THE MCKELL INSTITUTE

Capitalising on the lithium-ion waste resource challenge in South Australia

JUNE 2021

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ABOUT THE REPORT

This report is funded by Green Industries SA.

The McKell Institute and the authors would like to thank all who have contributed feedback, information and data to support this project.

Government of South Australia

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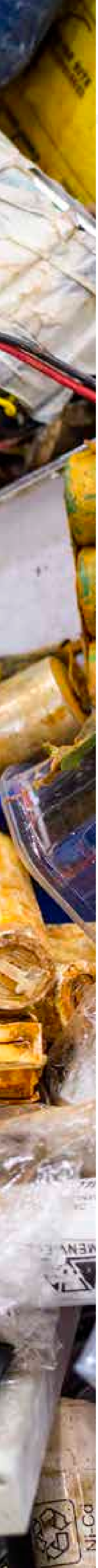

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LEFT: IMAGE COURTESY GREEN INDUSTRIES SA

TERMINOLOGY AND ABBREVIATIONS

2LB........................Second-life Battery

BESS.....................Battery Energy Storage System

BSC.......................Battery Stewardship Council

EBU.......................Equivalent Battery Unit

EOL.......................End of Life.

EV..........................Electric Vehicle

HEV.......................Hybrid Electric Vehicle

ICE.........................Internal Combustion Engine

KT...........................Kilotons

LIB.........................Lithium-ion Battery

MT..........................Metric Tonnes

OEM.....................Original Equipment Manufacturer

PHEV...................Plug-in Hybrid Electric Vehicle

FIGURES AND TABLES

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FOREWORD

In 1991, a team of Sony engineers in Japan first brought to market a radical new technology: the lithium-ion battery (LIB). Today, most of us use multiple devices on a daily basis that depend on the technology: our mobile phones, laptops, charging banks, TVs, other household devices, and home energy storage systems are typically dependent on rechargeable LIBs.

Already ubiquitous in modern life, LIBs are expected to proliferate even further as passenger vehicles transition from internal-combustion-engines (ICE) to electric vehicles (EVs), powered by advanced LIBs.

Incorporating EVs into the global vehicle fleet is essential if the world is to meet its emissions targets, and avert the worst impacts of climate change. However, the rapid infusion of EVs onto global markets, coupled with the near exponential growth in demand for consumer electronics, creates new environmental challenges: in particular, responsible management and recycling of LIB waste.

Waste management is important for all materials, but perhaps especially so for LIBs. End-of-life (EOL) batteries are challenging items to process. They present fire risks, contain hazardous materials, and established recycling processes are often expensive, highly technical, and energy intensive.

In an Australian context, these challenges have largely stood in the way of developing a domestic recycling or processing capacity for LIB waste. Instead, LIBs are either often stockpiled, sent offshore for processing, and in many cases end up in landfill – which presents a genuine safety risk for existing waste management authorities and businesses.

This inadequate status quo is not just bad for Australia's environment, it comes at a cost: the CSIRO estimates this LIB waste management sector in Australia could be worth $3 billion, were it to emerge, by the mid 2030s, with low case estimates still predicting a recoverable value of over $700 million. The size of this market is significantly less in South Australia, but still presents a unique opportunity for the state's economy – particularly in the context of a post-COVID recovery.

To date, little research aimed at identifying a path towards a LIB recycling or management sector has been undertaken in Australia. This report, however, attempts to outline how South Australia specifically could take advantage of this challenge, and emerge as a national and regional leader in LIB reuse, recycling, and repurposing.

While Australia's LIB waste stream remains relatively modest, it is expected to grow substantially in coming years. This gives South Australia the time to identify how the state can capitalise on the economic prospects found in developing this emerging sector, and implement forward thinking policy that positions the state to achieve this aim and become a policy leader in this critical area of waste management.

This report outlines a vision for SA to emerge as an Australian LIB waste resource management hub. It describes how the state can capitalise on its clean-energy credentials and circular economy leadership to become the natural home for a burgeoning industry, ultimately creating over 300 local jobs in the process.

MICHAEL BUCKLAND
CEO, MCKELL INSTITUTE

EXECUTIVE SUMMARY

The shift towards cleaner forms of energy and EVs are vital if Australia and the world are to mitigate the worst aspects of climate change, but the reliance of these technologies on lithium-ion batteries creates a challenging externality: battery waste.

It's not just EVs and home energy storage systems that are composed of LIBs. Since their commercialisation in 1991, LIBs have become a ubiquitous feature of the modern world. LIBs are found in smartphones, computers, and other consumer electronics. And the growth in demand for LIBs presents new challenges and opportunities for the waste management sector, which is explored in this report.

Today, Australia has only a modest capacity to recycle LIB waste domestically. Currently, LIB waste is collected by a patchwork of private sector actors who often export it for processing mainly to South Korea for recycling. While challenging to precisely identify the quantity of LIB waste that is collected in Australia, it is estimated that just 3-5 per cent of Australia's LIB waste is collected for responsible end-of-life processing in Australia – a rate similar to the United States. This compares with an estimated (and mandated) 45 per cent in the European Union, and similar rates in East Asian markets like South Korea and Japan. Given the national volume of LIB waste is growing by 20 per cent every year, government action on dealing with this challenge is well overdue.

This report explores this challenge through a South Australian lens, identifying the opportunities for South Australia's economy in developing a local capacity to engage in various LIB waste management practices – a $3 billion national industry yet to be developed significantly in Australia, and which provides South Australia a unique opportunity.

PART 1 explores the LIB waste challenge, offering a snapshot into the drivers of LIB waste, such as the growth in handheld devices, home energy storage devices, and the forecast growth in the EV market. It highlights the market dynamics at play that are driving this waste stream globally and in Australia. It also quantifies the scale of this challenge in South Australia, forecasting that the total LIB waste stream in the state is expected to reach around 10,000 tonnes per year by the mid-2030s. While this waste stream is likely too modest to sustain a local recycling industry alone, SA is well positioned to emerge as a centralised hub for managing Australia's national LIB waste stream in the years ahead.

PART 2 explores the nature of LIB waste management in Australia. It is clear that, while there is growing attention being paid to the LIB waste challenge in Australia, there is still much that needs to be done to ensure governments have the right policy settings in place, and industry has the support required, to responsibly handle this issue onshore. Part 2 details the complex recycling processes involved in handling LIB waste, and outlines how second-life batteries – batteries which are re-used for secondary storage applications before being recycled – are being creatively utilised in international settings. It also comments on the importance of developing markets for LIB waste to enable a sustainable and self-reliant recycling ecosystem to emerge, and how China's dominance in the raw-material supply chain for LIBs should compel Australian policymakers to prioritise the extraction of raw materials from LIBs to create new exportable commodities.

PART 3 works to identify the role South Australia should seek in LIB waste processing in Australia. South Australia is in a strong position to emerge as a national and regional LIB waste management hub, an opportunity that could create over 300 jobs in the medium term for the state in reprocessing LIB waste resources alone. However, there are real market considerations that need to be factored into any incentives or support measures provided by the Government of South Australia. An industry focused solely on recycling LIB waste to extract metals such as cobalt is highly vulnerable to international commodity prices. To ensure its economic viability, a future South Australian LIB recycling industry would be safeguarded by consolidating a majority of Australia's (and the region's) LIB waste resource, as well as diversifying its output to include not only raw materials, but second-life batteries, too. This section also notes that, while the global battery manufacturing market is contested, there is a considerable opportunity for South Australia in fostering second-life battery innovation.

PART 4 then tables a best practice framework for LIB waste management in Australia. Adherence to these principles has guided six recommendations addressed to the Government of South Australia below. This section emphasises the need to address South Australia's poor LIB collection rates, in order to prepare for the growing waste challenge that is emerging. It also highlights the range of measures that need to be adopted at a national level to best realise the LIB waste management potential of Australia, but the Government of South Australia can also take considerable steps forward to position itself as the home for Australia's LIB waste management sector.

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KEY FINDINGS

FINDING 1:

Australia's LIB waste resource stream is growing. The proliferation of LIBs in consumer electronics, EVs, and household storage devices creates a significant waste resource challenge. Consumer practices and industry capabilities needs to be developed to manage the existing LIB waste stream, in anticipation of growing future volumes. By 2035, it is expected that 137,000 tonnes of LIB waste will be generated annually across Australia, with close to 10,000 tonnes generated in South Australia alone.

FINDING 2:

There are economic opportunities for SA in LIB waste resource management. While LIB waste creates a challenge, there are considerable economic opportunities for the state in processing LIB waste and repurposing second-life LIBs. The CSIRO has forecast that the recoverable value of end-of-life LIBs could exceed $3 billion by 2035.

FINDING 3:

Forecast growth in EV use requires policy to ensure end-of-life EV LIBs are adequately handled. Though the EV fleet in Australia remains modest, it is expected to exceed 450,000 vehicles by 2030, with over 30,000 EVs in South Australia alone. The growth in this fleet creates new LIB waste resource management challenges.

FINDING 4:

LIB recycling is complex and expensive – but potentially lucrative. LIB handling, collection, processing and recycling can be labour, energy and capital intensive. However, if performed at scale, it can create highly valuable export products, strengthening South Australia's economy.

FINDING 5:

South Australia has existing assets that could be expanded to process LIB waste. South Australia's existing refining and metals processing infrastructure could be expanded upon to develop new processes aimed at recycling LIB waste resources.

FINDING 6:

South Australia can position itself as a national LIB waste resource management hub.
South Australia is well positioned to emerge as a national LIB recycling hub. Its geographic location and reputation as a clean-tech leader positions the state well to work to attract talent, innovation and investment into the state.

FINDING 7:

A South Australian LIB recycling industry could generate over 300 local jobs.
A South Australian LIB recycling industry would likely create over 300 local jobs, if the industry positioned itself to capture a significant portion of the growing LIB waste stream from other Australian jurisdictions, and potentially internationally.

FINDING 8:

South Australia cannot solve the LIB waste resource challenge alone. South Australia, through the combined efforts of the government and industry, can take meaningful steps to position itself as a leader and a natural home for LIB waste management in Australia. But significant policy steps need to be taken at federal and international levels. South Australia should aspire to serve as a leader in LIB waste management policy and innovation.

RECOMMENDATIONS

RECOMMENDATION 1

Explore the establishment an Australian LIB Waste Resource Management Hub in the state.

South Australia could emerge as the epicentre of Australia's LIB waste resource management industry. While a modest LIB recycling capacity has emerged in Victoria, the current national recycling capacity is around 3000 tonnes of waste per year – around 2 per cent of the expected LIB waste stockpile forecast to be circulating in Australia by 2035. As South Australia considers its post-COVID recovery, it should explore ways to capitalise on future-facing industries such as LIB waste resource management, in close consultation with industry and the battery peak bodies, and seek financial assistance where necessary from national bodies such as the Clean Energy Finance Corporation.

RECOMMENDATION 2

In collaboration with industry, improve the coordination of EV and LIB waste management in the state, focusing on educating and working with the sector to develop best-practice collection, pre-treatment and disassembly of LIB waste.

Participants in this study made it clear there was little coordination over tackling the LIB waste challenge in the state. While there is a growing understanding of the problem, there is little certainty over how the issue will be managed when the volume of LIB waste grows by 2035. The Government of South Australia should play a facilitating role in overcoming this challenge, working with the sector to identify the skills and equipment required to improve the collection and pre-treatment of SA's existing LIB waste, in preparation of large waste flows in the future. Additional LIB waste collection, and public awareness raising over the need to responsibly handle end-of-life LIB waste, would also help achieve a greater rate of recycling of existing LIB waste, and prepare the community to responsibly handle increase LIB waste streams in the future.

RECOMMENDATION 3

Incentivise international start-ups in second-life battery industry to establish themselves in South Australia, offering industry connections, start-up capital, and work with Australia's automotive sector to secure second life battery supply to develop novel solutions to EV and LIB waste.

The Government has made significant steps towards the creating of a start-up ecosystem in South Australia. This should be extended to realising opportunities in the EV and LIB waste sectors, including integration of second-life batteries into electric vehicle charging networks and remote area energy supplies. There is a growing international community of start-ups utilising second-life batteries for applications such as portable storage devices, home energy storage systems, public infrastructure, furniture with in-built device charging, developing-world focused energy storage, outboard motor replacements, and more. South Australia should aspire to be a home for this innovation stream.

RECOMMENDATION 4

Work to leverage SA's existing industrial and manufacturing assets to develop LIB recycling capacity.

The Government of South Australia could work with industry to understand the recycling capabilities or investment requirements of existing metal processing assets, including large smelters in Port Pirie and Whyalla, to incorporate end-of-life LIB and other battery metal processing.

RECOMMENDATION 5

Work through the National Cabinet to harmonise regulations regarding the transportation of dangerous goods in each state, to lower compliance costs for transporting LIBs and LIB waste within Australia.

Despite a growing degree of uniformity in various jurisdictions' approach to e-waste management, there is still confusion over differing waste management regulations in each state and territory, particularly with regards to the transportation of hazardous waste, including LIBs. For South Australia to emerge as a national processing hub for LIB waste, it needs to contribute to a process that streamlines hazardous waste transportation regulations nationally that will lower compliance costs for transportation firms delivering waste streams to South Australian processers.

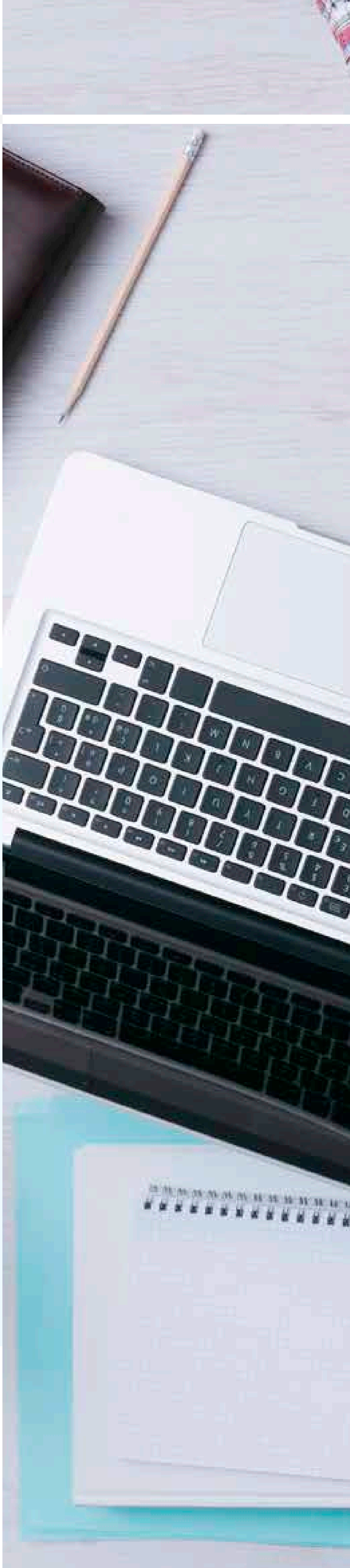
RECOMMENDATION 6

Working with industry, develop guidelines over LIB labelling, which could be harmonised at a national level.

LIB labelling remains a challenge for the recycling industry. LIB waste must be labelled in a clear, colour-coded manner which makes the identification clear for consumers and LIB waste handlers. The Government of South Australia should work closely with the Battery Stewardship Council to ensure LIB appropriate labelling regulations are adopted in the state, and use its seat in the National Cabinet to help advance a nationally consistent labelling framework. Particular attention should be payed to similar initiatives that have been proposed in the European Union, with any South Australian scheme ideally achieving consistency with international best practice.

PART 1: THE LIB WASTE RESOURCE CHALLENGE

1.1: The Coming Wave of Lithium-Ion Waste



KEY POINTS

1. The looming growth in EVs, and rapid growth of personal devices utilising LIBs, has created a significant waste management problem no Australian jurisdiction has sufficiently tackled.
2. Trends suggest the LIB waste management challenge will continue to grow in Australia and internationally.
3. A priority for governments should be managing the existing LIB waste flow, in preparation for the forecast growth in LIB waste as a result of the EV revolution.
4. Australia's inability to collect, process, reuse and recycle LIB waste comes at a cost, with the CSIRO estimating a $3 billion industrial opportunity is being missed.

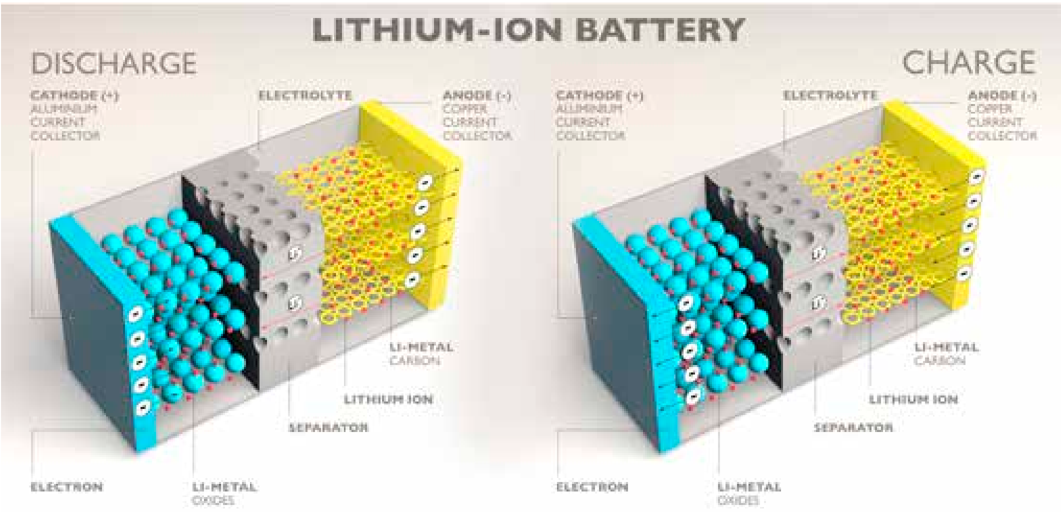
WHAT IS A LITHIUM-ION BATTERY?

- **Lithium-ion batteries (LIBs) are energy storage devices found in a range of modern applications, from smartphones to tablets, computers, household appliances, and more recently, electric vehicles.**
- **LIBs are 'secondary batteries', which means they are able to be re-charged.**
- **There are a large range of LIBs, each with different applications and composed of different raw materials. However, all LIBs are produced with a diverse number valuable commodities, many of which retain their utility, and are recyclable, once an LIB is extracted from its original application.**

What are LIBs and how do they work?

Lithium-ion batteries are part of everyday life. Every South Australian with a smartphone, laptop, home battery energy storage system (BESS), electric vehicle (EV) and other devices are consumers of lithium-ion batteries, or LIBs. The proliferation of LIBs has facilitated rapid technological advances, and enabled policymakers to aspire to an emissions free transport future with EVs. But the increasing uptake in LIBs creates new challenges for waste management. LIBs do not last forever – and they are difficult to dispose of responsibly. They are also technically challenging to recycle. This report explores the nature of this waste challenge, while articulating opportunities for South Australia's economy in making the state a national hub for LIB waste management.

FIGURE 1.1 DIAGRAM OF A LITHIUM-ION BATTERY.



Source: CivilsDaily.[1]

LIBs create electricity by generating a flow of electrons caused by a chemical reaction. The electrons exit the negative terminal (the anode) of the battery before being transferred through a device, and re-entering the battery through its positive terminal (the cathode).

It is the lithium itself that kick-starts this chemical process. The lithium in the anode is predisposed to releasing individual electrons, which flow from the anode through the electronic device, before re-entering the cathode.

The term 'lithium-ion' battery is derived from this chemical reaction caused by the lithium component of the battery, but in actuality, LIBs are composed from a diverse range of highly valuable commodities, which through complex processes can be harvested from disused LIBs, and re-integrated into the LIB supply chain.

LIB production is a five step process

Australia does not currently manufacture LIBs, nor add significant value domestically to the raw materials it exports which are refined and utilised for LIB manufacturing offshore. A major 2018 Australian Government study into the LIB value chain broke down the process, explaining that Australia's role is concentrated to the mining phase of the LIB value chain:

TABLE 1.1 LIB VALUE CHAIN.

PHASE 1 EXTRACT AND PROCESS	MINING (AUSTRALIA)	Identify and extract ore Mill spodumene concentrate into a powder Roast to create a concentrate Export (Australia)
	PROCESSING	Spodumene is mixed with sulphuric acid and subjected to water leaching to extract lithium sulphate Sulphate is purified into lithium hydroxide Further processes to create lithium hydroxide
PHASE 2 MANUFACTURE AND ASSEMBLE	ELECTROCHEMICAL PROCESSES	Manufacturers utilise raw material for patented processes designed for customers Cathode material is applied to aluminium foil collector Graphite anode material applied to cooper foil collector Lithium-based electrolyte is produced
	CELL PRODUCTION	Stack cathode, separator, and anode Insert into casing Insert electrolyte Seal and prime the cell by charge and discharging
	ASSEMBLE	Assemble cells into battery packs Connect cells electrically Attach battery management system

Source: Austrade.

The LIB waste stream is diverse

This report places significant attention on the challenges faced with the forecast growth in EV LIB waste in both South Australia and nationally. The LIB waste challenge is, however, already evident due to the rapid proliferation of LIBs. These different applications also demand different types of LIBs. Indeed, the growing diversification of LIBs and battery products more broadly is one of the major obstacles to streamlining the recycling and recovery process, given the logistical complexity associated with isolating specific batteries before proceeding to pre-treatment and processing.

Of course, the core recyclable materials within the cathode, anodes and electrolyte of LIBs – the valuable metals, like cobalt, lithium, nickel, manganese and graphite – are often housed in a range of casings, many of which are themselves recyclable. To date, most LIB recycling processes do not focus on extracting recyclable casings, instead opting to focus primarily on extracting the most valuable material, which as of November 2020 is typically cobalt.

TABLE 1.2

MOST COMMON TYPES OF LIBS, THEIR VALUABLE MATERIALS, AND APPLICATIONS.

TYPE OF LIB	COMMON ABBREVIATION	VALUABLE COMPONENTS	APPLICATION
Lithium Cobalt Oxide (LiCoO2)	NMC	Lithium, cobalt, graphite, aluminium	Handheld devices, laptops, cameras
Lithium Manganese Oxide (LiM2O4)	LMO	Lithium, manganese	Some EV batteries, medical devices, power tools
Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2)	NMC	Lithium, manganese, nickel, cobalt	E bikes and scooters, EVs, medical devices and various industrial applications
Lithium Iron Phosphate (LiFePO4)	LFP	Lithium, iron, phosphate, graphite	Various stationary storage applications
Lithium Titanate (Li2TiO3)	LTO	Lithium, titanate, manganese	Some EV powertrains

Source: Battery University.[2]

The LIB waste challenge is receiving more research attention

A growing literature in Australia has identified the LIB waste management challenge State and Federal Governments are facing, as well as the inherent value of that waste stream that is being forgone by disposing valuable waste, and exporting much of it overseas for processing. The CSIRO identified an estimated $813m to $3bn worth of valuable components currently ending up in landfill in a major 2018 study.[3] The report estimates 3,300 tonnes of LIB waste is produced each year and that this figure will grow by 20 per cent each year.[4]

Much of the innovation in LIB waste policy and technology is located within the European Union (EU). The EU waste collection and recycling industry revenue is valued at US$150bn, approximately 75 per cent of worldwide revenue, an achievement that has been driven by the EU's more stringent laws regarding battery recycling.[5] In 2016, more than 45 per cent of batteries were recovered under the EU scheme. While some EU Member States did not meet their targets,[6] the EU still oriented around 50 per cent of its battery mass towards recycling.[7] It has pushed for stronger targets and compliance measures with new recycling ambitions for 2030 and 2035 detailed by the EU in late 2020.[8]

Across Asia, there is also considerable research into the viability of lithium-ion battery recycling, particularly in South Korea. Dewulf et al. (2010) report that recycling lithium-ion batteries can result in a 51.3 per cent natural resource savings, not only because of decreased mineral ore dependency but also because of reduced fossil resource and nuclear energy demand.[9] In South Korea, the first electric vehicle battery recycling organisation has already been established in Yeongwang County, South Jeolla Province.[10] The facility will be in charge of disassembling EVs and recycling used batteries.

There is also growing research into automotive lithium-ion battery recycling given the growing consumer demand in many places in the world which is being met by large corporations like Tesla. Gaines (2014) describes a working system for recycling such batteries, using lead-acid battery recycling as a model.[11] While Gaines concedes recycling lithium-ion batteries is more complicated, many of these batteries will not require recycling for another decade.

While the challenge of LIB waste is increasingly understood, and steps are being taken to improve resource recovery, there remains considerable room for improvement across the world. This presents opportunities for countries like Australia to emerge as leaders in LIB end-of-life management, particularly within the Asia Pacific region.

Future LIB waste streams present an opportunity – but today's LIB waste issue must be addressed as a priority

As this report highlights, there are considerable opportunities for South Australia in developing a local LIB recycling capacity. However, in order to best position the state for that opportunity, the Government of South Australia should also work to improve the state's handling of existing LIB waste flows mainly from handheld devices, such as mobile phones. While there are national schemes in place to handle this waste stream with relative efficiency, it is clear that a significant portion of today's LIB waste stream is still ending up in landfill.[12] Improving community understanding of the importance of LIB waste management, and working with stakeholders throughout the recycling value chain to improve recycling rates of today's LIB waste streams, will be an important step in preparing the state to successfully capitalise on the economic opportunities future LIB waste streams present.

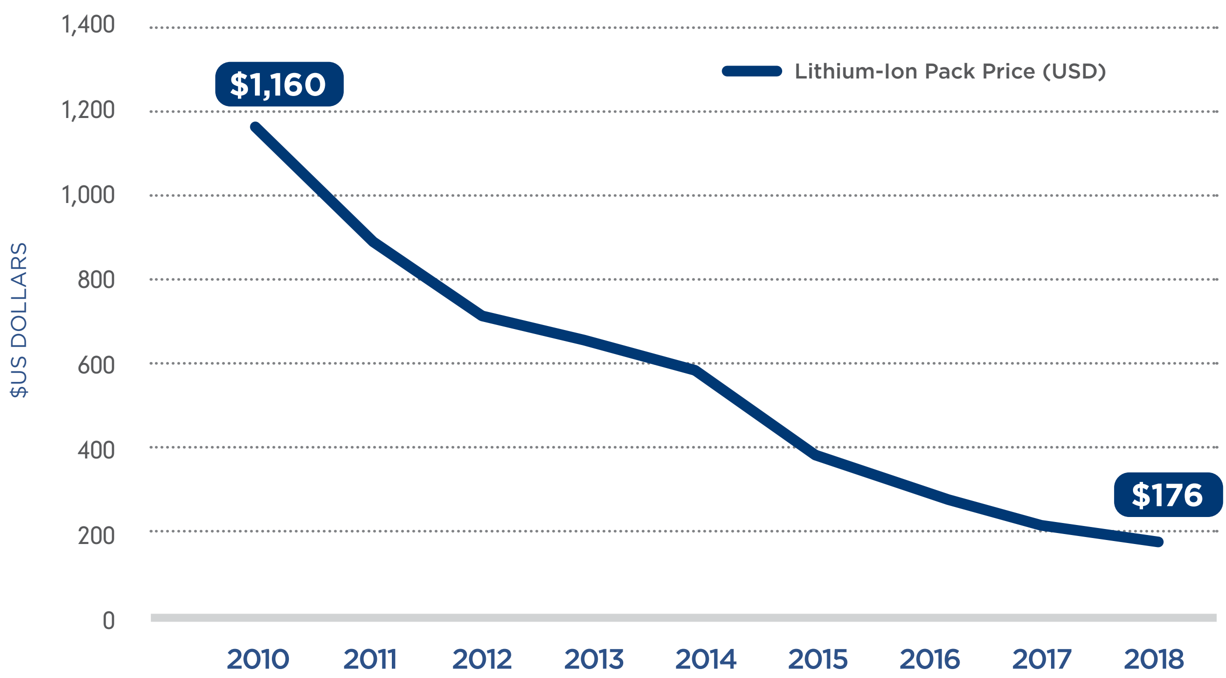
1.2: The Electric Vehicle Revolution

KEY POINTS

1. Australian consumers have been slow to embrace EVs, but they are here to stay.
2. LIBs are getting cheaper, which will see EVs become cost-competitive with traditional internal-combustion engine passenger vehicles by the mid-2020s.
3. The automotive sector is responding with transformative investments: a clear trend towards EV production is coming, and Australia needs to have policies in place to embrace that switch while safeguarding the environment through EV waste management.

The automotive industry is embracing an EV future

FIGURE 1.2 THE COST REDUCTION IN LIB PACKS, USD, 2010-2018.



Source: BloombergNEF.

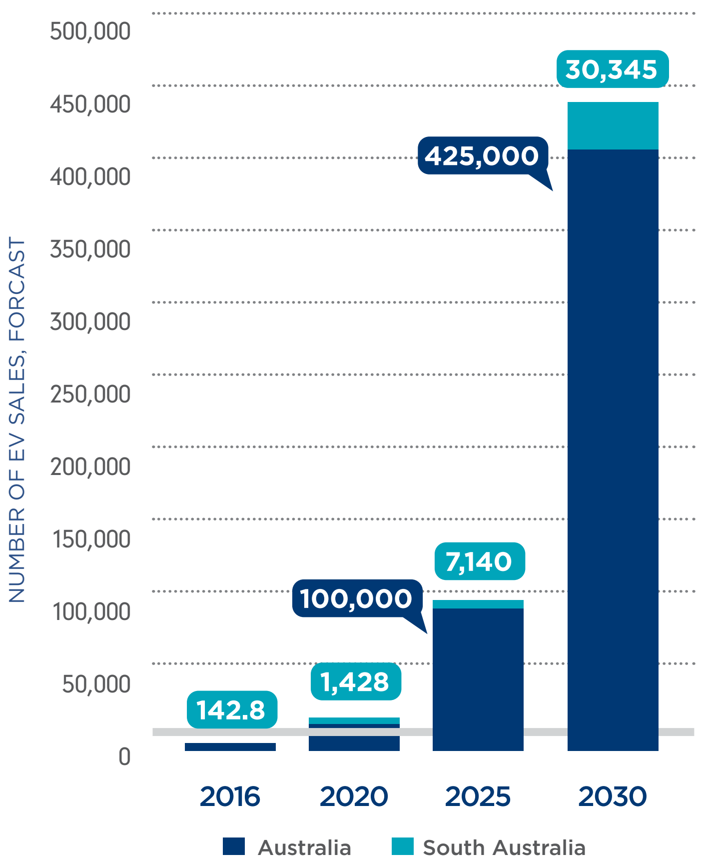
Market trends are exacerbating the LIB waste management challenge. In the past decade, the price of LIBs has fallen dramatically for EVs, but also for any other device incorporating LIBs (*Figure 1.2*). At the same time, automotive firms globally have been investing billions into EV research and development to drive down costs, all but ensuring the future of mobility will be electrified.

EVs will contribute significantly to future LIB waste volumes

Currently there are 22 types of electric vehicles – 9 are battery run and 13 are plug-in hybrid models – in the Australian passenger vehicle market.[13] Electric vehicles sales have increased over the past few years, with 2,284 sales in 2017, 2,216 in 2018 and a significant jump to 6,718 sales in 2019.[14] Currently, however, there are less than 20,000 vehicles across Australia – constituting just 0.1 per cent of the 19.8 million registered passenger vehicles in Australia.[15] The CSIRO, however, expects EVs to continue to enter the Australian market over the coming decade. By 2030, it forecasts over 450,000 EVs will be driving on Australian roads, with at least 30,000 expected in South Australia alone.

FIGURE 1.3

EV SALES ARE EXPECTED TO CONTINUE TO GROW IN AUSTRALIA OVER THE COMING DECADE.



Source: CSIRO.[16]

VARIATIONS IN ELECTRIC VEHICLES

- **EV (Electric Vehicle):** Powered solely by LIBs.
- **PHEV (Plugin-Hybrid Electric Vehicle):** Power by both fuel and LIBs. The LIB's can be charged by plugging in the vehicle.
- **Hybrid:** Powered by both fuel and LIBs with the battery being re-charged by the engine.
- **Hydrogen Fuel Cell (FCEV):** Powered by LIBs that are charged by reacting hydrogen to release electrons.

EVs rely on powerful LIB chains. In some vehicles, the performance of the LIBs are sustained over extended periods of time – with regulators in California even mandating EV batteries meet performance standards for up to 10 years.[17] In some instances, however, batteries do deteriorate quicker – whether as a result of owner behaviour or the quality of the battery. Often, an EV LIB that is removed from the vehicle can be refurbished. Alternatively, many manufacturers and third parties are utilising these batteries for second life purposes, such as stationary energy storage before needing to be recycled and eventually disposed of.[18] However, there is no framework in place within Australia to capitalise on the opportunities second-life batteries offer, leaving Australia potentially ill prepared for this looming waste challenge .

EV growth trend remains clear

The embrace of EVs in Australia has been low for various reasons. While State Governments, including the Government of South Australia, advance EV strategies, this hasn't occurred at a federal level, leaving a policy void which has arguably slowed the integration of EVs into the Australian market.

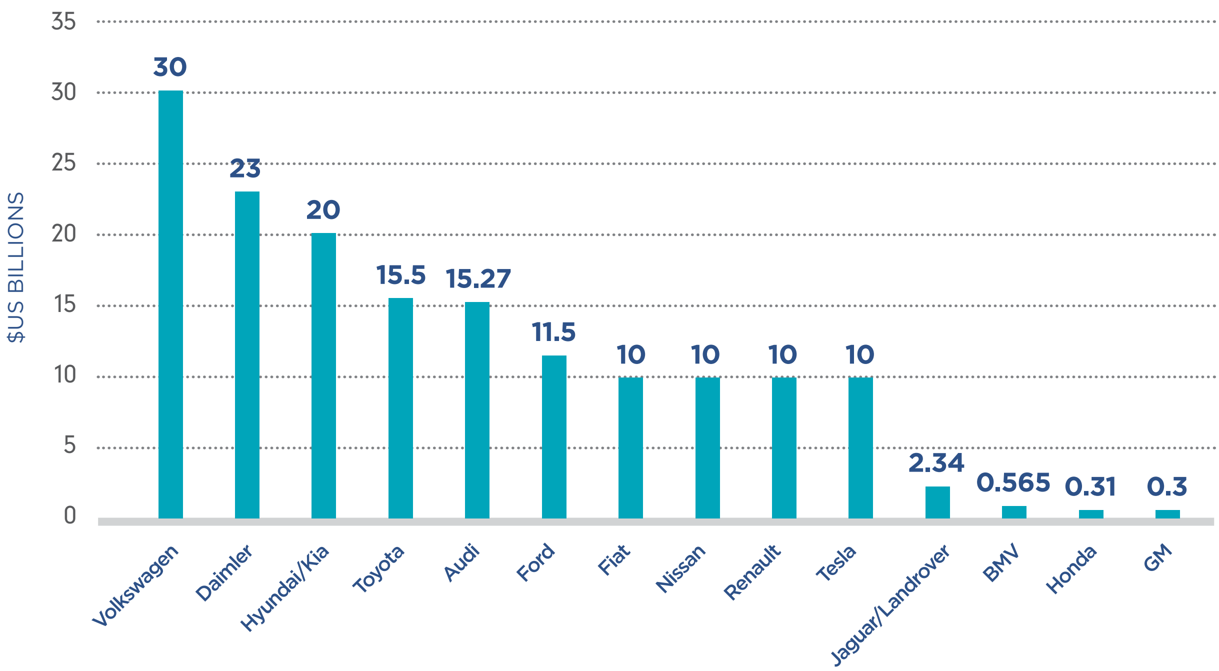
Beyond government policy, however, real market challenges have also dampened Australian consumers' appetite for EVs. Compared with traditional internal combustion engines vehicles (ICEs), EVs of all varieties remain expensive, though this is expected to change in coming years. As Ethan Zindler, head of Bloomberg NEF testified to a US Senate Committee into critical minerals in February 2019,

> " By the mid 2020s, consumers will choose EVs purely based on price".[19]

Given Australia's nascent EV market, no second-hand market for EVs of substance has emerged, limiting the purchase of EVs to a relatively niche subset of consumers. Despite this, most forecasts expect the uptake of EVs to increase in Australia. This reflects the transition by the industry itself. As *Figure 1.4* demonstrates, all major automotive firms are now investing significantly into EV production and development, which the International Monetary Fund predicts will see 250 million EVs in the global fleet by 2030 (*Figure 1.5*). While the global economic downturn from COVID-19 has affected sales forecasts for EVs in Australia and elsewhere the trend remains clear: EVs are here to stay, will continue to expand into the Australian market, and are a set to compound an already difficult LIB waste challenge.

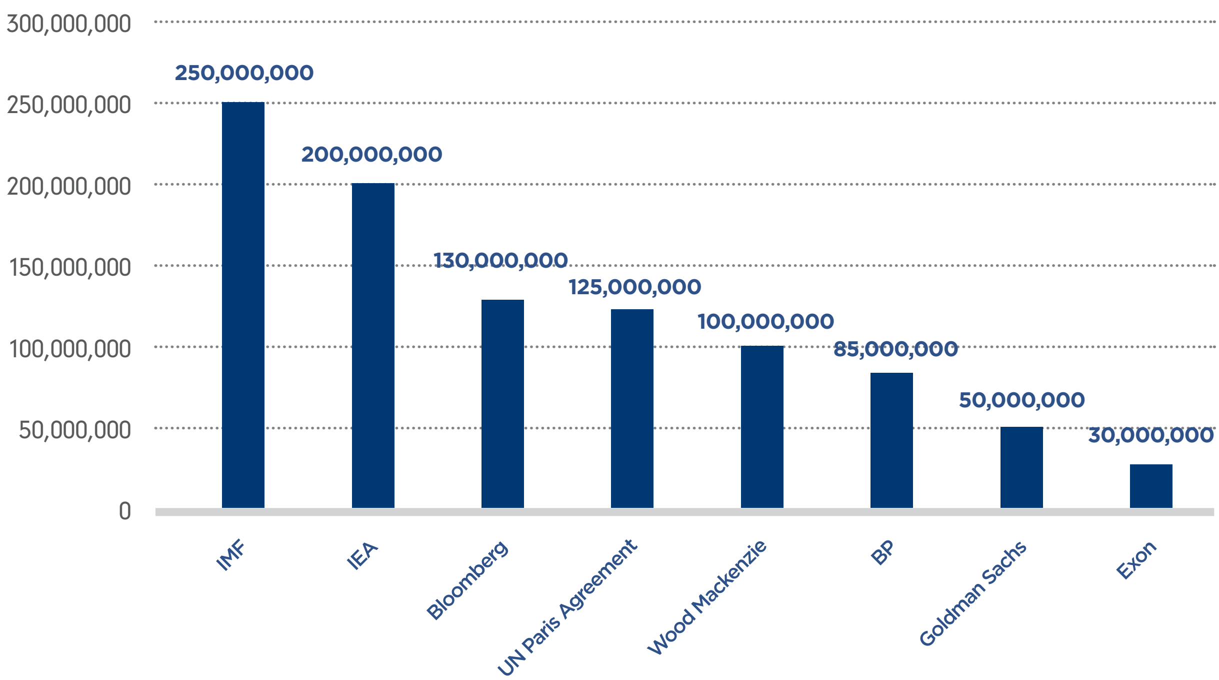

ELECTRIC VEHICLE
CHARGING STATION
Reserved for electric cars only.

FIGURE 1.4 TOTAL INVESTMENTS IN EVS BY AUTOMOTIVE FIRMS GLOBALLY (US$B).



Source: Author analysis of data compiled by the Electric Vehicles Council of Australia.

FIGURE 1.6 VARIOUS ESTIMATES OF GLOBAL EV FLEET BY 2030.



Source: Electric Vehicles Council of Australia.

Consumers expect the environmental risks of EV production to be mitigated

The environmental benefits of running an EV verses an ICE vehicle is unquestionable. However, there remain concerns over the environmental costs associated with the original production of EVs – particularly, LIBs that power EVs. Further, there is evidence consumer demand for EVs is not only curtailed by price, but also by the concerns of some that the environmental benefits of operating an EV don't outweigh the environmental concerns of manufacturing them. As has been highlighted by the World Economic Forum,

> " CO2 emissions during the production of batteries are significant, while the full life cycle emissions of batteries including its use phase are lower compared to traditional vehicles. Reducing the production footprint is a significant opportunity and major obligation to address. Improvements in the CO2 footprint can help make arguments for switching to battery applications even more compelling."[20]

Participants in this study also noted that EV consumers are highly conscious of the environmental profile of their purchase. Many consumers have 'done their research' before buying EVs, and are knowledgeable about the waste challenges associated with LIBs. It is, therefore, important for EV firms to be able to demonstrate their compliance with sustainability guidelines for LIB waste to meet customer demands – a goal which Australian governments should help the industry realise.

1.3: Sizing the LIB Waste Resource Challenge in South Australia

KEY POINTS

1. **By 2035, South Australia is expected to be generating almost 10,000 tonnes of LIB waste per year. A majority of this waste is, and will continue to be, originate from handheld devices.**
2. **While this quantity represents a significant waste management challenge, it is unlikely to be large enough a quantity to sustain a viable local recycling industry alone.**
3. **SA's LIB waste will need to be coupled with waste streams from interstate and across the region to allow for the scale required to sustain a South Australian based recycling industry.**

While it is challenging to precisely predict the volume of recoverable LIB waste that will be circulating in South Australia in the years to come, a growing evidence base enables estimates of waste volumes.

TABLE 1.3 BATTERY ENERGY STORAGE SYSTEMS (BESS) AND EV LITHIUM-ION BATTERY FLOWS IN 2017/18.

CHEMISTRY	BATTERY SALES (TONNES)	BATTERY SALES (UNITS)	BATTERY SALES (EBUS)	EOL ARISINGS (TONNES)	COLLECTION TO RECOVERY (TONNES)	COLLECTION RATE
Lithium-Ion	4,150	90,000	170,000,000	180	40	21 per cent

Source: Battery Stewardship Council.[21]

Modelling from the CSIRO has forecast LIB waste streams nationally to 2036. Using this modelling as a base, in addition to the forecasts of growth of individual LIB waste streams (i.e., mobile devices, EV batteries, and home energy storage systems) by Randell (2015), this report can estimate the likely growth in LIB waste specific to South Australia.

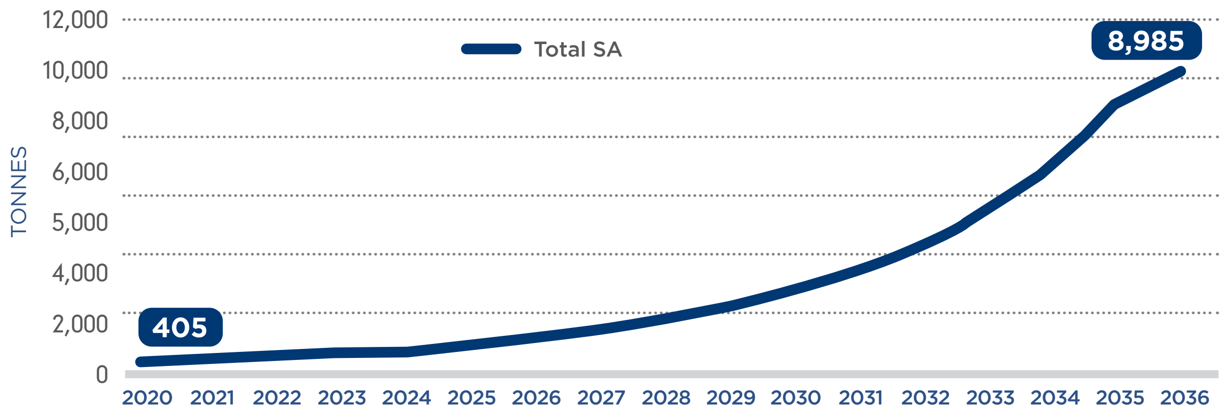
Using the CSIRO's estimates as a base, it is projected that approximately 120,000 tonnes of LIB waste will be produced in Australia annually by 2035. Were South Australia to see a quantity of this waste proportionate to its population, it is expected that South Australia will produce slightly over 8985 tonnes of LIB waste per year by 2035. The expected quantity of South Australia's LIB waste presents a genuine waste management challenge, but is also unlikely to be large enough to sustain a localised LIB recycling facility without incorporating waste from interstate and potentially international waste streams.

TABLE 1.4 BATTERY SALES BY CHEMISTRY IN AUSTRALIA, 2017/18.

BATTERY CHEMISTRY	WEIGHT (TONNES)	NUMBER
Lead acid	159,690	10,160,000
Lithium ion	13,010	35,830,000
Alkaline	8,040	276,600,000
Nickel metal hydride	600	6,320,000
Other	310	42,520,000
Nickel cadmium	190	2,140,000
Lithium primary	90	24,480,000
Zinc air	10	25,910,000
Silver oxide	4	4,050,000
TOTAL	**181,944**	**428,010,000**

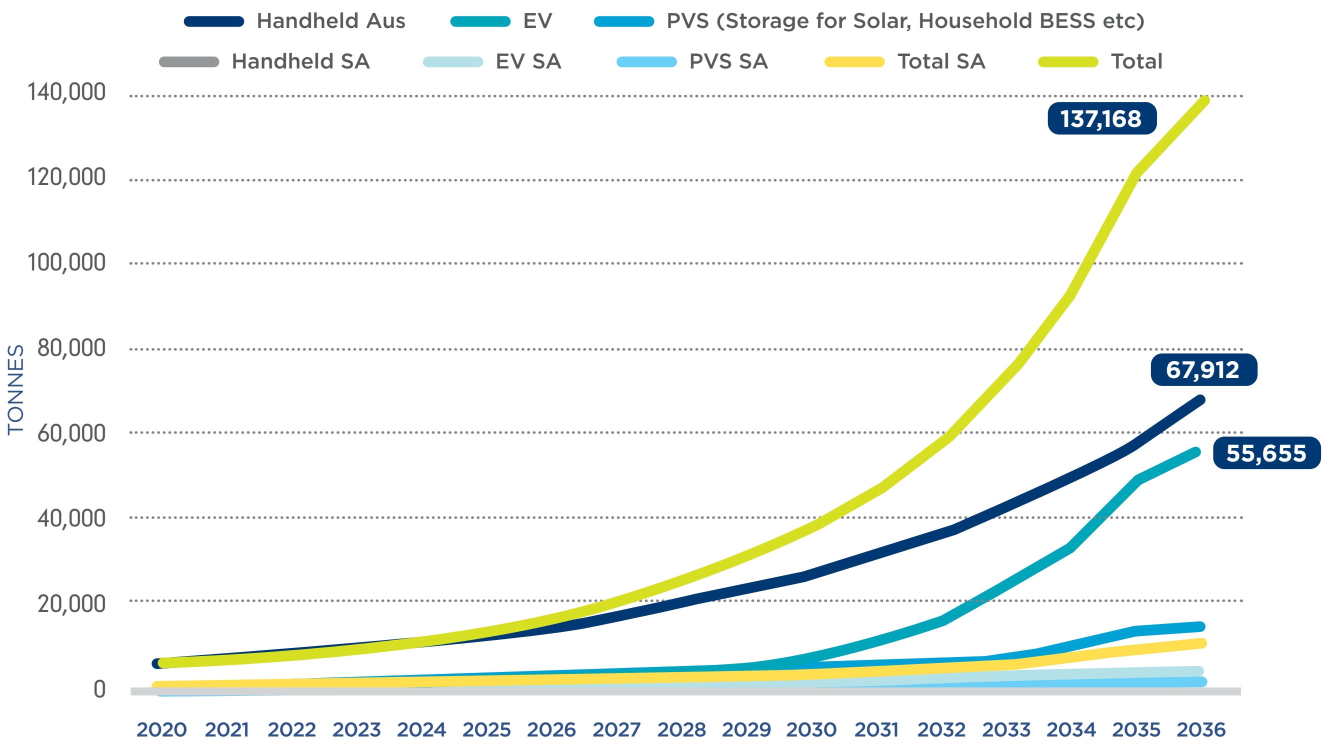
Source: Battery Stewardship Council.[22]

FIGURE 1.7 TOTAL LIB WASTE FORECAST IN SOUTH AUSTRALIA TO 2036.



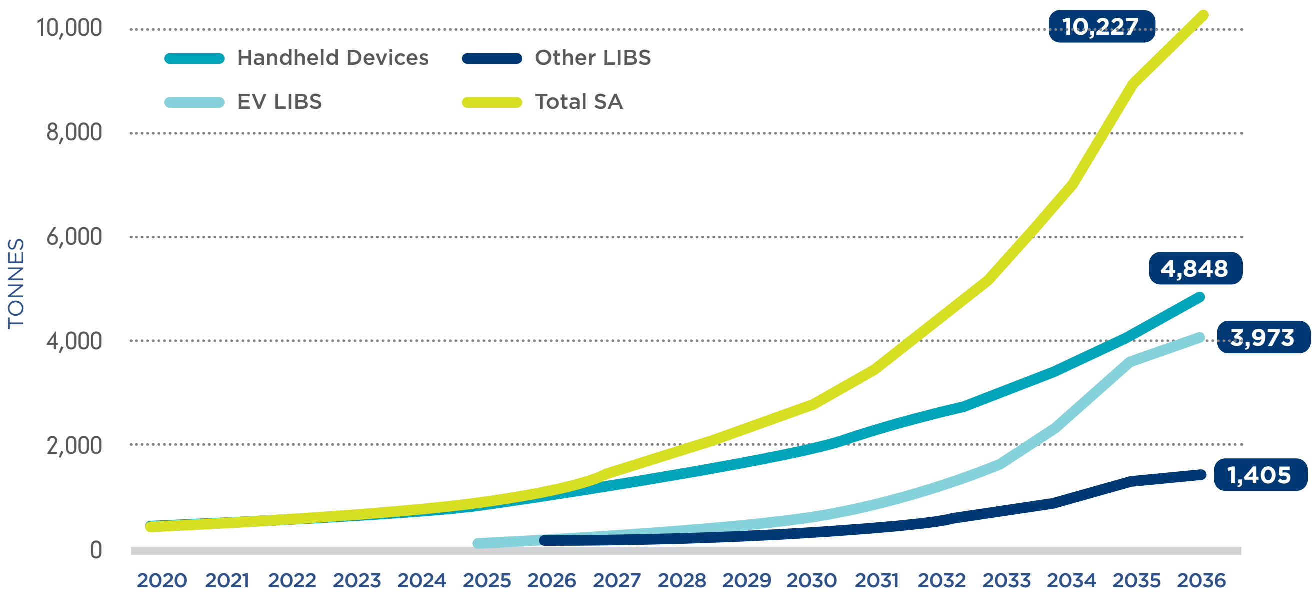
Source: Author analysis.

FIGURE 1.8 LIB WASTE FORECAST IN AUSTRALIA AND SOUTH AUSTRALIA, BY LIB WASTE CATEGORY, TO 2036.



Source: Author analysis of King, S., Boxall, N., & Bhatt, A. (2018).

FIGURE 1.9 LIB WASTE FORECAST IN SOUTH AUSTRALIA, BY LIB APPLICATION, TO 2036.



Source: Author analysis of King, S., Boxall, N., & Bhatt, A. (2018).

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There are a number of electronic devices containing elements of lithium-ion batteries across Australia and South Australia that are currently not being recycled. To value the size of this market, we must break down the components and various items that contain these materials. The largest of these categories are mobile devices and electric vehicles which will subsequently be explored.

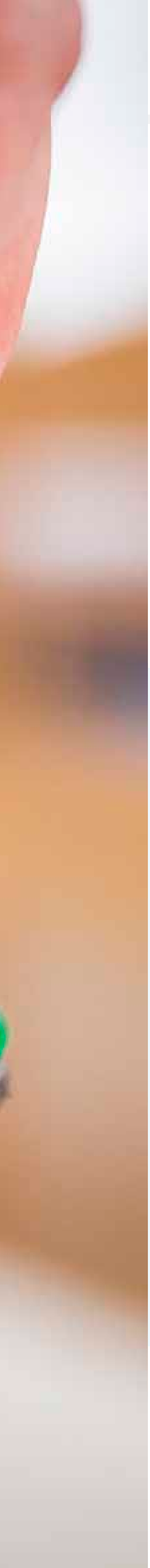
There are just under 18.5 million smartphone users in Australia,[23] and the number is projected to grow to as high as 19.3 million by 2022. With the increasing use of smartphones across all segments of society, there is a largely untapped market of phone recycling that is only starting to emerge. Programs such as MobileMuster have been around since 1998.[24] The program aims to keep old mobiles out of landfill and to recycle them in a safe and secure way. The program is voluntarily funded and managed by mobile handset manufacturers, service providers, network carriers and distributors. The program has collected and recycled over 1,323 tonnes of mobile phone components, equivalent to approximately 11.9 million individual handsets and batteries as at 30 June 2017.[25] The program claims that over 96 per cent of the materials in mobile phones, batteries and chargers collected by MobileMuster are recovered. This demonstrates that, with adequate community education, labelling and recycling, solving LIB waste streams is possible within Australia.

RECOMMENDATION 1

Explore the establishment an Australian LIB Waste Resource Management Hub in the state.

South Australia can become the Australian hub for LIB recycling. The Government of South Australia should explore the feasibility of establishing an Australian LIB Waste Resource Management Hub in the state as a pillar of its multiyear COVID-19 economic recovery.


BATTERIES
ONLY



PART 2: MANAGING LIB WASTE RESOURCES IN AUSTRALIA

2.1: How LIB Waste is Handled Today

KEY POINTS

1. It is estimated that between 3-6 per cent of LIB waste in Australia is recycled, with much of that recycling occurring offshore, not within Australia.
2. The current framework depends on overseas demand, and the risk-tolerance of international shipping firms charged with transporting waste – both vulnerable to disruption.
3. The solution to LIB waste management is three fold: LIBs should first be reused, then upcycled where possible into second life applications, before proceeding to end-of-life recycling.
4. Recycling LIB waste is expensive and energy intensive, requiring a stable and sizeable supply of LIB waste to make operations economically viable.

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Some of Australia's LIB waste is recycled, but most is stockpiled, sent offshore or inadvertently entering landfill

The current regime for handling and processing LIB waste in Australia, including South Australia, is of mixed efficacy. While there are some successful recovery programs in place for certain LIB waste streams, such as MobileMuster, which focuses in mobile phone recovery, there is concern that large amounts of LIB waste continue to end up in landfill. Of the volume of LIB waste that is collected, much continues to be shipped offshore for processing. As Buckley (2019) writes,

> "Australia lags far behind...with respect to battery recovery, achieving a low 6% recycling rate compared to the 45% targeted by the European Union. This is indicative of poor regulation; no government incentivisation; a lack of recycling infrastructure; careless consumer behaviour and low waste volumes. To correct this situation, an immediate effort to improve recycling is required via a complete collection to market system to future-proof the LIB industry."

Encouragingly, a small onshore capacity for LIB recycling has emerged since mid-2019, with two Victorian firms, PF Metals and Envirostream, each developing a modest scale LIB recycling in Melbourne. These applications have demonstrated the technical capacity of Australian firms to innovate and find economically viable solutions to the problem. In September 2020, Envirostream announced its intention to proceed with the recycling of 3000 tonnes of EV waste per annum.[26] It is unclear, however, how these plans will be affected by the company's temporary closure imposed by regulators in late September 2020, citing safety concerns.[27]

There is no consistent approach to end-of-life EV LIBs

However, for emerging LIB waste streams such as EVs, there is no consistent approach to handling and collection. Major auto manufacturers, for example, engage in their own practices, ranging from stockpiling EV batteries to reincorporating EOL batteries into their own manufacturing streams, and handing unusable LIB stock to third party recyclers who typically export the waste. One major EV supplier continues to house end-of-life batteries in a warehouse facility in Adelaide.

Some firms are in ongoing negotiations with local waste management firms about processing waste, presenting an opportunity to process much of this waste stream in Australia, but the primary motivation of firms appears to be a low cost option to sustainably recycle LIB waste, without a preference to whether that waste is processed onshore or offshore.

Some EV firms have focused on second-life battery applications, partnering with research institutions such as Flinders University, which is exploring second-life battery applications at Tonsley Innovation District. Flinders University researchers have successfully incorporated second-life batteries into fast-charging stations – which appears to be one of the most promising and achievable second-life applications for EV batteries, given the need for additional charging stations and the potential cost savings, electricity grid benefits and additional revenue streams of co-located energy storage.

There is a clear understanding, particularly in the EV sector but across the LIB waste stream more broadly, of the need to sustainably handle LIB waste. The industrial capacity to do so, however, remains in its infancy, and there is considerable room to shape it to ensure more waste is processed in Australia.

Slow EV uptake in Australia is dissuading innovation on recycling

There are cases in Europe and other markets of EV manufacturers willing to incorporate recycling of LIB materials into their manufacturing process to save on raw materials. Volvo, for example, have committed to keeping LIB recycling in-house, while working with third-parties to develop second-life applications for their batteries.[28] Given the size of Australia's EV market, it is improbable that any one EV distributor will commit to developing its own recycling capacity in Australia.

This scenario presents a challenging policy conundrum for Australian Governments. While there are clear advantages in developing localised LIB waste processing capacity, mandating stringent recycling requirements on an emerging industry might dissuade EV suppliers from seeking a foothold in the Australian market.

There is some concern by the EV sector about the appetite for EVs in the Australian market,[29] with a perception that the Federal Government has signalled to the industry that it will advance a national policy encouraging EV use. Given this context, the imposition of additional regulatory burdens could stifle uptake even further.

South Australia's leadership in EV policy, however, has been welcomed by the industry. Given its strong reputation as a clean-energy leader, the Government of South Australia has a unique role to play in facilitating best-practice EV policy, including LIB waste management guidelines, which can be adopted on a national scale.

RECOMMENDATION 2

In collaboration with industry, improve the coordination of EV and LIB waste management in the state, focusing on educating and working with the sector to develop best-practice collection, pre-treatment and disassembly of LIB waste.

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There are many Australian LIB waste collectors, but onshore recycling is nascent

Two Australian based firms, Envirostream and PF Metals, have commenced modest scale LIB recycling in Australian, though it is expected that these firms will only have the capacity to recycle a fraction of the forecast LIB waste stream. Most of the incumbents listed in *Table 2.1* are industrial scale recycling firms that already process other waste streams, and have leveraged their existing market positions to capture modest portions of the LIB waste stream primarily for export. While these firms do not yet process significant quantities of LIB waste in Australia, such processing services could be implemented with the assistance of government.

TABLE 2.1

AUSTRALIA'S EXISTING LIB RECYCLING ECOSYSTEM. MOST RECYCLERS THAT TARGET LIB WASTE EXPORT THE WASTE OFFSHORE FOR PROCESSING, WITH ONLY ONE FIRM, PF METALS, CLAIMING IT HAS FULL ONSHORE RECYCLING CAPACITY FOR LIB WASTE.

LIB RECYCLER	LOCATION	METHOD
CMA Ecocycle	Branches across Australia, including in Adelaide	Collects and sorts batteries in Australia, ships some batteries overseas for further processing.[30]
Envirostream Australia	Melbourne, Victoria	National collection, up to 3000 tonnes of mixed battery processing capacity onshore including LIBs,[31] exports to South Korean battery recycler SungEel.[32]
MRI	Campbellfield, Victoria	Collection of e-cycle; export LIBs offshore for processing.[33]
Powercell Trading	Headquartered in Dudley Park, South Australia	Collection, recycling process unspecified.[34]
PF Metals	Melbourne, Victoria	Onshore resource recovery of 95% of metals.[35] No collection service.
TES ANZ Pty Ltd	Villawood, New South Wales	Works with MobileMuster to collect mobile phone waste. Engages in physical disassembly and onshore pyrometallurgical processing to extract metals from all phone components. Volume of LIB-specific recycling unspecified.

Legislation typically bans LIB waste from landfill, but active support for recycling is also needed

As the LIB waste issue has become more apparent, Australian jurisdictions have begun implementing specific regulations banning the disposal of LIB waste in landfill. On 1 July 2019, the Government of Victoria became the first to amend e-waste legislation to add specific regulations focused on safely handling LIB waste.[36] E-waste more broadly is banned from landfill across Australia, including in South Australia. Bans and regulations are important measures, but need to be coupled with active support of recycling capacity to ensure that those bans are able to be complied with by LIB waste producers. For Governments, this means providing financial support for firms focused on collecting, handling and sorting LIB waste streams.

A potential regulatory model for the Government of South Australia to explore replicating is that adopted in the European Union. A Batteries Directive, first legislated in the European Parliament in 2006, was amended in 2012 to include a recycling target of 25 per cent of LIB waste. A majority of EU member states have achieved that target, with a 2016 revision expanding the recycling target to 45 per cent.[37] Though the success of the EU's battery directive varies across jurisdiction, the mandates coincided with increased commercial and government investment in recycling, from collection through to processing. The EU's update on the 2012 directive, published in late 2019, documented the large number of collection points that had emerged in the EU since the directive came into force. Ireland, for example, had developed 10,500 battery collection points under the directive – around one for every 440 citizens. This infrastructure enabled Ireland to achieve a battery collection rate of 48 per cent across all battery streams.[38]

In addition, the European Union have also flagged the introduction of compulsory recycling targets for manufacturers of batteries. The EU Commission for Environment, Oceans and Fisheries announced their intentions to mandate a certain portion of recycled components in battery products manufactured within the EU, which would be coupled with mandatory reporting requirements by manufacturers to ensure they're in compliance.[39] Recycled component quotas have, however, been called into question given the rapid evolution of battery technology, which may render specific targets legislated in 2021 redundant when they come into force.[40] What is clear is that any targets need to be realistic, enforceable, and backed in by capital – be that from government or private sector actors – to achieve their intended goals.

Offshoring waste leaves Australia vulnerable to market shocks

Australia's tendency to offshore recyclable commodities, rather than nurture local recycling capacity, has proven a vulnerability. In 2017, this risk was demonstrated with China's decision to ban the imports of waste plastics, which Australia, like much of the world, had relied upon.[41] China's snap decision caused ripples through Australia's recycling sector, which was suddenly faced with stockpiling mixed plastics and mixed paper/cardboard waste with nowhere to export for processing. The inevitable result was an increase in recyclable material entering Australian landfill unnecessarily.

A similar dynamic is emerging with LIB waste. Given the challenges and expenses associated with developing an onshore LIB recycling capacity, it is understandable that recycling firms have established EOL LIB collection services that depend on exporting the waste for processing.

This model, however, exposes Australia's LIB waste stream to similar vulnerabilities that were exposed by China's 2017 waste import ban. Were policy shocks like this to emerge in the future with regards to LIB waste, Australia would not have the capacity to safely handle, stockpile, process or dispose of the growing amount of LIB waste. Indeed, it is probable that existing collectors of LIB waste, which are typically the firms that also export the waste for processing, may cease collecting LIB waste if they have nowhere to handle it. Simply, the status quo leaves Australia's LIB waste stream highly vulnerable to international policy makers, and the decisions of international investors.

At scale LIB recycling and reprocessing could further improve Australia's critical minerals position

Australia is currently a leading supplier of the raw materials that supply the LIB value chain, behind only China. This is a strong position for the country to drive investment into the LIB value chain. China continues to dominate the market, however, controlling up to 80 per cent of the raw material supply for LIB value chains globally. Bloomberg NEF forecast that, while there will be significant volatility in the rankings of other nation's that contribute to the LIB supply chain, Australia and China's market dominance will continue well into the decade.[42]

TABLE 2.2
BLOOMBERG NEF'S 2020 RANKING OF NATION'S BY THEIR CONTROL OF THE RAW MATERIAL THAT SUPPLIES LIB VALUE CHAINS.

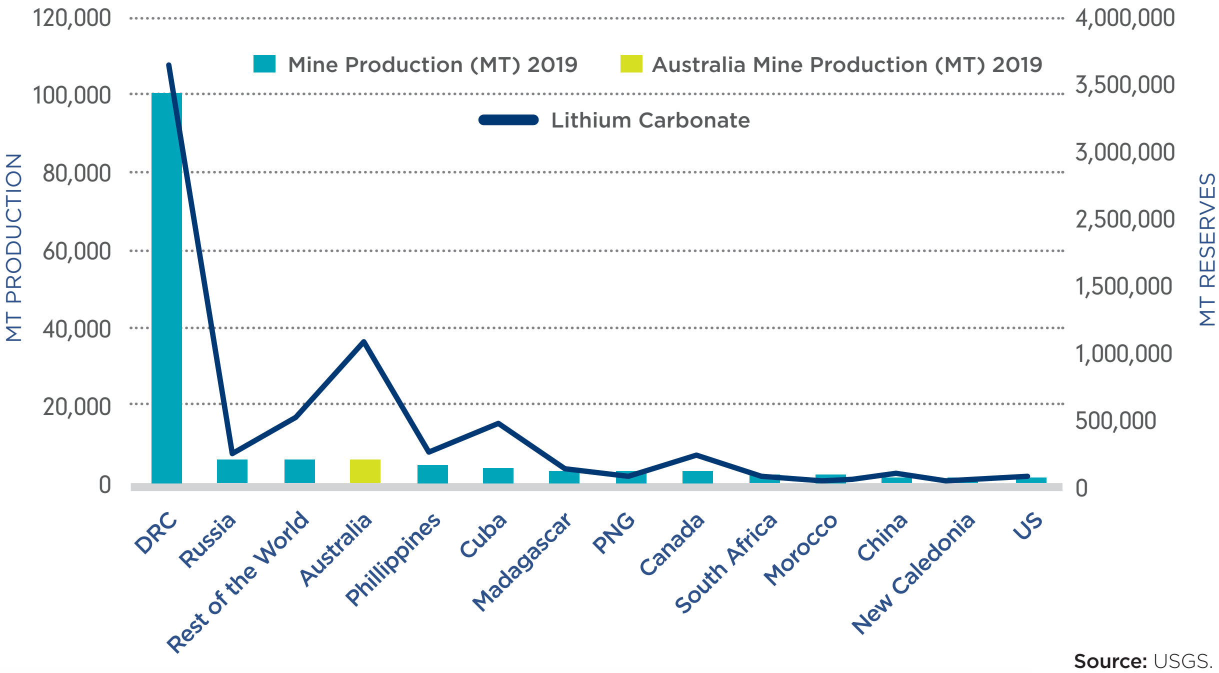
COUNTRY	2020	2025	CHANGE
China	1	1	-
Australia	2	2	-
Brazil	3	7	-4
Canada	4	3	+1
South Africa	5	4	+1
Chile	6	5	+1
Indonesia	7	4	+3
DRC	8	10	-2
Philippines	9	13	-4
India	10	13	-3
Finland	11	10	+1
Argentina	12	8	+4
Japan	13	8	+5
US	14	13	+1
Vietnam	15	17	-2

" Both cobalt and lithium are highly concentrated in a few countries. For example, from 2014 through 2016, an average of 53% of global mined cobalt production came from the Democratic Republic of Congo (DRC), while an average of 47% of global cobalt refining took place in China" ***– IGOGO ET AL, 2017.***[43]

China dominates most LIB raw material supply chains – Australia is close behind

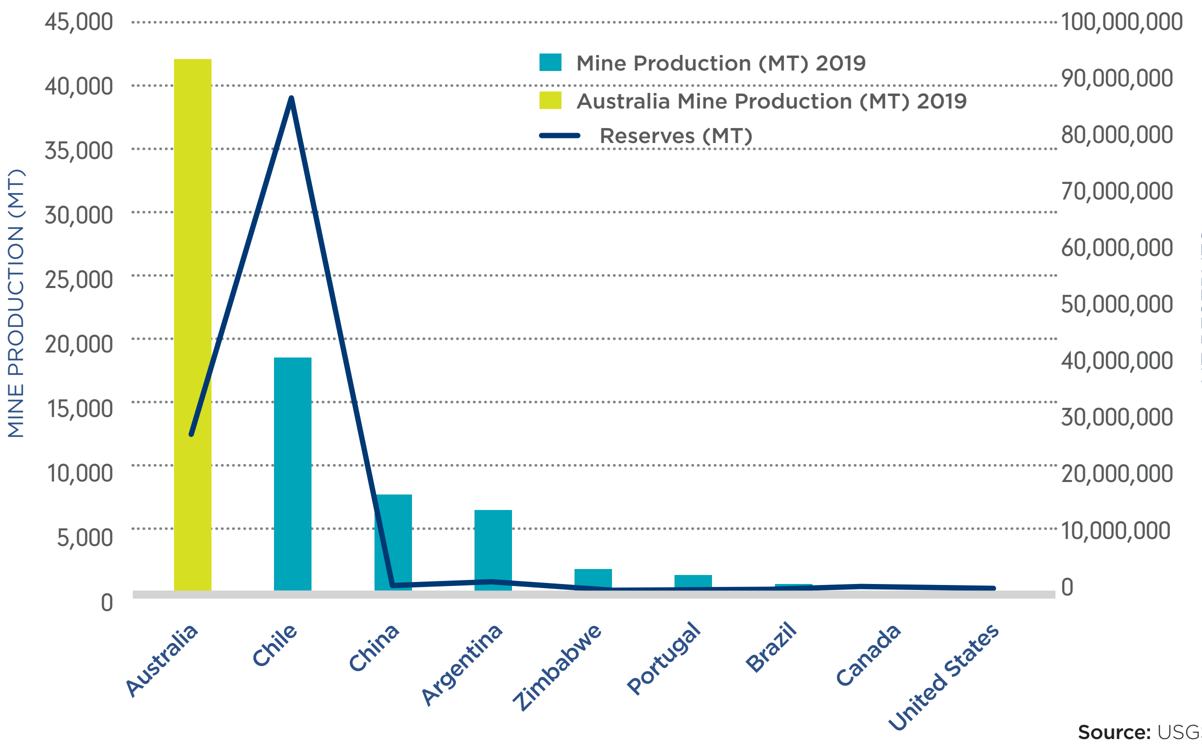
Figures 2.1 to 2.5 illustrate the origins of the various raw materials that are essential for the creation of LIBs. Australia is a leading producer of raw lithium, but its dominance is less apparent in other resource stocks. Australia does not mine any graphite, for example, but exports considerable sums of more common raw materials, such as copper, which are also components of LIBs. While Australia has a dominant position in terms of lithium supply, the Commonwealth Government has stated its desire for Australia to see more value adding on these raw materials occur within the country. Such a focus would also be complementary to the associated development of a LIB recycling capacity, which would see the Australian economy benefit from selling increasingly sought after LIB raw materials that it derives from the recycling process.

FIGURE 2.1 GLOBAL COBALT PRODUCTION AND RESERVES, MT, 2019.



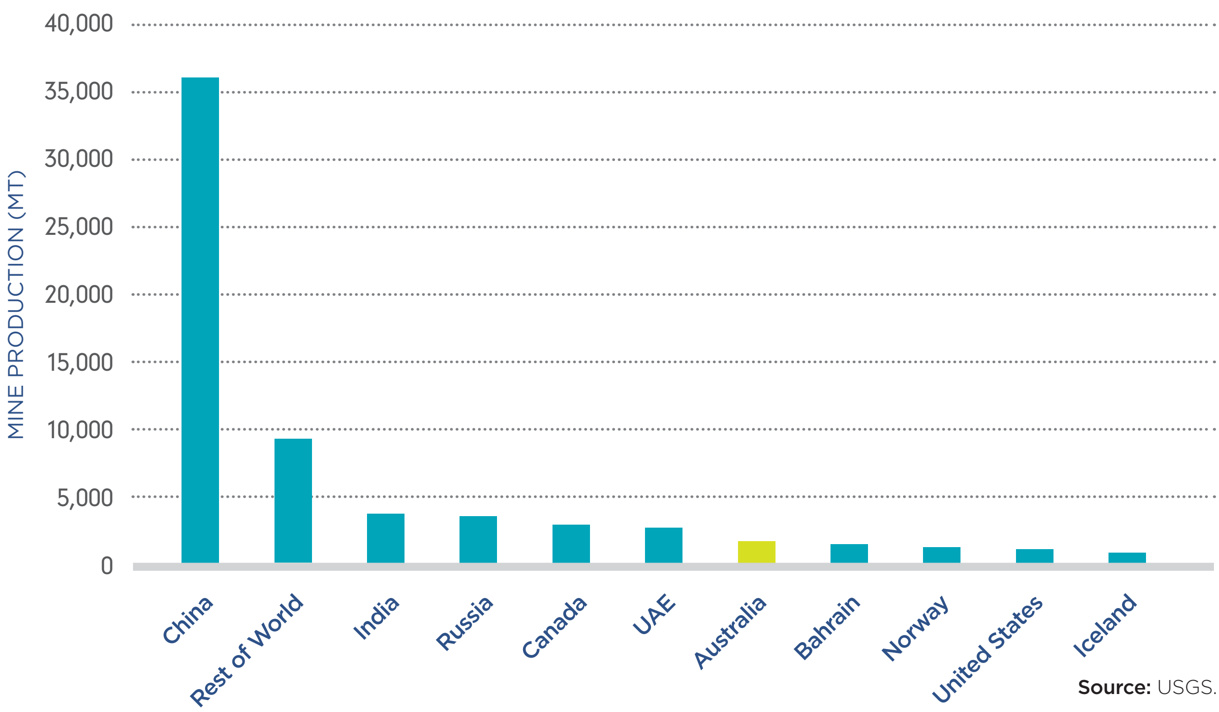
Source: USGS.

FIGURE 2.2 GLOBAL LITHIUM PRODUCTION AND RESERVES, MT, 2019.



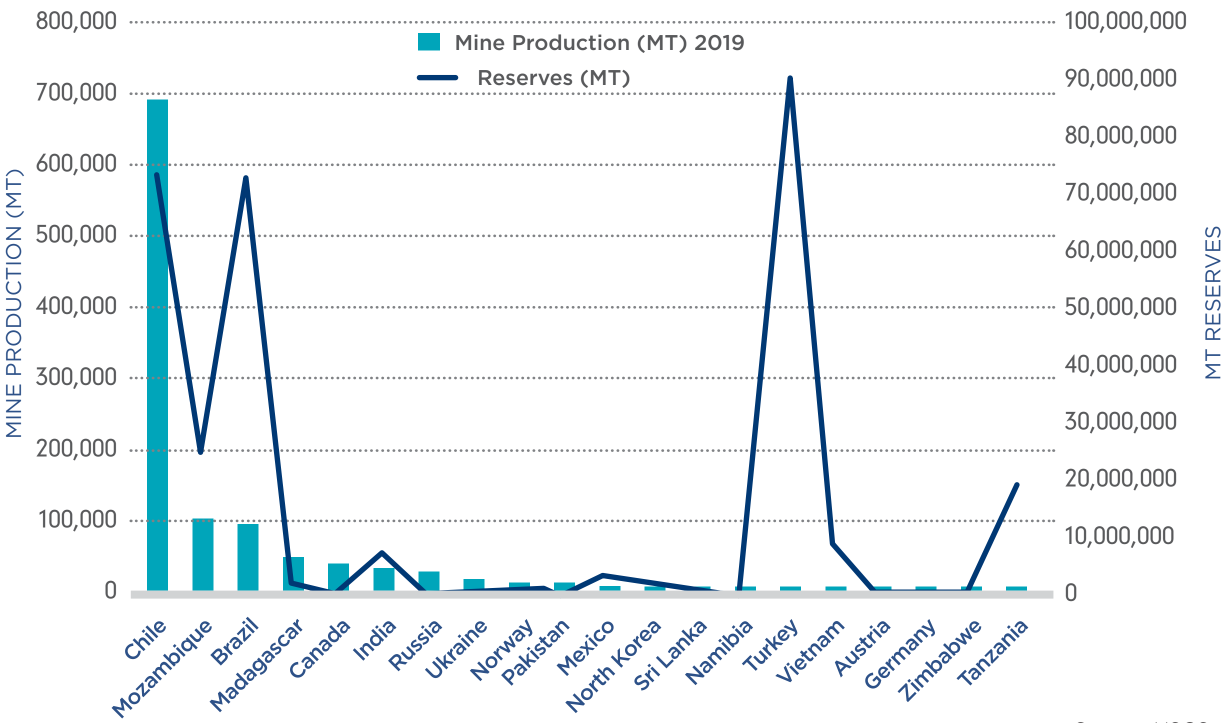
Source: USGS.

FIGURE 2.3 GLOBAL ALUMINIUM PRODUCTION, MT, 2019. DATA ON RESERVES UNAVAILABLE.



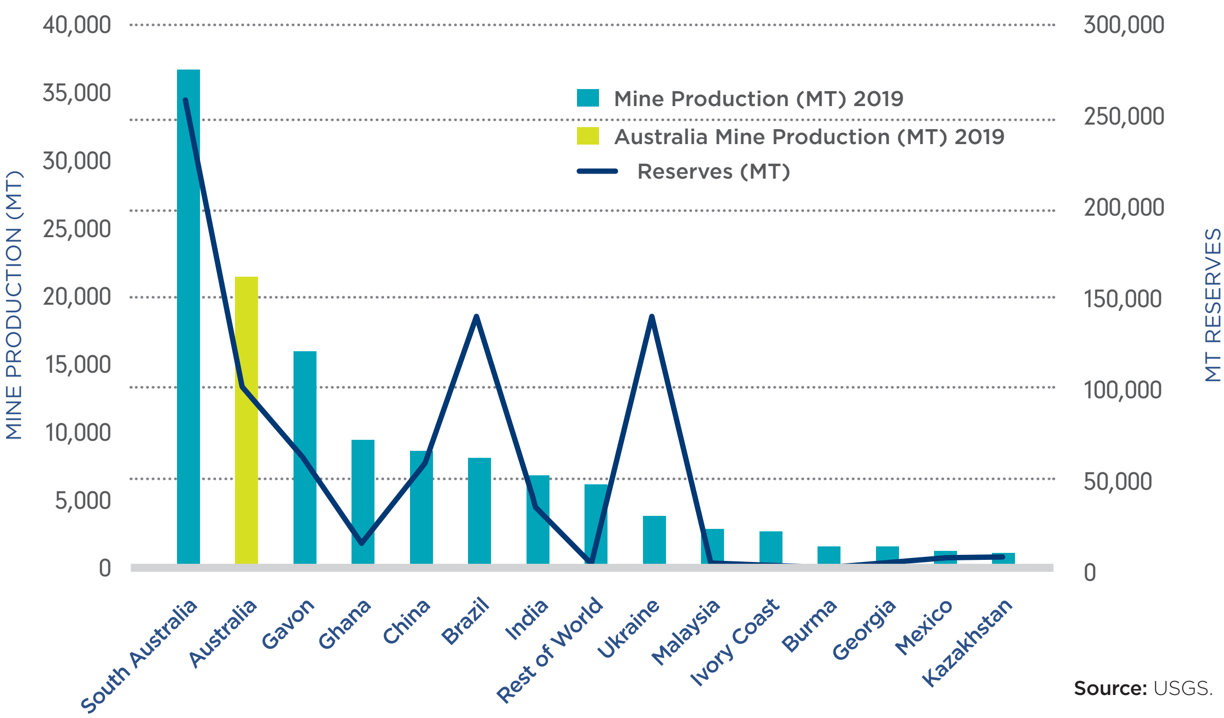
Source: USGS.

FIGURE 2.4 GLOBAL GRAPHITE PRODUCTION AND RESERVES, MT, 2019.



Source: USGS.

FIGURE 2.5 GLOBAL MANGANESE PRODUCTION AND RESERVES, MT, 2019.



Source: USGS.

2.2: Managing LIB Waste is a Three Step Process

KEY POINTS

1. LIB waste management is challenging, and can be expensive and labour intensive.

2. While LIBs should always be reused and incorporated into second-life applications when possible, every LIB will reach EOL at some point, and require recycling or safe disposal.

The conventional hierarchy of waste applies to LIBs

Best practice recycling of LIBs broadly follows the existing hierarchy of waste that guides recycling of other materials. While Australia has a poor LIB waste management framework, private firms are cognizant of the need to adhere to the recycling hierarchy. Best practice waste management aims to follow the Government of South Australia's waste hierarchy outlined in *Figure 2.6*, with the disposal of waste typically avoided where possible. The status quo in Australia, unfortunately, sees between 94-96 per cent of LIB waste being disposed – the least desirable outcome. While Australia is yet to develop a holistic LIB waste management capacity, there is a clear three step process to managing LIB waste which can form the basis of a regulatory approach to the challenge .

FIGURE 2.6 THE HIERARCHY OF WASTE, RANKED FROM MOST PREFERABLE TO LEAST PREFERABLE.[44]

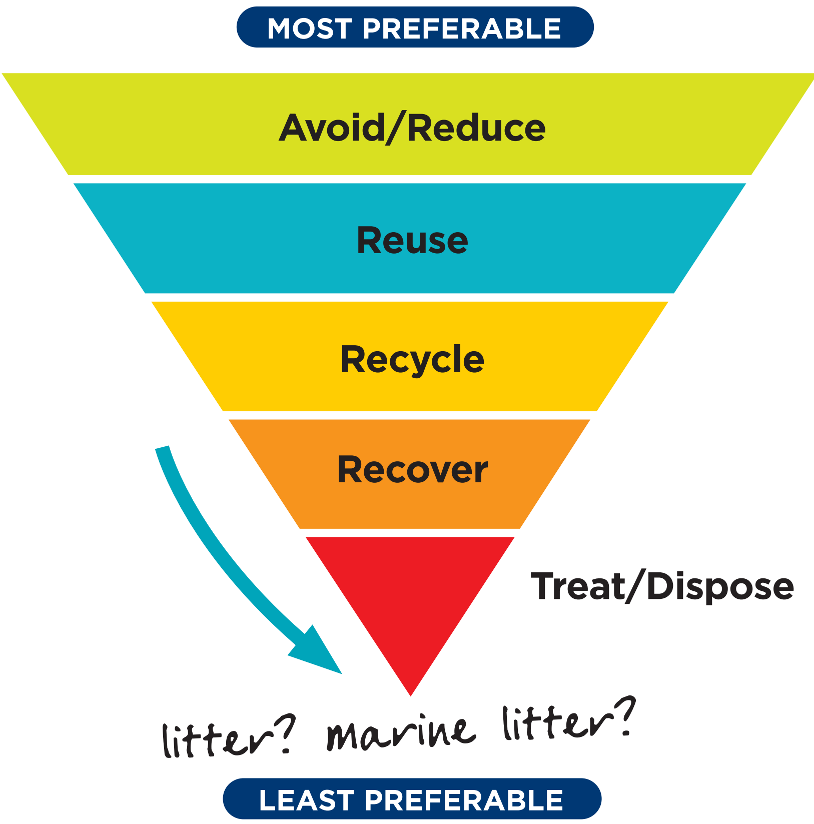


IMAGE COURTESY GREEN INDUSTRIES SA

STEP 1

REUSING LIBS FOR THEIR ORIGINAL PURPOSE

The waste management hierarchy prioritises re-use or repurposing above recycling. Where possible, LIBs – especially EV LIBs – should be repurposed into existing applications. Refurbishment and reuse is common in many LIB devices, such as laptops and mobile phones. Often, retailers serve as a place where faulty LIBs can be returned and replaced, allowing consumers to dispose of end-of-life LIBs at the point of sale.

In the case of EVs, faulty LIBs are typically returned to an auto retailer, which in Australia typically stockpile the faulty battery, and replace the faulty device with a new LIB.[45] At times, LIB batteries will not be able to be refurbished, particularly if damaged in motor accidents. But the EV industry is aware of this need, and has some capacity to refurbish and reuse batteries for their original purpose before proceeding to the next step of the waste management process.

STEP 2

GIVING LIBS A SECOND LIFE

WHAT IS A SECOND-LIFE BATTERY?

- **LIBs are often removed from their original application with storage capacity still remaining. This is likely to be true of LIBs extracted from EVs, which may be removed once the LIBs have declined in their performance.**
- **A second-life battery is a battery that has been extracted from its original application, re-purposed for a second-life application, like household energy storage, instead of being recycled or discarded in landfill.**

While not all LIBs can be re-used for future energy storage applications, the key emerging LIB applications, like EVs and home energy storage systems, often have the capacity to be applied to secondary storage applications after their original use. This is most common with LIBs from EVs. EVs rely on powerful energy storage systems that can rapidly discharge the energy required to propel a vehicle. For this reason, LIBs in some EVs are extracted once the batteries deteriorate in performance. There is a high degree of variability in the performance of batteries in different EVs.[46] Many EVs are expected to see only modest deterioration in battery performance over the expected lifetime of the vehicle,[47] while other models may see a more rapid deterioration. While many of these EV LIBs will be extracted, refurbished and re-used in EVs once they are unable to be re-used, some can be also be applied to second-life storage applications.

Second-life batteries installations are becoming more common

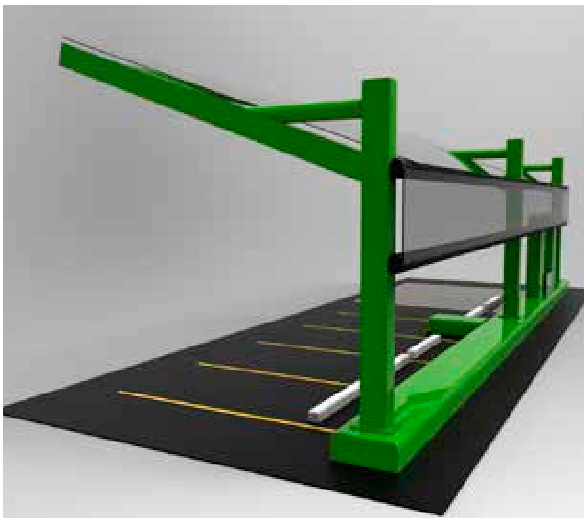
Second life battery installations have transitioned from being merely a proposed solution to EV waste, to be actively installed across the world. For most EV companies, or traditional ICE manufacturers developing EVs, the integration of 2LB projects is an essential step in both delaying the EOL recycling requirements of their LIBs, and adding maximum value to LIBs, which are composed of expensive materials. Every major EV firm now has pilot projects in place internationally, ranging from experimental projects like Nissan's Streetlight initiative, to re-integrating 2LBs into storage systems within the firms' own manufacturing facilities.

On occasions, EV manufactures partner with third-party firms to advance and implement 2LB technology. Within Australia, one 2LB company, Relectrify, has secured supply deals with major international EV manufacturers, who deliver used LIBs to the company to be implemented into future applications. This model presents a novel industrial opportunity for South Australia that is likely less risky than the development of an industrial-scale recycling capacity within the state.

Innovative 2LB installations are occurring globally, including in SA

TONSLEY INNOVATION HUB'S SOLAR GARAGE

South Australia has already entered the second-life battery space with an installation at Tonsley Innovation Hub, in Adelaide's south. Utilising second-life batteries received from Mitsubishi, Flinders University researchers have installed them into fast charging stations for EVs, which are themselves charged by solar. Fast chargers are a logical second-life application for LIBs, and the Tonsley Solar Garage provides a window into the future of EV charging infrastructure in Australia.



CASE STUDY
AMSTERDAM'S JOHAN CRUIJFF ARENA

In 2016, Nissan announced it would be partnering with Ajax Amsterdam, a professional soccer team, to utilise second-life batteries in a new lighting installation at Johan Cruijff Arena in Amsterdam. The installation has seen second-life batteries from 148 Nissan Leaf utilised to create 2.8MWh of storage, which is charged by solar.[48]

CASE STUDY
RENAULT'S SMART ISLAND INITIATIVE IN PORTUGAL

Renault have incorporated 2LBs into a major circular economy initiative in Madeira, Portugal. The Smart Island initiative has seen 2LBs incorporated into grid storage applications, and form part of an energy solution for the island that enables its transportation and grid electricity to be run off wind energy and storage. The Smart Island initiative incorporates existing Renault Zeo EVs into household storage devices, and then incorporate 2LBs designed by UK energy storage firm Powervault to deploy storage aimed at grid stabilisation.

CASE STUDY
RIVIAN'S PROJECTS IN PUERTO RICO

US auto manufacturer Rivian have demonstrated the power of 2LBs in a major off-grid solar storage application in Adjuntas, Puerto Rico. The system is designed to provide energy stabilisation to a poorly functioning grid, and is charged by solar. The project is designed to demonstrate both the power of second-life batteries to provide energy security, but also to demonstrate the technology's capacity to serve as a viable energy storage solution in developing world applications.

CASE STUDY
AUSTRALIA'S RELECTRIFY

Relectrify are an Australian firm that has designed novel technology integrating second-life batteries with an in-build inverter, creating an affordable energy storage system for grid and microgrid sized applications. Relectrify have received funding from ARENA to advance their technology, and have independently secured 2LB supply from major EV manufacturers.

CASE STUDY
NISSAN'S STREETLIGHTS IN JAPAN

Nissan's Reborn Light initiative as seen prototype streetlights developed that incorporate second-life storage from used Nissan Leaf batteries. The initiative has seen the streetlights installed in the town of Namie, creating solar-powered street lighting that is highly scalable.[49]

CASE STUDY
MAN GRID ENERGY STORAGE TRIAL IN HAMBURG[50]

German truck manufacturer MAN have developed second-life charging infrastructure for commuter buses in the suburb of Bergedorf, Hamburg. The installation s in partnership with Volkswagen, and has created 495 kwh of stored grid-sourced energy.

As Table 2.3 demonstrates, 2LBs are being used in a disparate array of applications, some of them experimental, such as the BIEV EV-charging initiative in Beijing. Given the breadth of innovation in this space, disparate commercial applications for this technology are likely to emerge.

TABLE 2.3 VARIOUS SECOND LIFE BATTERY INITIATIVES GLOBALLY.

EV MANUFACTURER	NATURE OF SECOND-LIFE BATTERY INITIATIVE	LOCATION
BJEV	EV-charging	Beijing, China.[51]
BMW	Grid scale storage; EV charging	Uppsalla, Sweden; Union City, California, USA.
Daimler	Grid scale storage,[52] commercial storage[53]	Shenzen, China;[54] Beijing, China.[55]
GM	Remanufacturing	Michigan, USA.
Great Wall Motor	Backup power	China.
Hyundai	Grid scale storage for commercial application	Seoul, South Korea; Helsinki, Finland.
Nissan	Remanufacturing, commercial energy storage, EV charging; streetlights[56]	Warwick, UK;[57] Tokyo, Japan.
Mitsubishi	Commercial energy storage (in Mitsubishi plant)	Oakazaki, Japan.[58]
Renault	EV charging, residential energy storage, grid scale energy storage	Madeira, Portugal.
Tesla	Remanufacturing	California, USA.
ableToyota	Commercial energy storage, grid scale energy storage	Across Japan.[59]
Volkswagen	Remanufacturing	Saltzgitter, Germany.[60]
Volvo	Residential energy storage	Gothenberg, Sweden.[61]

The State Government could identify and support South Australian based second-life battery pilot projects

In line with Australia's modest EV market, 2LB projects are yet to be deployed in any significant way in Australia. While various individual projects within universities have occurred, and private sector firms such as Relectrify have significantly advanced 2LB technology within Australia,[62] no grid scale or commercial scale 2LB projects have yet to be developed in the Australian market. This provides an obvious opportunity for South Australia to help nurture the sector through State Government procurement which accommodates novel and experimental applications for 2LBs, be it grid scale energy storage, mini-grid scale energy storage for diesel-dependent communities, or the integration of 2LBs into public infrastructure such as EV charging stations and streetlights.

RECOMMENDATION 3

Incentivise international start-ups in second-life battery industry to establish themselves in South Australia, offering industry connections, start-up capital and collaboration with Australia's automotive sector to secure a second life battery supply.

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STEP 3

RECYCLING ALL EOL LIBS

FIGURE 2.7 THE END-END PROCESS FOR RECYCLING LIBS.

Source: Buckley, 2019

All LIBs, even those reused and utilised in second-life applications, require responsible disposal at their end-of-life (EOL). But the recycling of lithium-ion waste is a complex, expensive and time-consuming process, yet to be scaled in Australia (Bhatt et. al, 2018).[63] There are also environmental considerations that need to be made when establishing advanced recycling capacity which can be energy intensive, as is the case with certain forms of LIB recycling. While there are a range of applications for the materials found in LIBs, these complex and costly processes present a significant challenge to the emergence of a native recycling industry in Australia or South Australia. However, given the nascent state of the LIB waste problem in Australia, there is likely a window of time for the Government of South Australia to begin proactively taking steps to ensure it is best placed to house any future LIB waste management capacity in Australia, and potentially isolate individual aspects of the recycling process to specialise in within the state.

Pre-treatment & charge deactivation

Pre-treatments are aimed at 'separating components and materials according to different physical properties such as shape, density, conductivity, magnetic property, etc' (Huang et al, 2018).[64] This process is important at improving overall recovery rates. This process is still evolving and being made more efficient in terms of both energy use and labour costs.

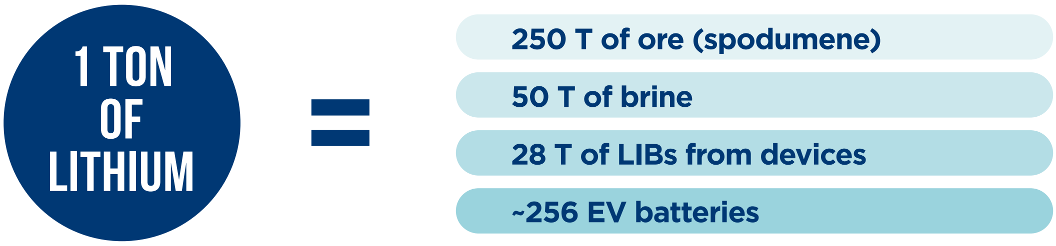
LIBs almost always have residual energy, which when they arrive at a recycling plant, require discharging, or they could lead to fires. Deactivating LIBs can be done in various ways, but is a prerequisite to any further handling of the devices. As Diekman et al explain,

> " Deactivation can be carried out by discharge of the whole battery system, battery modules, or battery cells. To avoid relaxation behaviour, namely the rise of voltage after discharge of the batteries, short-circuiting is required. Another deactivation method consists of a thermal pre-treatment. During this process the batteries are heated up to maximum temperatures around 300°C. At this temperature gas generation and evaporation of the solvents take place, which opens the battery cells, combusts the electrolyte solvents, and therefore inactivates the batteries. Although a disassembly of the battery systems does not deactivate them, it lowers the attached energy by decreasing the size. Normally, all further processing steps require a disassembly process."
>
> ***– DIEKMAN ET AL, 2019.***

LIBs also require relatively basic pack and module disassembly. This process is performed in various ways, depending on the type of LIB. Harper et al (2019) highlight that much of this work is still performed by hand, particularly for second-life reuse.[65] Hand processing has some advantages, but is dangerous and highly-skilled work, to which it is near-certain Australia does not have the labour-market capacity to meet at this stage. A study of the UK motor technicians workforce found that less than 2 per cent of the 170,000 motor technicians in the country were qualified to perform technical services on EVs – a rate which would be expected to be found in a similar study in the Australian context.[66] This would suggest that the work of physically handling or dismantling batteries should not be conducted through crash repairs or the existing repair industry in South Australia without dedicated training campaigns to ensure mechanics have the requisite skills to safely handle EV batteries. Rather, batteries would likely be handled by specifically skilled technicians at centralised recycling depots.

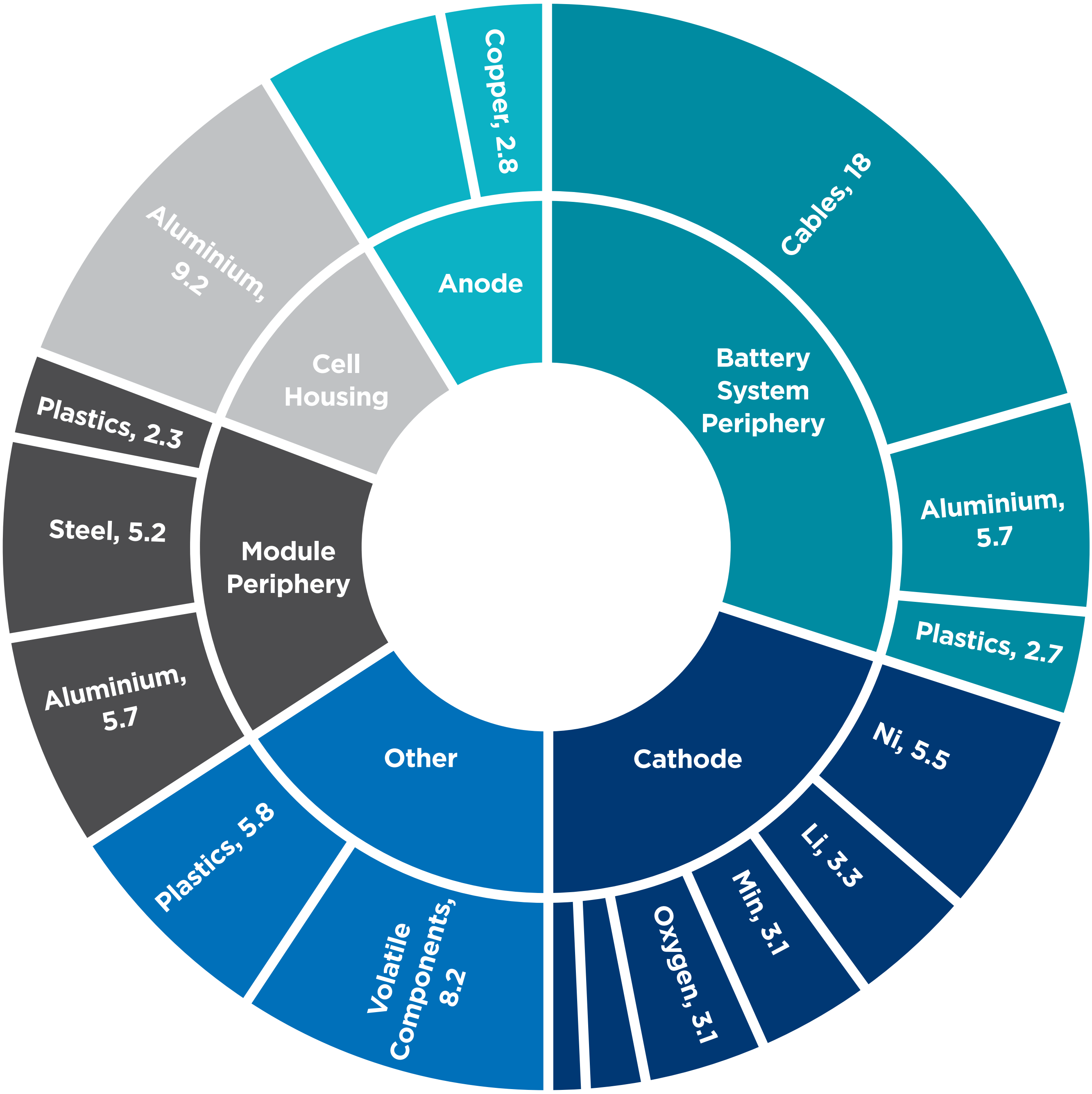
FIGURE 2.8

VOLUMES OF COMPOSITE MATERIALS CONTAINING LITHIUM REQUIRED TO SOURCE 1 TON OF USABLE LITHIUM.[67] WHILE THE TECHNICAL REQUIREMENTS FOR EACH PROCESS IS RADICALLY DIFFERENT, THERE IS AN OPPORTUNITY TO EXTRACT VAST QUANTITIES OF LITHIUM THROUGH THE RECYCLING PROCESS.



Just as the cell composition of EV LIBs and other LIBs vary, so too do the casing and modules in which the LIBs are found, depending on their function, application and source of manufacture. Given Australia's relatively modest size in comparison to advanced LIB markets (particularly EV markets: the European Union, the United States, and China), it will always be a challenge for Australian regulators to mandate or recommend any uniformity that may streamline EOL recycling, Such considerations would likely dissuade investment into Australian markets by OEMs.

FIGURE 2.9 THE METALS AND MATERIALS COMPOSITION OF A TYPICAL EV LIB.



Source: Author interpretation of Diekman et al, 2017.[68]

Pyrometallurgical processes

Pyrometallurgical processes use furnaces to isolate the recyclable components of LIBs, and is primarily focused on the extraction of cobalt rather than lithium. Less valuable commodities, including copper and nickel, can also be recovered form LIBs during this process. This process uses blast furnaces to incinerate any plastic remanence of LIBs, before heat of up to 700 degrees Celsius is employed to isolate the desired materials. Huang et al (2018) note that this form of LIB recycling is a high-risk economic proposition, heavily dependent on the price of cobalt, as well as affordable energy inputs associated with creating the heat required. Some studies have demonstrated that it is technically possible to extract lithium from the slag created by the pyrometallurgical process, (Li et al, 2019),[69] but this remains to be tested at a commercial scale.

Given its inability to isolate and extract lithium, pyrometallurgical processes may not be the most economically viable recycling method in South Australia, given its resource intensity, which make the process less profitable. Further, the quantity of cobalt in LIBs is decreasing, and given the early stage of LIB technology, will likely continue this trajectory. Huang et al (2018) argue that, while cobalt recovery is still environmentally advantageous over discarding LIBs, "recycling technologies should be moved away from cobalt recovery to the comprehensive utilization of spent LIBs". Given the long-term challenge of lithium supply, a recycling industry that focuses more on the reutilization of lithium rather than the short-term economic opportunities associated with cobalt recovery is most viable.

Hydrometallurgical processes

Hydrometallurgical processing of LIB waste is a more common form of waste management, able to extract 99 per cent of both lithium and cobalt. (Huang et al, 2018). This processes uses leaching, which applies a solution to the materials to isolate and extract desirable raw materials including cobalt and lithium. Close to 100 per cent of all other materials in LIBs can also be recovered through this process. A broad literature has identified numerous methods of extracting raw materials through myriad hydrometallurgical processes, including bioleaching, which utilises fungus and bacteria in the extraction process, as well as acid leaching.

Direct recycling processes

While pyrometallurgical and hydrometallurgical processes are utilised to extract raw materials from EOL LIBs, not all LIBs have to go through complex and expensive chemical processes to be responsibly handled. More direct, physical handling and extraction of materials can be an important and less invasive method of handling LIBs which may have some further utility. Again, there are numerous methods of direct recycling of LIB waste. After being discharged, these processes can range from physical disassembly of LIBs and cell components within LIBs, to more technically complex and novel recycling approaches, such as heat treatment which is less invasive than cobalt-focused pyrometallurgical processing, and the extraction of electrolytes utilising subcritical CO2. (Rothermal et al. 2016).[70] Direct processes often include the physical dismantling and separation of core components, such as the cathode and anode plates, and may create further employment opportunities than alternative recycling or reprocessing methods.

As Huang et al argue, the 'direct physical recycling process has the advantages of short recycling route, low energy consumption, environmental friendliness and a high recovery rate'. The long-term health of the recovered assets, however, is yet to be determined given the novel nature of the technology (Huang et al, 2018).

There are multiple methodologies deployed to recycle LIB waste

> " Some lithium batteries are similar in shape and form to others, such as lead acid batteries, which comprise different chemistry, and if mixed into lead acid waste streams can create significant safety issues or chemical incompatibility issues during the recycling process."
>
> ***– ANAND BHATT, 2019.[71]***

There remains no consistent or best-practice recycling process for LIB waste, with various firms globally engaging in contrasting recycling methods aimed to creating different end products. The determination of individual firms with regards to the method of recycling they adopt is dependent on economic decisions relating to the forecast value of certain commodities, and local input prices such as energy and labour. Each major operation internationally adopts differing processes, leading to a lack of uniformity in the recycling of LIB waste abroad. Many of the existing waste processes are energy intensive, particularly pyrometallurgical processes, which at scale may somewhat negate the positive emissions reductions associated with widespread EV uptake. What is consistent in literature exploring the LIB recycling challenge is the need for innovation in the sector.

TABLE 2.4 LIB RECYCLING PROCESSES IN VARIOUS PRIVATE SECTOR APPLICATIONS

FIRM	COUNTRY OF OPERATION	MAIN LIB RECYCLING METHOD
Batrec Industrie AG	Switzerland	Mechanical recovery focused on lithium recovery.[72]
Umicore	Belgium & Sweden	Pyro & Hydrometallurgical processes focused on nickel and cobalt recovery. Not capacity to recover lithium.[73]
OnTo Technology	USA	Mechanical pulverisation extracting electrolytes.
Recypyl	France	Mechanical 'valibat' process aimed at recovering all LIB components, from plastics to steel and copper, to cobalt, nickel and lithium.[74]
Sony	Japan	Pyrometallurgical process at scale aimed at cobalt recovery.
Accurec GmbH	Germany	Mechanical treatment and subsequent hydrometallurgical process aimed at cobalt, with some lithium extracted from slag through acid leaching.
Retrieve (formerly Toxco)	Canada	Hydrometallurgical process focused on harvesting li-ion fluff which can be a source of lithium. This process also isolates plastics, which can be recycled, and cobalt. Some mechanical pre-treatment.
AEA Technology	UK	Patented hydrometallurgical process aimed at recovering all resources from LIBs.
LithoRec (Uncommercialised)	-	A novel process combining "electrical, mechanical, mild thermal and hydrometallurgical treatment" designed to recover "nearly all valuable materials of battery systems".

Source: Mersham et al, 2014; Diekman et al, 2019.

The raw materials in LIBs can be utilised in a variety of advanced applications

There are many end applications to which LIB waste can be applied. Huang et al (2018) identify three broad categories of re-usable waste from LIBs: metals and chemicals, electrode materials, and other functional materials. Metals and chemicals extracted through LIB processing, such as cobalt, copper, electrolytic manganese dioxide, each of which have been found to have a high degree of purity after being extracted from EOL LIBs. Electrode materials can be extracted from the cathode materials of EOL LIBs, and can be reincorporated into LIB value chains.

Other functional materials, including ferrite, MnCo2O4 (which can be used in nanocarbon materials which themselves are incorporated into novel battery storage technology),[75] and graphite are also able to be extracted through hydrometallurgical LIB recycling. Each of these materials and chemicals have existing market value, and existing demand in value chains around the world. A challenge for Government in incentivising the development of a native recycling and processing industry is in proactively identifying, and potentially working with Federal authorities to open, international markets for raw LIB materials.

The economics of LIB recycling remains a hurdle – but present a first mover advantage

> " At present there is little hope that profitable processes will be found for all types of current and future types of electric-vehicle LIBs without substantial successful research and development, so the imperative to recycle will derive primarily from the desire to avoid landfill and to secure the supply of strategic elements." –
> *HARPER ET AL, 2019.*

The economics of LIB recycling remains a hurdle, particularly in Australia which currently has a modest uptake of EVs. However, there remains an opportunity to harmonise EV LIB and other LIB waste streams in Australia, particularly if much of that industry is concentrated to a single jurisdiction. South Australian policymakers should be cognizant about the challenges and opportunities presented by the growing lithium-ion waste stream. While the volume may not be there today to sustain a native recycling industry, there is time available to government to take proactive steps to ensure that, when the volume of LIB waste is inevitably available to create an economically viable recycling capacity within Australia, that South Australia is the logical home for that industrial capacity.

South Australia is also fortunate to already be a participant in industrial scale metals processing. The lead smelter at Port Pirie, owned and operated by Nyrstar, is illustrative of South Australia's existing role in the refining of metals that are essential contributors to international battery supply chains. Where possible, the Government of South Australia should explore collaboration with existing private sector actors in metal processing to see where existing industrial capacity can be expanded to incorporate at-scale LIB recycling and processing.

RECOMMENDATION 4

Work to leverage SA's existing industrial and manufacturing assets to develop LIB recycling capacity.

Markets need to be developed to sustain a recycling export industry

One of the key challenges in developing sustainable recycling schemes within any jurisdiction is in identifying and opening markets for the recycled products. For many South Australians, recycling household waste is merely a matter of responsibly disposing of materials which are then collected and processed elsewhere. But for the organisations responsible for recycling any material – be it paper waste, plastic waste, or more technically complex materials such as LIB waste – it is essential that the recycled product, or materials extracted through the recycling process – are directed towards a willing consumer of those recycled materials.

This report has identified the critical minerals that compose lithium-ion batteries, and the inherent value in those materials. But given the complexity and the expenses involved in processing LIB waste, a degree of market certainty is required if investors are to develop private recycling capacity in South Australia. Part of the Government of South Australia's response to this challenge could go beyond drafting regulations and guidelines to actively leveraging its convening, procurement, and intergovernmental negotiation capacities to identify and potentially open new markets for recycled LIB materials. Government procurement power can play an important role in creating markets for recycled LIB materials, in particular encourage the development of a fast-charging network for EVs that prioritises the integration of second-life batteries.

PART 3: IDENTIFYING SOUTH AUSTRALIA'S ROLE IN LIB WASTE MANAGEMENT

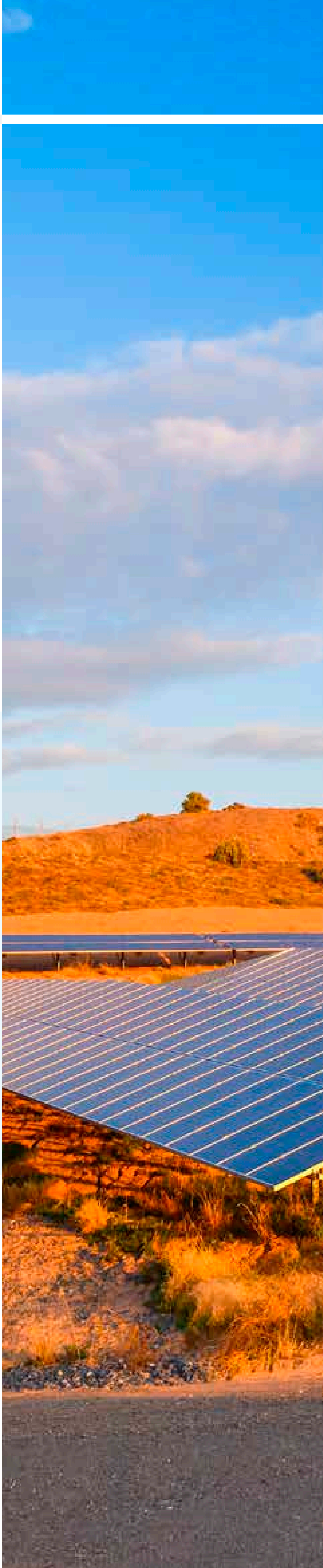
3.1: Identifying South Australia's Opportunity

KEY POINTS

1. While there are considerable opportunities for the South Australian economy in handling LIB waste, the State Government should be cognizant of the myriad challenges associated with nurturing a local LIB waste management capacity.

2. South Australia can act now to get ahead of the curve, investing in skilling the South Australian workforce, identifying and developing markets for LIB waste, and preparing existing waste management actors, for the growing challenge that is LIB waste.

This section highlights the challenges that may prevent the emergence of a LIB recycling industry in South Australia. Given market volatility associated with lithium, cobalt, nickel and manganese and the high expenses involved in the recycling process, the State Government should strategically identify where South Australia can best position itself within the LIB waste ecosystem.



South Australia's strong environmental credentials position it well to foster a LIB waste processing industry

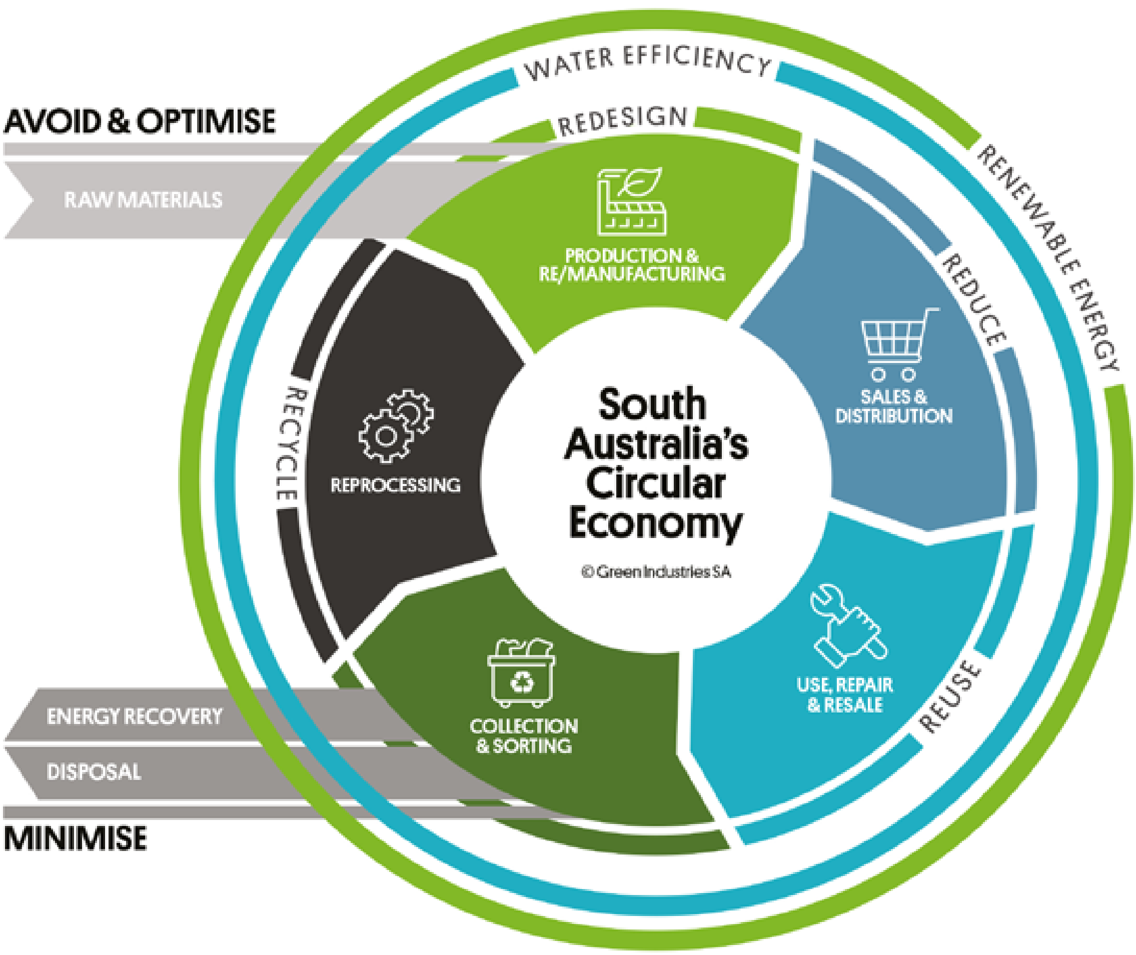
Over the past decade, South Australia has built upon its international waste management reputation and emerged as a leader in clean-technology and environmentally positive legislation aimed at making the state's economy more sustainable. The highly publicised policy achievements, such as the state's high penetration of renewables into the energy mix, and successful integration of battery storage into the energy grid, are complimented by a largely bi-partisan approach to environmentally sustainable policy. This has been demonstrated by the success of the Home Battery Storage scheme, as well as the Government's facilitation of circular economy initiatives advanced through Green Industries SA. The Department for Energy and Mining have also been forward movers in terms of fostering a hydrogen strategy for the state.

Each of these initiatives breathe confidence into investors' minds . The development of a LIB waste management strategy in the state would help to further SA's clean energy and circular economy credentials, adding to the state's reputation and attractiveness for both investors and future residents.

South Australia's Circular Economy goals will create jobs

In 2017, South Australia published a study estimating potential benefits of a circular economy in South Australia, which would see the creation of over 27,000 jobs within the state if the State were to move towards a more circular economy by 2030. The circular economy benefits report aspired to a state economy that would become a "self-sustaining system driven by renewable energy" with an "imperative to keep material resources in use, or circulating for as long as possible".

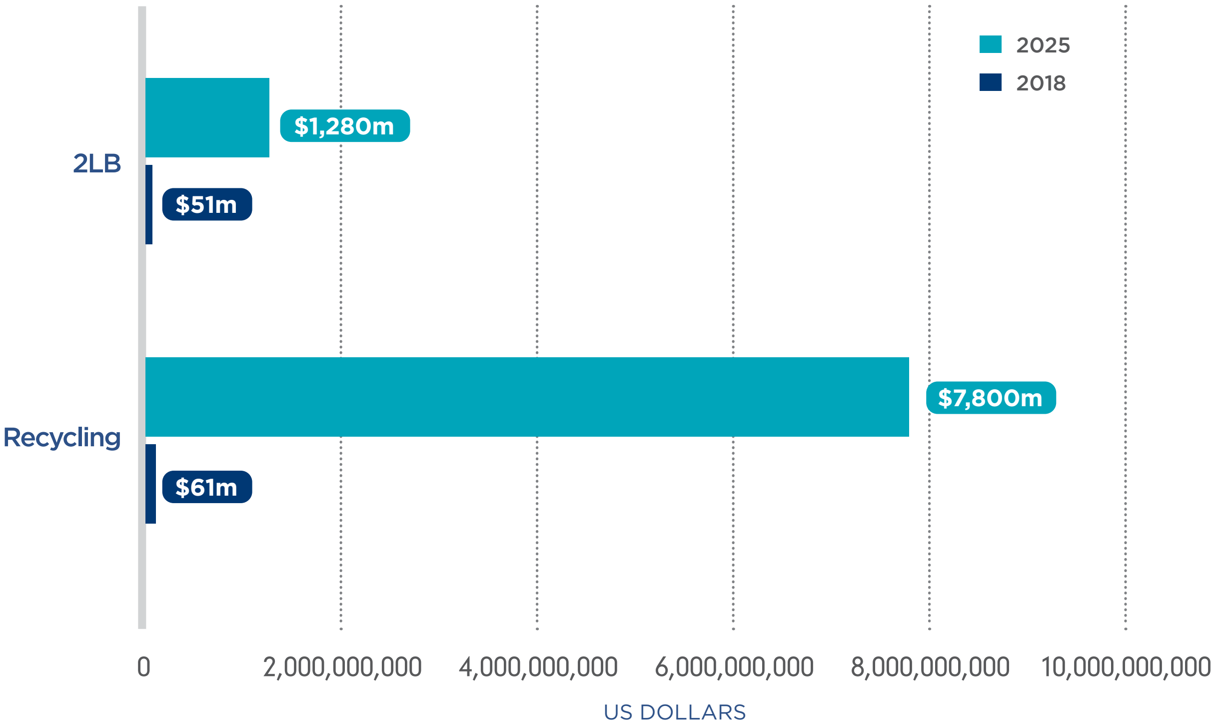
FIGURE 3.1 SOUTH AUSTRALIA'S CIRCULAR ECONOMY FRAMEWORK.



South Australia should carve a new niche in the LIB value chain

South Australia's approach to realising the economic opportunities associated with LIB waste management must be shaped by identifying practical but ambitious role for South Australia in a growing international market. As with any new and emerging market, there is considerable opportunity for first movers. But despite the LIB recycling and second-life battery market's forecast exponential growth in the coming years (*Figure 3.2*), South Australia still requires a strategic approach to consolidate a corner of this growing market.

FIGURE 3.2 FORECAST GLOBAL REVENUE IN 2018 AND 2025 IN THE SECOND-LIFE BATTERY AND LIB RECYCLING INDUSTRIES.

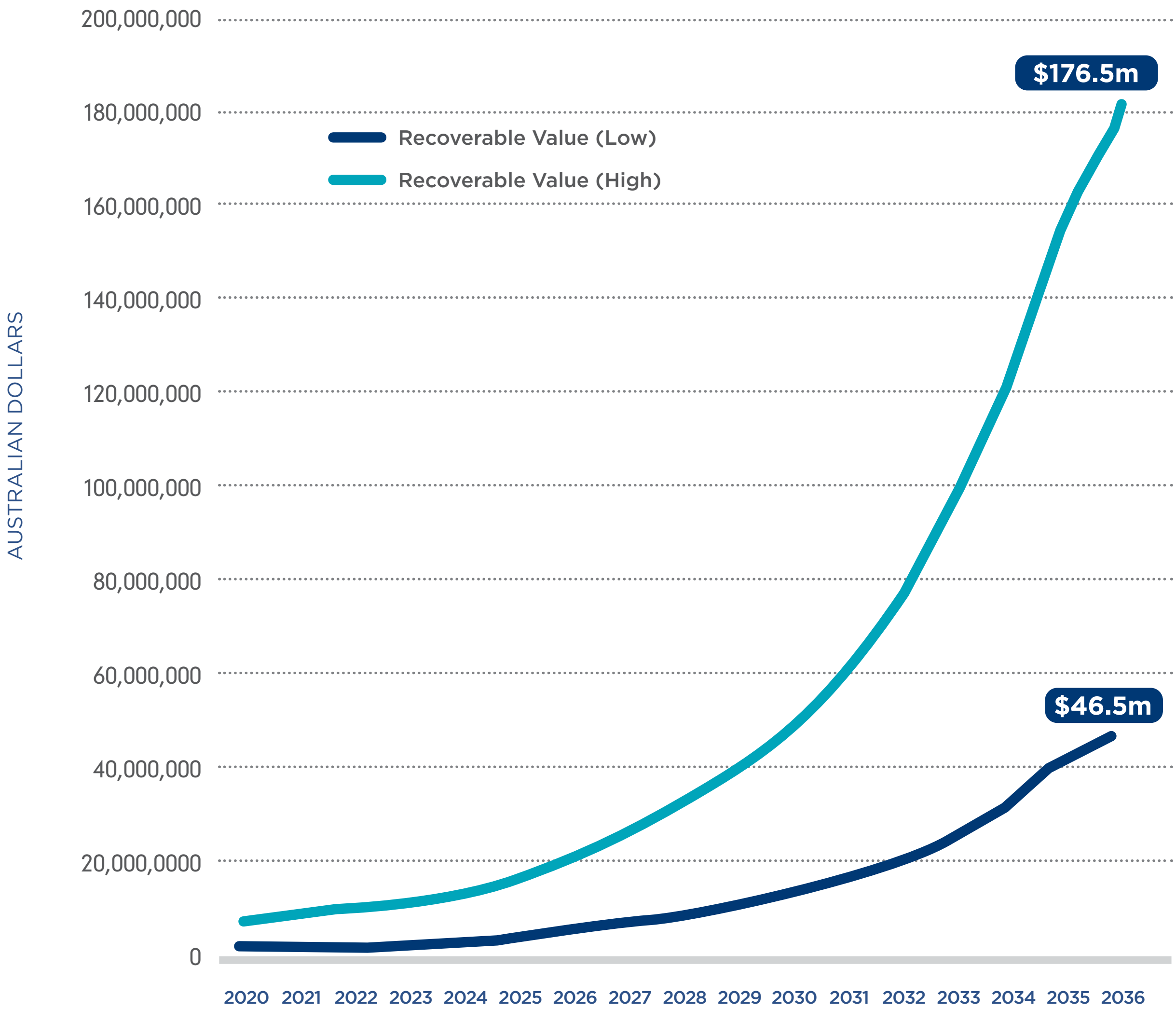


Source: Bloomberg NEF.

The value of LIB waste in South Australia is modest, but growing

The estimated recoverable value of the LIB waste in South Australia is modest. In 2020, total recoverable LIB waste within South Australia is likely valued between $1.85 million and $7 million. Under high value scenarios outlined by the CSIRO, it is likely the total recoverable value of LIB waste in South Australia will reach $176 million per annum by 2036, but could be as low as $46 million per annum (*Figure 3.3*). These are not insignificant waste streams, but the modest value when compared with the high Capex and OpEx requirements of recycling this waste stream does render it unlikely that a private sector LIB recycling industry will emerge independently without State Government leadership.

FIGURE 3.3 ESTIMATED RECOVERABLE VALUE OF LIB WASTE IN SA, 2020-2036.

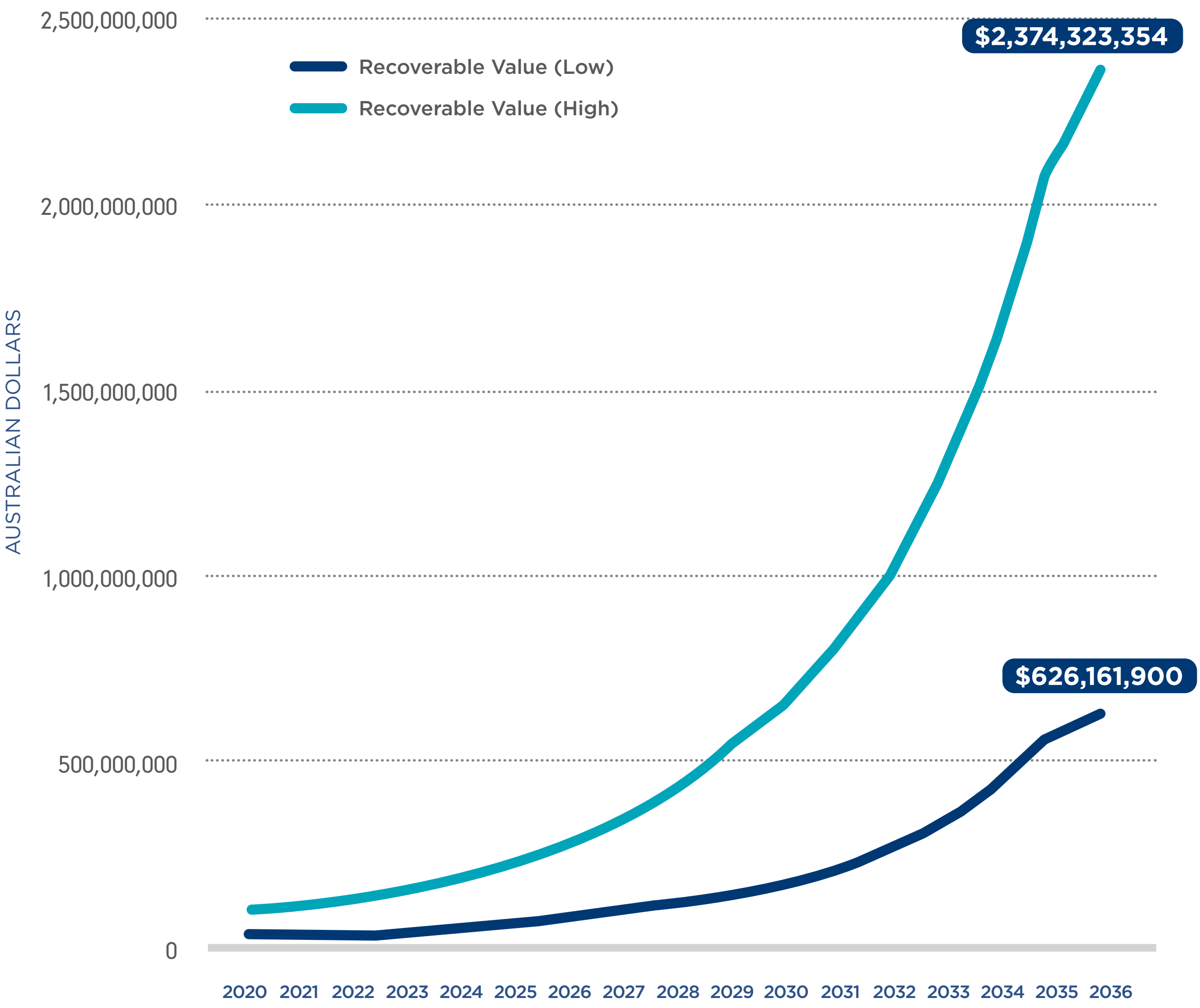


Source: Author analysis of Bhatt et al (2018).

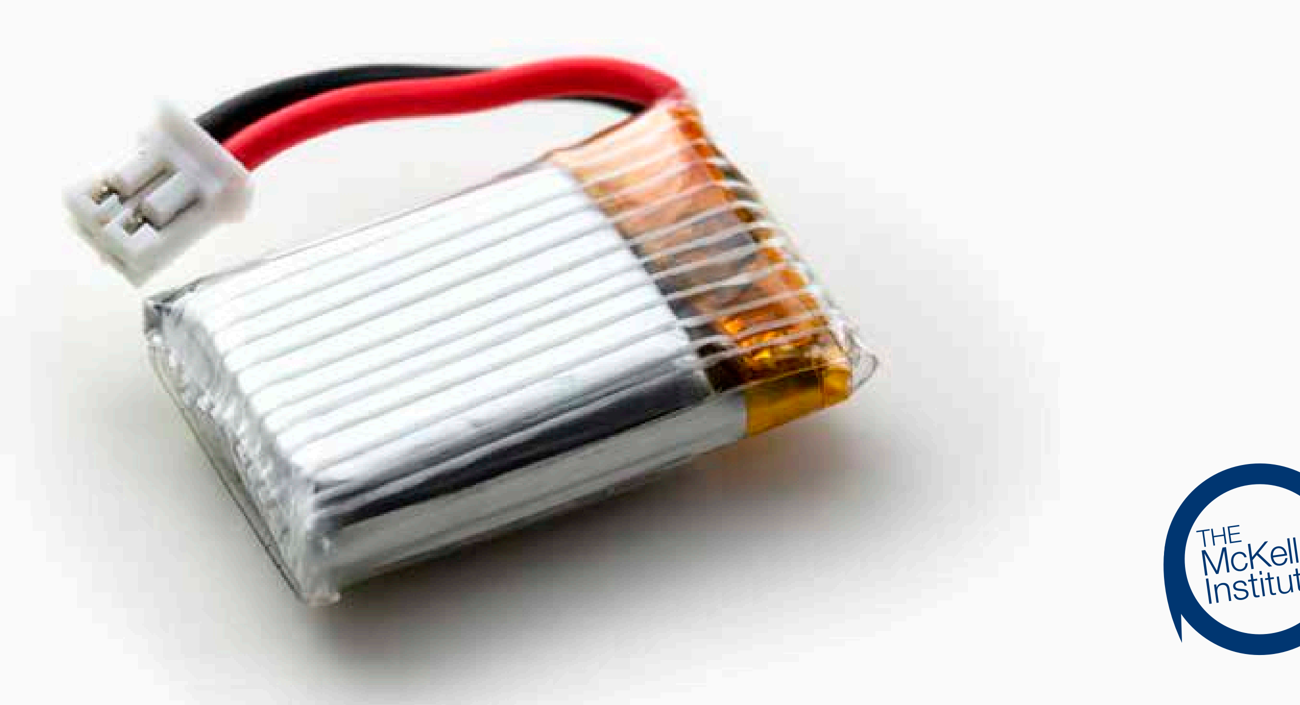
Viable LIB recycling in Australia likely requires national and regional supply

The economic viability of recycling in South Australia becomes more apparent when looking at the value of recoverable waste expected nationally. The CSIRO predicts overall value of LIB waste to exceed $3 billion in the 2030s, with low case estimates still predicting a recoverable value of over $700 million. However, under low EV uptake and low cobalt price scenarios, the overall recoverable value by 2025 remains modest, at approximately $60 million nationally. While there is potential for a LIB recycling industry in South Australia, any recycler would require a significant share of the national supply to be viable. More room for competitors may emerge if Australia actively pursues the importation of regional waste streams, particularly from New Zealand and the Pacific, and potentially South East Asian and South Asian markets without local LIB waste management capacity.

FIGURE 3.4 ESTIMATED RECOVERABLE VALUE OF LIB WASTE IN AUSTRALIA, 2020-2036.



Source: Author analysis of Bhatt et al (2018).



3.2: Market dynamics for resources extracted from LIBs

KEY POINTS

1. **To date, LIB recycling has been focused largely on cobalt recovery, given cobalt's high value.**
2. **Spikes in prices for both lithium and cobalt in 2017/18 have largely subsided, demonstrating a degree of volatility in price forecasting for these commodities.**
3. **While demand for lithium is growing, so too is supply, negatively impacting price. A raw lithium-recovery focused recycling industry may be economically unviable in Australia, without a consolidation of national and regional LIB waste streams in a centralised hub like SA.**

Lithium and cobalt pricing

The economic viability of a sustainable LIB recycling industry is pinned to the value of the dominant commodities, lithium and cobalt, that are found in LIBs. While Geosciences Australia identifies both commodities as 'critical', the market price for both cobalt and lithium has continued to decline since peaks in late 2017. There are numerous underlying market dynamics associated with the 2017 spike, followed by a flattening of the commodities' prices. Recent production spikes in both lithium and cobalt in China have driven prices below their historic peaks (industrial grade lithium is still well above historical averages pre-2015 and a premium market has emerged for very low impurity, battery quality chemicals).

The flattening of lithium and cobalt prices highlights the need to scale, and focus on high purity product-specific outputs

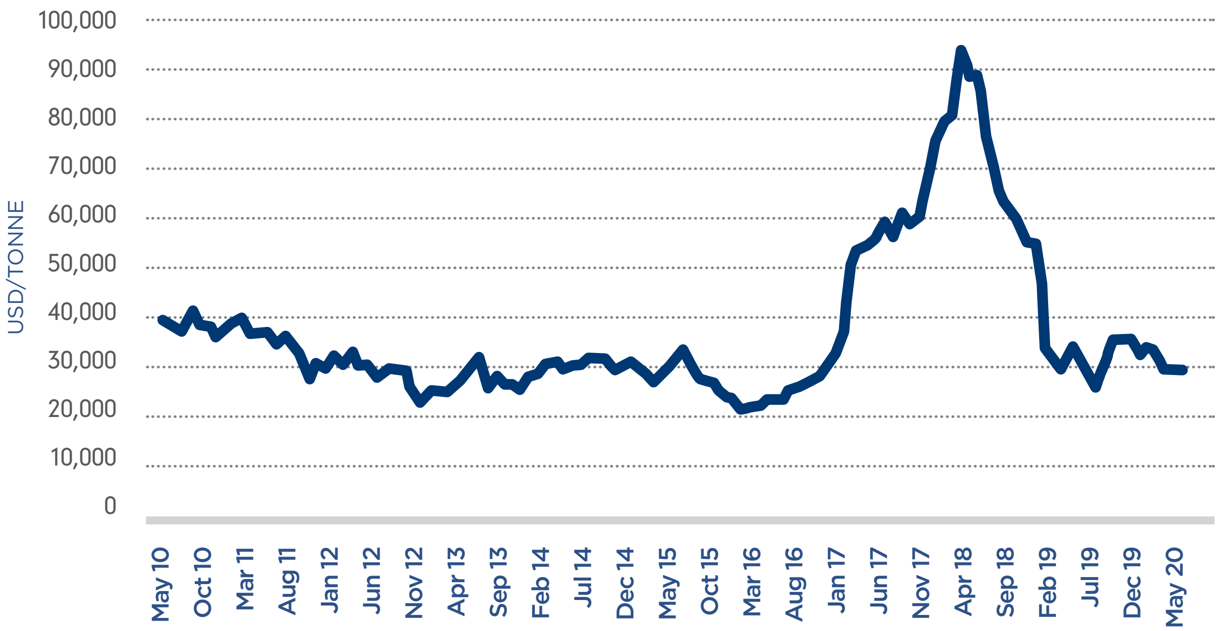
With the recent flattening of both cobalt and lithium prices (*Figures 3.5; 3.6*), the economic viability of LIB recycling in Australia is impacted. What this demonstrates, however, is not that Australia has no role to play in LIB recycling, but that in order to maximise the economic sustainability of a domestic LIB recycling industry, Australia must position itself to be a regional LIB waste recycler, harvesting the LIB waste of neighbouring countries and producing high purity product-specific outputs that secure economically viable and sustained pricing.

> " For almost all Li-ion battery materials, the product required is highly specific, calling on a particular corner of the wider commodity market concerned; dynamics for particular battery-grade products might be quite different from those of the commodity overall"
>
> ***– ROSKILL INFORMATION SERVICES.***[76]

While cobalt remains a highly valuable commodity, industrial grade lithium's value is unlikely to dramatically increase in the near future, despite the expected growth in demand for lithium-ion batteries. Other forms of lithium, however, have more potential to achieve high returns. Product-specific grades of lithium or other refined materials have different market dynamics to raw commodities, and may achieve a more predictable rate of return than simply recreating a product, like unrefined lithium, of which there is ample global supply.

FIGURE 3.5

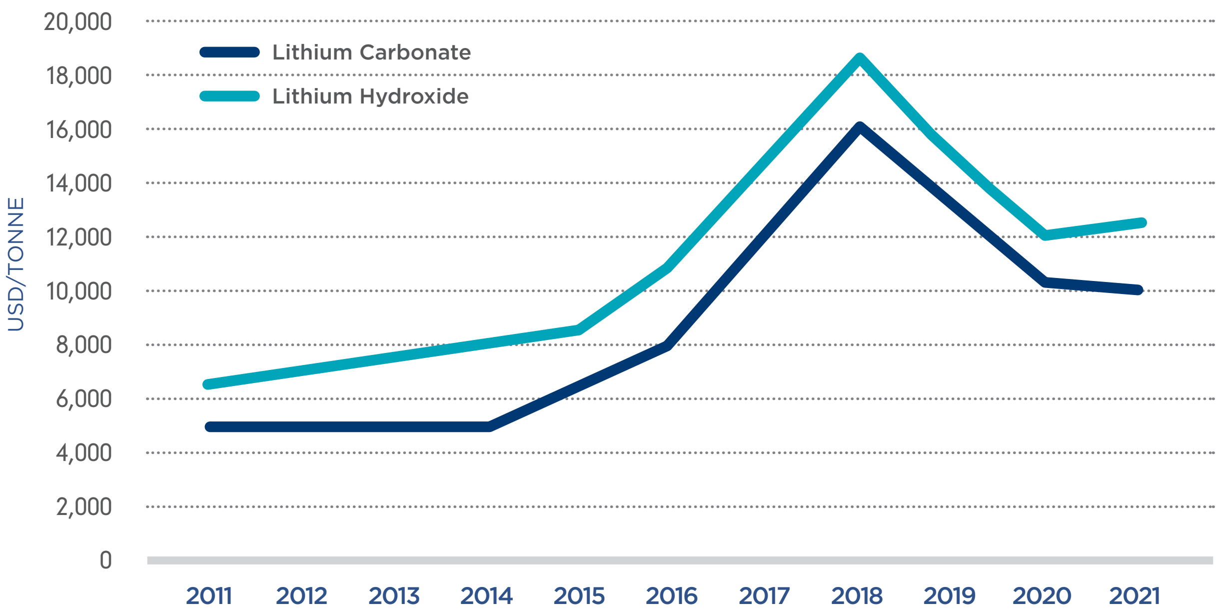
MARKET PRICE OF COBALT, 10 YEARS TO MAY 2020 (MOST RECENT DATA ASCERTAINABLE).



Source: LME.

FIGURE 3.6

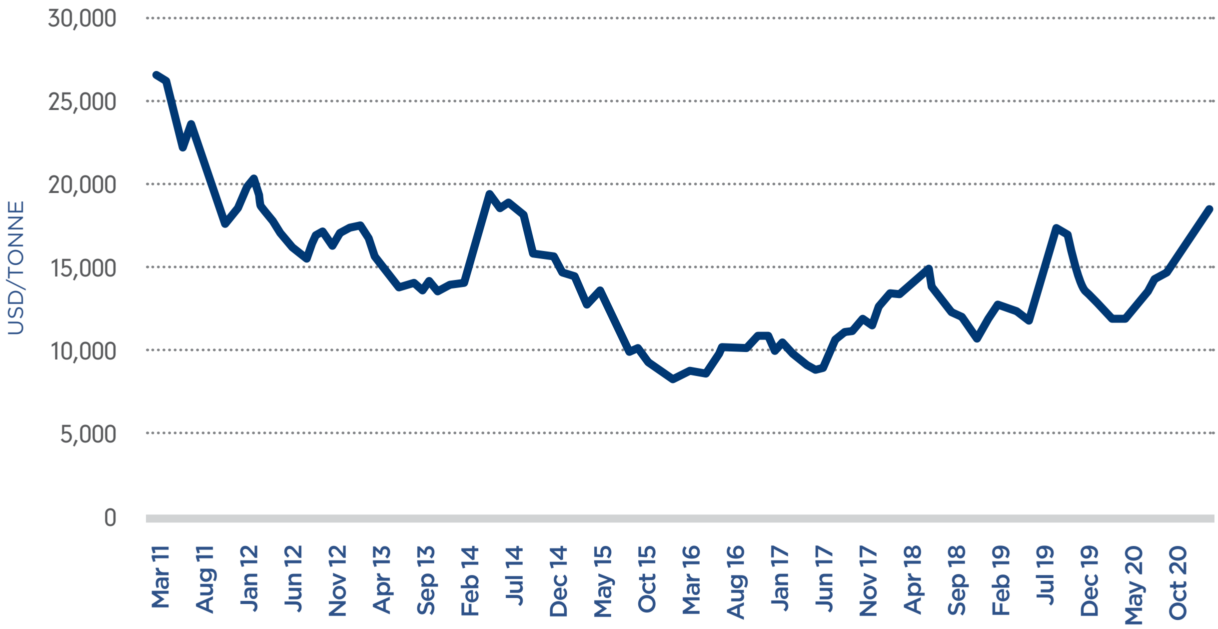
MARKET PRICE OF BATTERY GRADE LITHIUM, 2010-2020.



Source: Piedmont Lithium.[77]

As Figures 3.8 to 3.9 demonstrate, there is currently a significant global supply of lithium that currently meets demand. This has led to modest market price volatility, which is expected to remain the case until 2025. However, according to industry forecasters, these prices will stabilise at approximately USD$13,000/tonne.[78] The cobalt market also offers a lucrative supply/demand dynamic, with forecast demand to 2025 outstripping supply. This dynamic suggests that recyclers should not just focus on lithium extraction, but also harvesting cobalt in the near future. Recyclers should also consider the opportunity in focusing on nickel extraction in any LIB recycling process. Nickel is a valuable commodity (*Figure 3.7*) with less market volatility than other raw commodities, and focusing on extracting nickel provides additional opportunities for diversifying the recycled-LIB export stream.

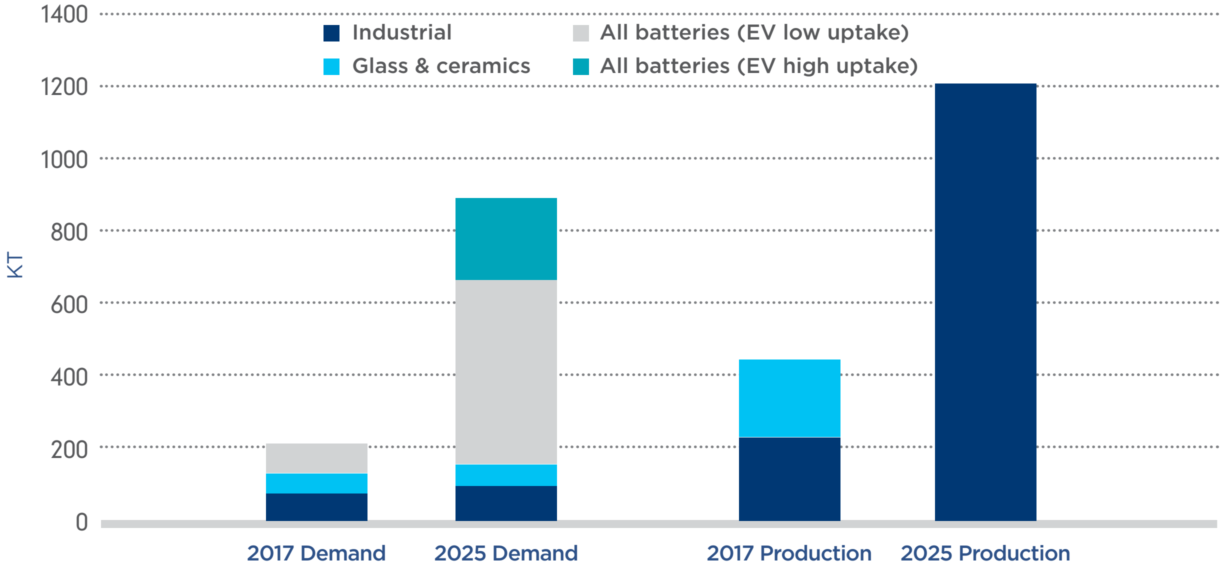
FIGURE 3.7 NICKEL PRICE, 2011-2021, USD/T.



Source: IndexMundi

FIGURE 3.8

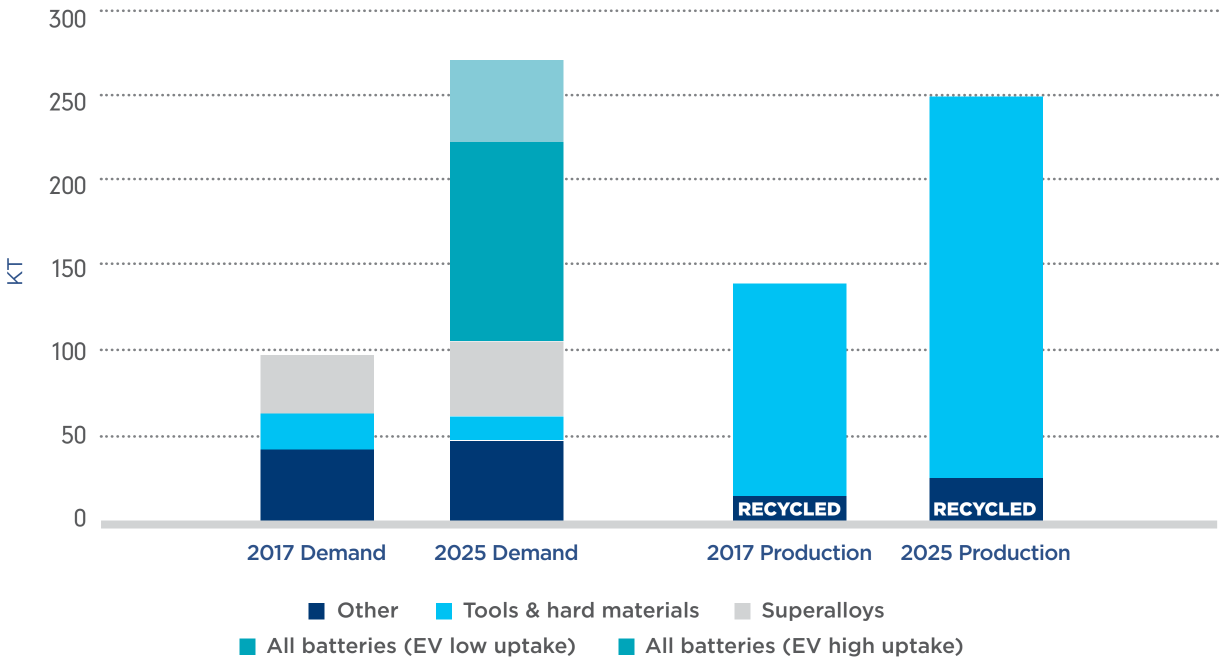
GLOBAL DEMAND FOR LITHIUM IS EXPECTED TO BE OUTMATCHED BY GLOBAL SUPPLY FOR SOME TIME, EVEN WITH HIGH EV UPTAKE SCENARIOS, BUT THERE PRICES ARE EXPECTED TO STABILISE AFTER 2025.



Source: Azevedo et al, 2018.[79]

FIGURE 3.9

GLOBAL DEMAND FOR COBALT IS EXPECTED TO OUTPACE THE TOTAL SUPPLY OF COBALT BY 2025, NECESSITATING AN INCREASE IN RECYCLING OF LIBS.



Source: Azevedo et al, 2018.[80]

LIBs may not always require cobalt

While the existing broad market dynamics suggest that a recycling strategy focused primarily on cobalt extraction is more economically viable in the long term than one focused on lithium, LIBs without cobalt are also beginning to be developed, which may call into question the long-term viability of focusing on cobalt extraction. The current price of cobalt is one of the drivers of the high price in LIBs, and therefore in consumer products as well as EVs. A pinnacle of battery research has been in identifying ways to manufacture high performance LIBs without requiring cobalt, which will ultimately minimise the cost of LIBs in numerous applications.

Svolt, a Chinese battery company, announced in May 2020 it will be releasing 'zero cobalt' batteries in 2021, which it claims can be incorporated into EV power trains that deliver ranges of over 600 kilometres on a single charge.[81] Similar technology is already being incorporated into EVs manufactured by Daimler, with Ford also experimenting with the technology.[82] Such innovations demonstrate the rapid advances in battery technology, and the need to develop a recycling capacity that is flexible enough to accommodate changing technology and market dynamics.

The expected introduction of a Battery Stewardship Scheme improves the economics of collection and recovery

In September 2020, the ACCC approved the Battery Stewardship Council's (BSC) proposed levy on battery units imported into Australia.[83] Since 2015, stakeholders within the Australian battery industry have been deliberating on the best way to introduce battery stewardship in Australia. The ACCC approval allows the BSC to implement a new levy on all imported batteries into Australia.

The levy is proposed to sit at $0.04 per equivalent battery unit (EBU), which equates to around $1.67 per kilogram of imported battery. As currently proposed, the BSC levy is voluntary for participating stakeholders, but its adoption is expected to be widespread given the extensive consultation the BSC had undertaken throughout the five year period prior to the ACCC approval.

The BSC forecasts that, in its initial year, the scheme could, from 2020, inject $22 million of capital into the national recycling industry – a significant sum that can enable some of the cost barriers of collection and disassembly of battery stock to be overcome, and encourage actors into the industry. If the levy was applied to the future forecasts of LIB stock in Australia, the sum is increased significantly. A $0.04/BCU levy on incoming LIB stock could, by 2035, inject over $200 million annually into the stewardship scheme, if the levy was universally applied (*Table 3.1*).

While the levy is yet to be implemented, its approval suggests the industry is already working to solve the cost barriers associated with recycling and reprocessing battery waste, which paves the way for governments like South Australia to work alongside the industry to facilitate the emergence of a larger national recycling capacity. The Battery Stewardship Council's adoption of a levy of $0.04 /BCU reflects the Council's expectation of the costs of handling under forecast recovery rates. Should this significantly increase, there may be room for that levy to be adjusted.

TABLE 3.1 POTENTIAL REVENUE FROM THE ACCC APPROVED BATTERY STEWARDSHIP LEVY

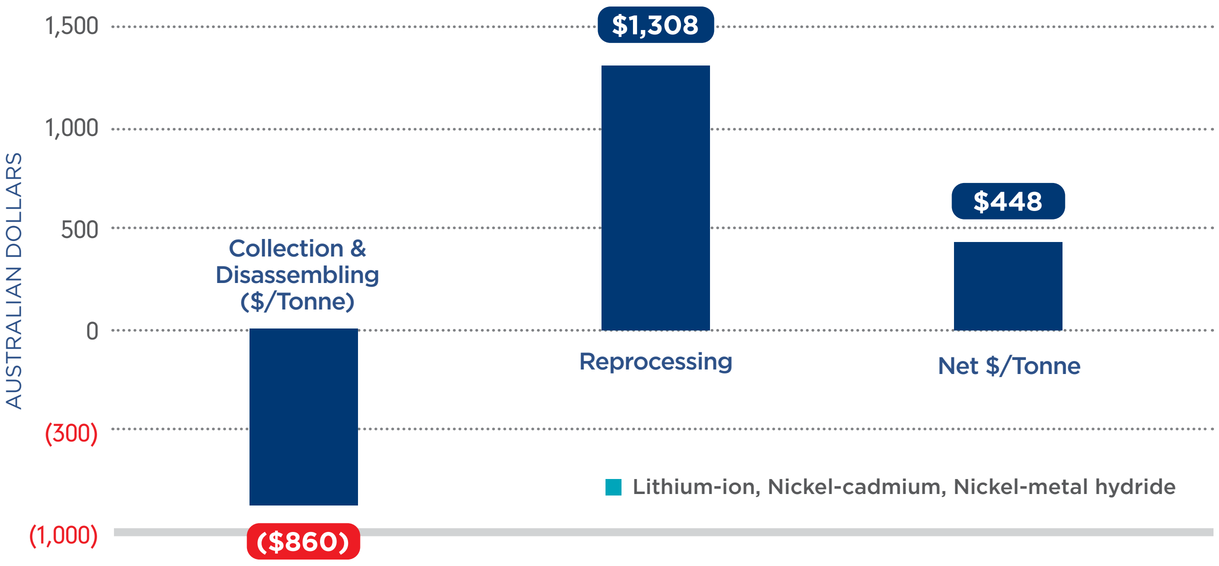
	POTENTIAL REVENUE FROM BSC LEVY
1 EBU	$0.04
1 kg	$1.67
1 tonne	$1,667
1000 tonnes	$1,666,667
SA 2035 LIB Waste Forecast	$16,833,333
National 2035 LIB Waste Forecast	$ 216,666,667

Source: Author estimates based upon Battery Stewardship Council analysis.

Collection and disassembly are loss-making, but can be offset by selling processed waste resources

The Battery Stewardship Council's proposed levy paves the way for a much more viable domestic LIB recycling industry. As *Figure 3.10* demonstrates, the collection and disassembly process within the broader LIB recycling process is a significant cost, but can be offset by the profit (~$448 per tonne) made by the on-sale of reprocessed LIB raw materials. The emergence of a viable battery stewardship scheme will see an inflow of capital into the system, improving the costs effectiveness of LIB recycling.

FIGURE 3.10 FINANCIAL ASSESSMENT OF THE LIB BATTERY RECYCLING PROCESS. COLLECTION AND DISASSEMBLING IS A COSTLY AND UNPROFITABLE PRACTICE, REQUIRING SCALE AND POTENTIALLY GOVERNMENT SUPPORT.



Source: Battery Stewardship Council

3.3: Envisaging a South Australia-Centric LIB Waste Hub

KEY POINTS

1. **While no formal plans have been put forward aimed at developing a national LIB waste management industry, a growing literature identifying how to make an LIB recycling industry viable in Australia is emerging.**
2. **Two primary models are plausible: a 'centralised hub', or a 'state centric' national capacity.**
3. **South Australia is well positioned to emerge as a 'centralised hub' for Australia, New Zealand and the Pacific's LIB waste processing, if national barriers are removed.**
4. **A South Australian LIB Processing Hub could see LIB waste imported from the east, extracting metals in Adelaide which can then be transported west to export internationally.**

Australia is the world's largest lithium producer. But so far, much of the lithium that is extracted, predominately in Western Australia, is shipped internationally before being incorporated into any value-added products in Australia. A much quoted statistic, highlighted by the Federal Government in its development of a lithium roadmap for Australia, is that 99 per cent of the end-value of the lithium Australia produces is sent offshore, to be incorporated into manufactured products abroad, which are sold into international markets.[84] It is clear that Australia has, so far, been unable to expand its participation in the lithium-ion supply chain beyond resource extraction. But developing a domestic LIB recycling capacity would help to address this deficit.

South Australia has a competitive advantage over other states in developing at-scale recycling capacity

South Australia is a logical jurisdiction in which nascent recycling technology can be adopted. Firstly, its location within Australia enables the state to offer prospective investors a centralised location in which operate. The geographic advantage of South Australia, as highlighted in *Figure 3.11*, permits direct overland access to all Australian states. This would permit the state to serve as a central hub in which LIB waste flows from all Australian jurisdictions could be directed. In a future scenario where Australia enables the international importation of recyclable LIB waste, South Australia's ports infrastructure, and the proximity of that infrastructure to existing industrial environments, would serve as an advantage. South Australia also has among the lowest commercial property prices in Australia, lowering the overall cost burden on any private sector investor that is seeking to scale its LIB recycling capacity in Australia. Further, South Australia's existing skills base and industrial capacity would allow any investor engaged in LIB recycling to tap into an existing local skills pool, with experience in advanced manufacturing and metals processing. Additionally, the state has developed a strong bipartisan commitment to green industries and the pursuit of a circular economy initiatives. This political stability offers investors certainty. By making clear its commitment to implementing circular economy practices to battery recycling, the Government of South Australia can leverage its existing advantaged to encourage private capital into the state's nascent sector.

South Australia could aspire to be an intermediary LIB waste processing hub

Australia's lithium export industry is concentrated to Western Australia, which is working on capitalising on its lithium dominance to grow a localised battery manufacturing sector. South Australia is well placed to serve as an intermediary between LIB waste streams from Australia's populous eastern seaboard, and Australia's existing mineral export capacity in Western Australia. In this 'Intermediary Model' (*Figure 3.11*), South Australia could harness low cost renewable energy and green hydrogen to position itself as not only a sustainable processor of LIB waste, but also as a remanufacturer, working to secure LIB waste streams from the growing EV market and electronic waste streams for South Australian firms specialising in resource recovery, and second-life battery processing and remanufacturing.

FIGURE 3.11

THE *"INTERMEDIARY MODEL"*: SOUTH AUSTRALIA ACTING AS A WASTE STREAM MANAGEMENT HUB FOR LIB WASTE EMERGING FROM AUSTRALIA'S POPULOUS EASTERN SEABOARD, THE NZ AND PACIFIC, BEFORE TRANSPORTING EXPORTABLE LIB RAW MATERIAL WASTE THROUGH EXISTING EXPORT CHANNELS IN WESTERN AUSTRALIA.

Existing recycling capacity and LIB waste transportation a hurdle to the intermediary model

Though South Australia is well positioned to realise the *Intermediary Model (Figure 3.11)*, considerable steps would need to be taken to bring this vision to life. The first steps would be identifying the various policy impediments that stand in the way of SA LIB recycling hub, and working with other jurisdictions to overcome them. This includes the challenges for transporting LIB waste in Australia, as well as securing waste streams from interstate and internationally. Ideally, a nationally consistent approach to waste management should be legislated through the National Cabinet process. However, even in lieu of a nationally consistent hazardous waste transportation framework, South Australia – which borders each Australian mainland jurisdiction but the ACT – is uniquely positioned to design a regulatory framework that facilitates the inward delivery of reusable and recyclable waste into South Australia.

South Australia should aspire to be a second-life battery innovation hub

The battery cell market is becoming increasingly crowded and focussed upon China, Japan, Korea, Europe and North America. South Australia is yet to see considerable battery innovation or manufacturing within the local market. There is a gap, however, in the second-life battery market. Existing innovation hubs, such as Western Australia's *Future Battery Industries CRC*, are large scale initiatives with a broad focus on the new battery chemical and cell industry. Western Australia's approach has been borne out of its dominance of the lithium supply, understanding that it is missing out on the opportunities associated with value adding to its raw lithium before exporting the commodity to the world. Given WA's advances in this space, South Australia needs to identify a niche in the battery industry which it can support. Given the need for second life battery innovation and commercialisation, active State Government support for the second life battery industry would be a logical focal point in South Australia.

A SA-based battery recycling hub could create over 300 South Australian jobs

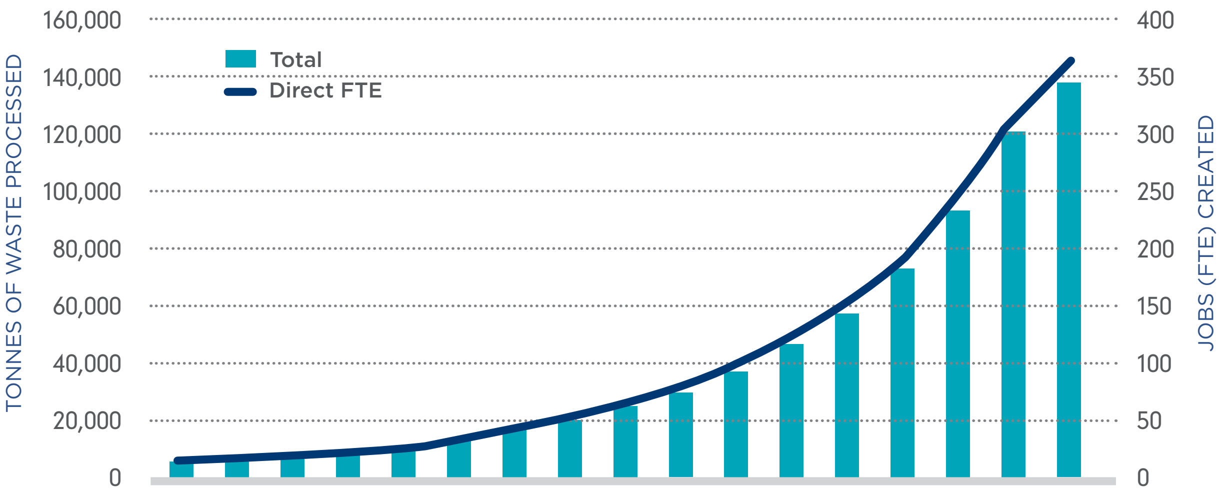
South Australia is emerging as a premier jurisdiction for environmentally conscious jobs creation, and the centralisation of an Australian LIB recycling industry would further that reputation.

Given the mechanisation of battery recycling, however, a significant consolidation of the overall supply of recyclable LIB material would need to be concentrated in order to facilitate a sustainable local industry and a high level of associated employment. The Battery Stewardship Council, in its 2020 *Australian Battery Market Analysis*, identified that for every 10,000 tonnes of reprocessed batteries, 26.4 direct full-time equivalent jobs are created. This estimate is derived from existing survey data that has identified current employment levels in comparable recycling facilities around Australia.

While this is a modest direct level of employment, this figure ignores that broader economic dividends associated with the on selling of recycled or reprocessed battery materials, or the sale or remanufacturing of second life batteries. It also fails to account for the indirect employment impacts associated with freight and handling of the materials.

The analysis suggests that, by 2030, the direct jobs created by lithium-ion battery recycling Australia-wide could reach around 300 full-time equivalent positions. By 2035, the industry would be creating 365 FTEs before considering associated employment in freight, and the indirect jobs created by the 365 FTEs (*Figure 3.12*). As *Table 3.2* illustrates, the greater the resource consolidation, the higher the jobs expected within the state.

FIGURE 3.12 FTE CREATED BY WEIGHT OF LIB WASTE PROCESSED.



Source: Author estimates based upon Battery Stewardship Council analysis.

TABLE 3.2 FTE CREATED BY WEIGHT OF LIB WASTE PROCESSED UNDER VARIOUS LIB WASTE RESOURCE CONSOLIDATION SCENARIOS.

	EST. TONNES PROCESSED ANNUALLY	DIRECT RECYCLING FTES
South Australian LIB Waste Only	8000	22
Australian LIB Waste	120,000	317
Australia + Oceania LIB Waste	150,000	396
Oceania + South East Asia Waste	250,000	660

Source: Author estimates based upon Battery Stewardship Council analysis.

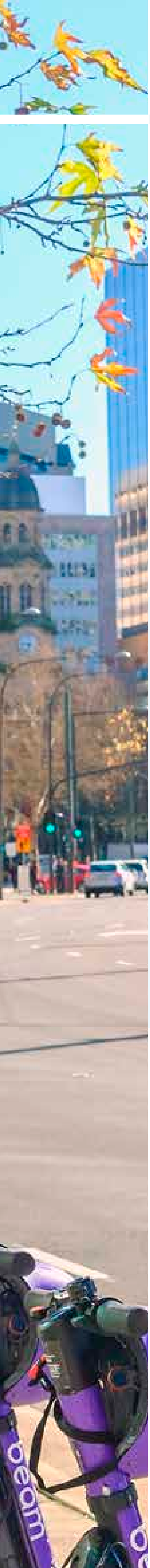
The path to high employment in recycling LIB waste depends on regional waste resource consolidation

> "Smaller firms have significantly lower revenues from reprocessing compared with that earned by those employing 20 or more in reprocessing."
>
> *– BATTERY STEWARDSHIP COUNCIL*

The key goal for the Government in shaping a LIB waste resource management industry in South Australia is exploring ways for such an industry to reach scale. While the proposed battery stewardship levy will ameliorate some of the high costs associated with collecting and disassembling LIB stock, waste resource processors require large volumes of recyclable waste to generate enough revenue to sustain a local industry.

Indeed, the emergence of such a stewardship scheme positions Australia well to incentivise prospective recyclers to establish a foothold in Australia, and presents South Australia with an increased opportunity to expand upon its already established reputation as a clean technology leader. Further leadership is required to shift consumer behaviours towards very high levels of consumer product recycling.


beam



PART 4: BEST PRACTICE GUIDELINES

4.1: Best-Practice LIB Waste Management Principles

KEY POINTS

1. While there are reforms South Australia can make within its borders, the Government will also need to advocate for best practice LIB waste management reform at a Federal level.

2. There are seven urgent priorities that need to be addressed before investment certainty in the LIB waste management sector can be delivered.

While there are clear actions that the Government should adopt to grasp the opportunities associated with EV and LIB waste, there are significant national barriers that also need to be addressed. However, given a current disengagement from Federal authorities on the issue of EV policy and LIB management, there is room for the Government to lead on developing best practice guidelines, identifying the national policy challenges that all jurisdictions need to address, and proceed to work through the National Cabinet or other national bodies to affect change beyond South Australia.

PRIORITY 1

Improve collection and recycling of today's battery waste to build the foundations for tomorrow's industry

This report has looked to the future of South Australia's LIB waste resource challenge. But a battery resource challenge continues to impede the viability of a future LIB recycling sector. As this report has noted, battery recycling – across all battery streams - in Australia is inadequate. This is highly evident with the sizeable existing LIB waste streams that come from consumer electronics in Australia. Despite this waste stream being prohibited from entering landfill, it is estimated that a majority of LIBs from consumer electronics in Australia still end up in landfill. This creates a significant environmental problem – but it also signals the difficulty of collection and recycling of this waste stream in Australia.

While governments should always work to position themselves to take advantage of emerging economic opportunities, existing challenges at times need to be addressed in order for those larger opportunities to emerge. This is the case with LIB recycling. Although there are considerable opportunities for the South Australian economy in developing an advanced LIB waste resource processing capacity, it must first address the fundamental issues of today's LIB waste flowing into landfill.

PRIORITY 2

National regulations for the transportation of LIBs must be streamlined

There are significant challenges and expenses associated with the transportation of lithium-ion waste across Australia. The Australian Code for the Transport of Dangerous Goods by Road and Rail (Page 165) has complex guidelines for transporting LIBs.[85] These guidelines expect transportation firms to be able to demonstrate detailed understanding of the manufacturing process of the batteries they are transporting, including cell composition and the date of their manufacture. Some participants have noted challenges in complying with these regulations, in addition to different regulations in each state and territory. While regulations regarding the safe transportation of LIBs are essential, there is a case for modernising and streamlining the existing regulations.

RECOMMENDATION 5

The Government of South Australia, in should work with the National Cabinet to identify how to harmonise regulations regarding the transportation of dangerous goods in each state, to lower compliance costs for transporting LIB within Australia.

PRIORITY 3

A nationally consistent LIB labelling framework needs to be implemented, guided by the industry-led Battery Stewardship Scheme's recommendations

Inadequate labelling of LIBs is a major roadblock to developing an economically viable recycling industry in Australia. While LIBs are often labelled with a generic 'Li-Ion' label, this is not universal, nor does it provide any information to the chemical composition of the LIB that is labelled. No single jurisdiction within Australia can advance and legislate a labelling system unilaterally; rather, the state's need to coordinate or work with the Federal Government to implement a nationally consistent labelling system. Such a system could be built upon the existing 'Li-Ion' label, with colour-coded labels specific to LIBs with certain chemical compositions. See *Figure 4.1*.

Mandating labelling isn't as simple as passing legislation. Given that LIB products entering Australia are typically manufactured overseas, Australian governments need to work with actors throughout the supply chain to implement requisite labelling. The Government of South Australia, and other Australian jurisdictions, should work closely with the Battery Stewardship Council, which has developed a stewardship scheme that considers best practice labelling requirement.

Labelling systems also need to be simple enough to allow consumers to responsibly dispose of their EOL LIBs, while providing access to information for recyclers to isolate LIBs by their composition to expedite the recycling process. A simple solution to incorporating complex technical information into labelling would be to ensure LIB casings have QR codes printed on the device, enabling EOL handlers to scan the device and ascertain its precise chemical composition and other important information before recycling. As Buckley (2018) outlines, best-practice labelling would not only include the metal composition of LIBs, but also display information including the size, power rating, and voltage of the device, as well as a label specifying that the LIB is a 'dangerous good'.[86]

RECOMMENDATION 6

Working with industry, develop guidelines over LIB labelling, which should ideally be harmonised at a national level.

FIGURE 4.1 AN LI-ION LABEL.

PRIORITY 4

Development of a localised discharging, sorting and dismantling infrastructure nationally

While a modest size ecosystem of LIB waste handlers have emerged nationally, there is still a need to improve the national capacity to sort, handle, discharge and manually dismantle LIB waste in Australia. In some instances, this will require the expansion of existing waste management facilities. In other instances, it will require the waste sector designing new tools and techniques to automate the complex process of sorting different battery waste streams. The battery stewardship levy will aid in reducing the capital costs for some private sector actors engaged in this process, but government engagement at state and federal levels would be welcome.

PRIORITY 5

A nationally consistent LIB recycling target needs to be legislated, with distinctions made between each LIB waste stream

This report has highlighted Australia's poor capacity to recycle LIB waste. While targets alone won't overcome the myriad challenges associated developing LIB waste markets, such guidelines can help shape investment and internal policy decisions by industry. It is important, however, to recognise the various points of development different LIB waste streams are in. While the waste from mobile devices is significant, for example, EV LIB waste is nascent and currently not occupying landfill. These different waste streams require different timelines for any recycling targets, but broadly, there should be an aspiration to achieve an ambitious recycling rate for LIBs by 2030. Governments should work with the Battery Stewardship Council to implement its recycling targets nationwide.

PRIORITY 6

Consumers need to be made more aware of LIB recycling options and encouraged to modify behaviours

There remains a need for consumers to receive more educational material about LIB waste at the point of sale. The estimates of only 3-6 per cent of Australia's LIB waste being responsibly recycled demonstrates not only that Australia does not yet have the capacity to recycle large volumes of LIB waste, but that consumers are also contributing to the mismanagement of LIB waste. There is a need to improve consumer education regarding LIB recycling, and encourage behaviour change across all LIB waste streams including handheld devices.

Consideration could be given to international schemes that have proven successful or a refundable levy similar to South Australia's system of container deposits that is embraced by consumers, successful in diverting material and has now been largely adopted nationally.

PRIORITY 7

Working with industry to ensure the BSC's battery stewardship scheme is successful

There is a need to develop oversight of LIB waste by LIB manufacturers themselves. While onerous regulations today could stifle the uptake of EVs, battery stewardship will inevitably be required to ensure the task of recycling EOL LIBs is conducted responsibly. The LIB waste in Australia that doesn't enter landfill is often being handled responsibly, exported to reputable firms engaged in LIB recycling predominately in South Korea, though some firms have been warehousing batteries, unsure of what the most economical and environmentally friendly way of disposing of them is. There is some concern over the nature of battery recycling in other locations, such as Indonesia, where exposés have uncovered dangerous and environmentally destructive practices in the local battery 'recycling' industry.[87] The industry-led work by the Battery Stewardship Council to develop a battery stewardship scheme in Australia provides an ideal framework for governments to adhere to ensure best practice LIB waste management.

CONCLUSION

As South Australia emerges from the COVID-19 pandemic, creative and future-facing ideas from Government are required to rebuild the state's economy. SA is uniquely positioned to capitalise on the need for bold and productivity-enhancing policy to implement new programs that benefit the economy, create local jobs, and remain true to the state's world-class reputation as a circular economy leader.

The emerging waste stream of lithium-ion batteries presents a unique opportunity for SA to step up, take control of a looming national environmental challenge and establish a LIB waste resource management hub in the state. The CSIRO predicts this waste resource stream to be valued at up to $3 billion by 2035. And while a modest LIB recycling capacity has emerged in Victoria, South Australia remains well position to lead from the front, drive national reforms in LIB waste resource management, and ultimately incentivise private sector investment in LIB waste resource management into South Australia.

But a focus on responsible end-of-life management of lithium-ion battery waste shouldn't just consider recycling. It should also explore the opportunities associated with the repurposing if lithium-ion batteries. The second-life battery market is forecast to be a $1.3 billion global industry by 2030, and few jurisdictions have taken advantage of this economic opportunity. Fostering local innovation, South Australia could emerge as a national leader in creatively repurposing second-life batteries into a variety of applications, potentially including a fast-charging network for EVs, home storage applications, and other public infrastructure.

The rapid growth in consumer electronics and the forecast expansion of EVs into Australia's fleet presents a significant waste management challenge. But there is still time for the Government of South Australia to consultatively design practical and ambitious policy that aims to capture the value from this growing waste stream, benefiting the state economy, creating hundreds of local jobs, and further bolstering the state's clean-technology reputation.

This report has outlined how South Australia can realise these opportunities, and emerge from COVID-19 as a more vibrant, more productive and environmentally sustainable economy.

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