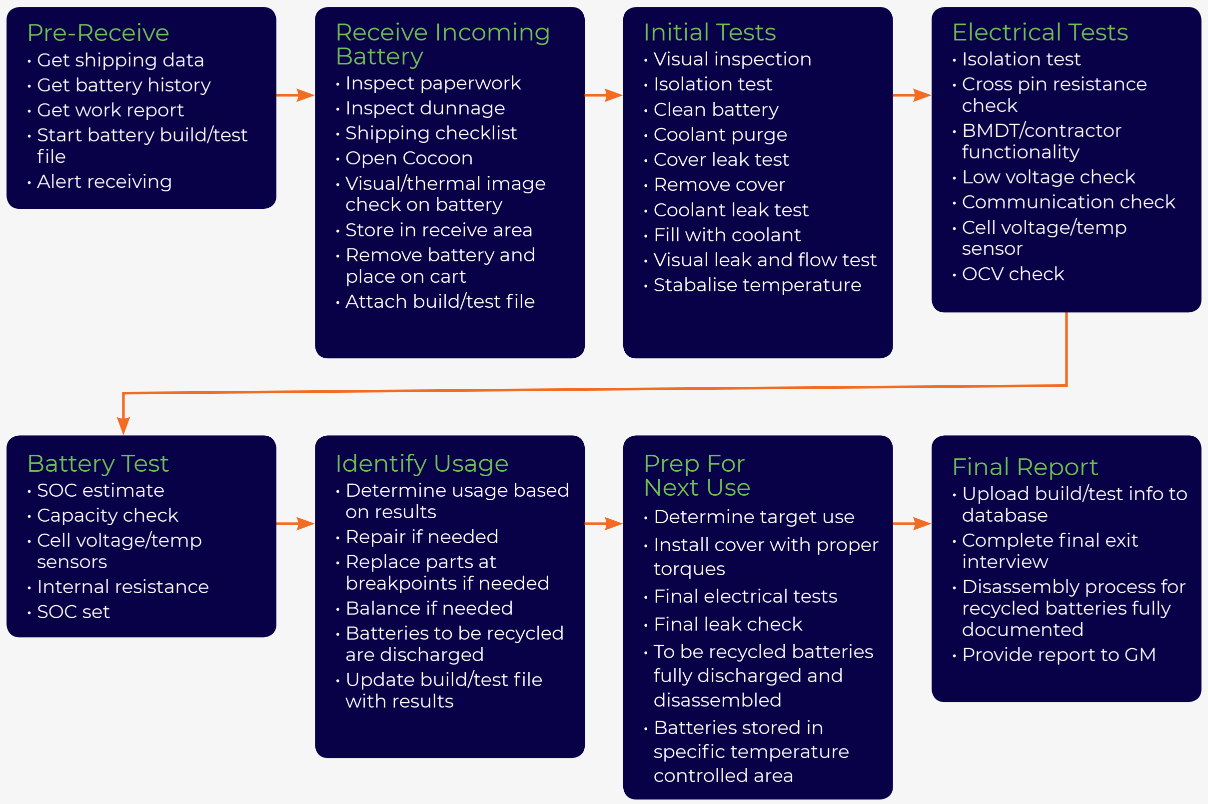
opportunities in the new battery ecosystem continued

Astara Technologies Limited has been active in the lithium battery space since 2008. A significant amount of research and development and 'hands on' projects have been undertaken on: drive, control, charging and storage systems for electric vehicles (EVs) and stationary storage applications using lithium power systems.

Astara has built strategic overseas relationships in the advanced battery 'end of first life' space, and have visited a major hub in the U.S. to study their processes for EV batteries including grading of battery health.

A member of the Sustainable Energy Association New Zealand (SEANZ), Astara is currently investigating options for a locally-situated and resourced Advanced Battery Centre to safely and securely process large-format lithium batteries for second-life applications and end-of-life materials recovery and disposal. This could potentially provide regional upskilling and employment opportunities for NZ.

Example process flow for batteries at an Assessment Centre (source: ATC)



4. Battery assessment platforms and services

COMMERCIAL OPPORTUNITY:

Companies which can provide an accurate and convenient financial 'residual value' of used batteries and a market valuation of either repurposing or recycling used batteries. This could include a digital self-assessment kit or process for battery users. A key opportunity is a solution to easily assess battery health and assess where a battery is its lifecycle, given its manufacturer, use etc. This could include a digital self-assessment kit / process for battery users.

Assessment of battery health could also take place at a central assessment centre(s), the services of which includes the collection / reverse logistics and storage of used batteries.

Such companies could either provide the full service or a user-friendly platform and/or marketplace for users to sell their assets into a second-use market.

5. Collection platforms and matching services

COMMERCIAL OPPORTUNITY:

User-friendly (both direct end consumers and business users such as leasing companies) schemes that incentivise and allow for easy assessment and collection/ transportation of used batteries. Likely to have a digital web/app-based user interface. Could be integrated into battery manufacturer's after-sales offering, or provided as an independent service.

TradeMe is the largest Internet auction website operating in New Zealand. It does a great job of matching users with used batteries, with those interested in refurbishing used batteries for second life.

However, generic platforms like Trade Me will not guarantee the safety or quality of used batteries, nor do they provide a user-friendly means of matching used batteries to second-life applications, based on design specifications.

6. Battery chain of custody solutions (e.g. blockchain and Internet of Things-based)

COMMERCIAL OPPORTUNITY:

New digital, supply chain and technical services (e.g. using the blockchain /Internet of Things / Artificial Intelligence / big data) to support the circular economy including tracking chain of custody, providing high quality waste data and enabling collaboration will be a commercial opportunity.

The Blockchain, for example, offers exciting potential to enable effective data-gathering through a digital ledger. This has enormous implications for ensuring a traceable route to proper recycling at end of life and a means to correctly apportion costs of reuse and recycling.

Furthermore, if commodity prices for key materials continue to rise, and the key demand for batteries is in vehicles, then this could make it more attractive for manufacturers to take back and recover the materials than to repurpose them.

Everledger Ltd is applying its experience establishing the provenance of diamonds to improve the sustainability of lithium ion batteries to support the new energy future and meet the goals of the Paris Accord. It has built a digital ledger validating the provenance of diamonds, gemstones, fine wines and other high-value and/or high-risk assets. Everledger is currently developing a similar construct to track and trace the lifecycles of lithium-ion batteries, from battery manufacturer to assembly, trade dealership, repurposing and responsible recycling at end of life. By assigning each battery a digital thumbprint, the company is focused on improving efficiencies for life extension, repurposing and recycling and thereby reducing mining demands and eliminating disposal.

what's next?

In this paper, we used the three 2030 scenarios to explore opportunities for New Zealand. As discussed, given the pace of change of battery technology, this Paper is intended to provide a snapshot of developments in the battery industry and circular opportunities for New Zealand. The topics discussed in this Paper are intended to inspire New Zealand businesses to seize the opportunities that a circular economy for batteries will generate.

The Battery Industry Group (B.I.G.)

The Battery Leaders Group was formed by Vector in August 2018 to explore circular solutions and responsible end-of-life management of large batteries in New Zealand. The Group fed into the research shared in this Paper and the Technical Addendum.

The members of the Battery Leaders Group are now part of a wider 'Battery Industry Group', funded by industry and Government. B.I.G. will design some of the new enablers for the circular economy ecosystem we wish to see, such as a circular Product Stewardship Scheme for large batteries and safety guidance for second-life batteries.

This Paper and Technical Addendum are intended to provide the vision and context for such a Scheme. A Core Delivery Team (B.I.G. Chair Vector, Lead Researcher Eunomia and Project Coordinator WasteMINZ) will meet regularly to design the proposed Scheme and will be accountable to the B.I.G. Governance Group.

B.I.G. has three working groups: a Safety & Logistics Group, a Battery Innovation Hub and a Battery User Group, and new members are welcome.

The working groups, plus an Advisory Group (including the Ministry for the Environment, Everledger and the Global Battery Alliance) and a Stakeholder Reference Group from across the battery value chain, will inform the Scheme design.

The aim of the B.I.G. is to deliver a **proposal for a circular Product Stewardship Scheme** for large batteries (EV and stationary) which is:

- Applicable to all large batteries but focused on lithium-ion
- Aligned with other related schemes such as Tyrewise, whole-vehicle end-of-life scheme etc but design a scheme that responds to the unique characteristics of the battery value chain
- Aligned with smaller batteries where possible
- Flexible and adaptable, given the nature of battery E-waste
- Appropriate for the unique characteristics of large batteries (potential for reuse, changing chemistries and technologies)
- Inclusive i.e. developed with input from a wide range of stakeholders
- Self-financing
- Tested (uniquely this proposal with test end-of-life stewardship in parallel)
- Practical e.g. provides guidance around safe use, transport, storage and end-of-life of used batteries
- Supporting a circular economy for batteries

Join us on the journey to a New Energy Future

In order to move to a new energy future, we need a complete systems-shift from a linear battery value chain to a value loop. We need to remember that batteries are part of a wider, interconnected system and that we are stewards responsible for battery products and materials throughout their lifecycles.

We need to innovate - and to optimise the value of the materials that are extracted and processed to make our batteries, which are key to powering the Fourth Industrial Revolution.

Transparency and open communication of our successes and failures will be key. We must learn from, and collaborate with, our Australian and Pacific Island neighbours, our indigenous cultures and international leaders to help embed this new way of thinking and scale solutions across the region.

We can't do it alone – we hope you will join us on our journey to a circular future.

Want to know more? Contact us at: sustainability@vector.co.nz and visit www.big.org.nz

vector