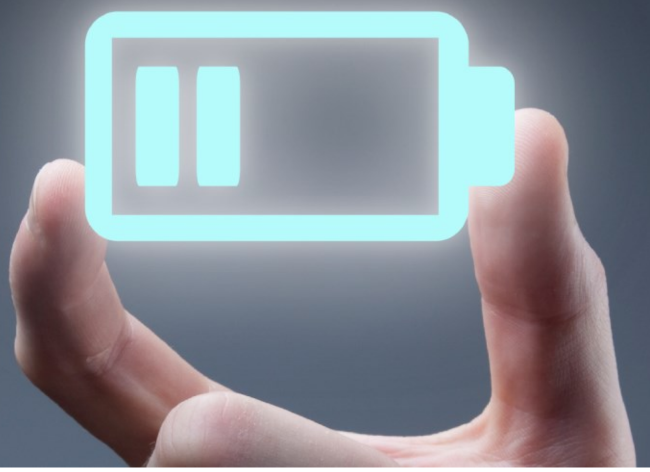
BatteryStewardshipCouncil

Creating a national Battery Stewardship Scheme for Australia



AUSTRALIAN BATTERY MARKET ANALYSIS

Project report (final)

22 June 2020

Report prepared by

Envisage Works — Positive Impact Consulting

In partnership with

Marsden Jacob Associates

REC Randell Environmental Consulting

SRU Sustainable Resource Use

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Authors:	Kyle O'Farrell, Peter Kinrade, Philip Jones and Leticia Roser
Reviewers:	Paul Randell and Fiona Harney
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Envisage Works contact details:
ABN: 12 584 231 841
Post: PO Box 7050, Reservoir East VIC 3073
E-mail: admin@envisageworks.com.au
Phone:+61 (0)3 9016 5490

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EXECUTIVE SUMMARY

BACKGROUND

The Battery Stewardship Council (BSC) and the Queensland Department of Environment and Science (DES) on behalf of all Federal and state/territory environment departments commissioned this study to analyse the Australian battery market and undertake a stocks and flows analysis of all battery consumption (sales), use and end-of-life by battery chemistry, format/size and application.

The requirements and objectives of this project are to:

- Inform the design of the consultation phase of the national product stewardship scheme for batteries.
- Support the identification of recommendations for inclusion in the scheme design.
- Provide a robust information base on quantitative flows of batteries through the Australian economy, information that is of interest more widely to industry, government and the community.
- Assess the financial characteristics of the battery recycling sector, which will inform on the current status of the sector.

PROJECT SCOPE

Material flow analysis (MFA) of batteries

The MFA component of the project is a significant update and expansion of prior MFA work with battery flow modelling forecasts out to 2049–50. Time series data across a period of time is required to better understand the changing flow and market share of batteries in Australia.

The scope covers batteries of all sizes, including those sold embedded within products, with the analysis splits including:

- Battery chemistry.
- Battery size and application.
- Single-use (primary) and rechargeable (secondary or accumulator) battery types.
- Batteries that are separately purchased (standalone) batteries, e.g. alkaline AA cells, and embedded batteries sold in electrical and electronic equipment (EEE).

Batteries already covered by existing product stewardship schemes (e.g. the co-regulatory National Television and Computer Recycling Scheme and Mobile Muster) are also included in the scope to facilitate a complete analysis.

Battery recycling market assessment

Also undertaken in this report is a market assessment of the Australian battery recovery and recycling sector. The purpose of this assessment is to:

- Assess the current and potential value of the market.
- Explore the market characteristics and cost structures within which the battery recovery sector currently operates.

- Inform consideration of the implications for the recovery of increasing flows of end-of-life batteries in the future.

Data sources

The key data sources informing the project are battery sales and recovery data, and market characteristics information, obtained from a combination of sources:

- Battery related brand-owners and retailers – National survey undertaken as part of this project.
- Battery collection service operators, e-waste disassemblers and sorters, and battery reprocessors – National survey undertaken as part of this project.
- Extensive review of Australian import and export data (Australian Customs import/export Harmonized Tariff Item Statistical Code (HTISC) data extracts) across the period of 2012–13 to 2018–19.

Note that Appendix D provides extensive detail on the key data sources and underlying assumptions applied in the modelling undertaken for this study.

OVERVIEW OF THE AUSTRALIAN BATTERY MARKET

This section of the executive summary provides an overview of battery markets across three market segments. The following three sections of the executive summary then explore the market flows and characteristics within each segment.

The Australian battery market spans all stages in the life cycle as shown in Figure E-1.

Figure E-1 – Battery life cycle

Batteries sold into the market	Battery stocks	End of life waste arisings	Disposition	End markets
Imports & local manufacturing	Batteries in use	Collected for recycling, disposal or stored	Recycled, sent to landfill or legal/illegal export	Commodities or products

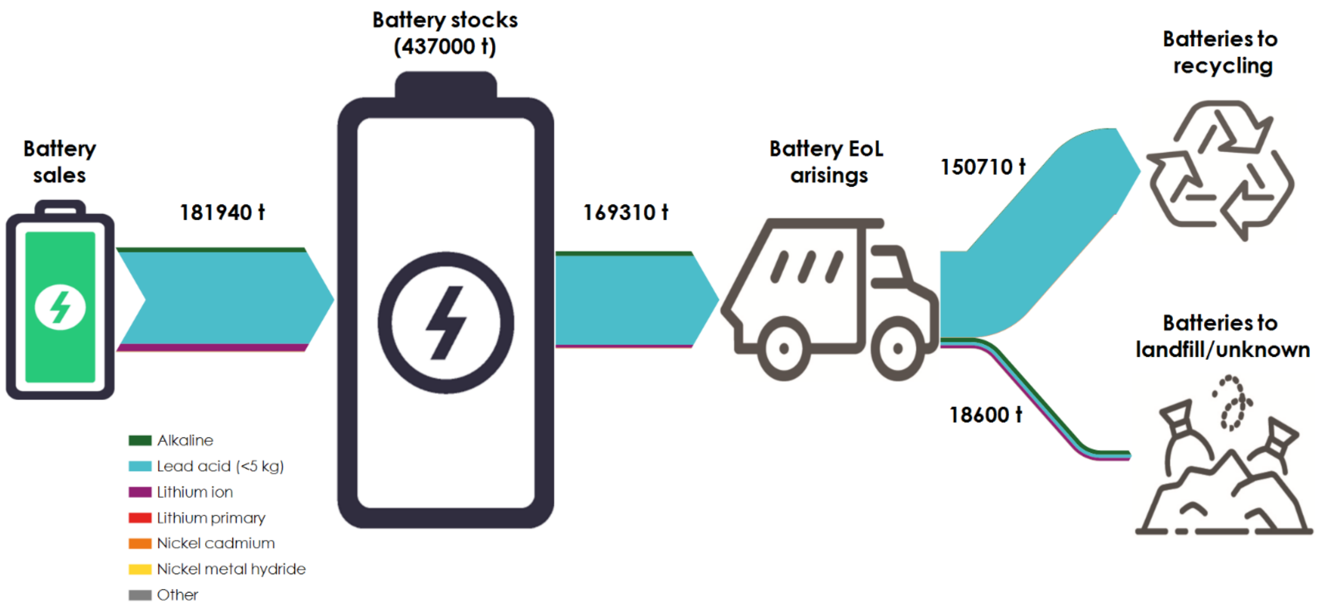
When considering Australian battery related energy security and beneficial end-of-life solutions, it is important to note that ~95% of batteries sold in Australia were imported in 2017–18.

Provided in Figure E-2 is an overview of battery flows across sales, stocks, EoL arisings and fates in 2017–18.

There were 182 000 tonnes batteries sold onto the market, with stocks of batteries in use totalling 437 000 tonnes. It is estimated that during 2017–18 169 000 tonnes of batteries were disposed of, and of these 151 000 tonnes were collected for reprocessing, giving a collection rate across all batteries of 89%.

Most of the remaining 18 600 tonnes of batteries reaching EoL were probably sent to landfill. The 18 600 tonnes largely consists of handheld (<5 kg) batteries with non-lead acid chemistries.

Figure E-2 – Australian battery flows in 2017–18



Battery flows by market segment

The Australian battery market consists of the following three market segments that have been defined for this study:

- **Handheld batteries (<5 kg)** – All batteries under 5 kg, except for BESS & EV batteries. Includes all lead acid batteries under 5 kg.
- **Battery energy storage system and electric vehicle batteries (BESS & EV)** – Battery energy storage system (BESS) are battery systems intended for continual use and are either electricity grid connected, or stand-alone power systems that replace the electricity grid. Electric vehicle (EV) batteries are those that can be used as the primary energy source for vehicles during use. The BESS & EV segment includes a relatively small quantity of lead acid batteries of 5 kg or more.
- **Lead acid batteries (≥5 kg)** – All lead acid batteries of 5 kg or more, except for lead acid batteries going into BESS & EV applications.

A summary of Australian battery flows in 2017–18 is provided in Table E-1. Only lead acid batteries coming out of the lead acid (≥5 kg) and BESS & EV market segments currently have a viable recycling market, with an end-of-life (EoL) collection rate of 98–99%. Handheld batteries (<5 kg) have a low EoL collection rate of 11%.

Table E-1 – Overview of Australian battery flows in 2017–18, by market segment

Market segment	Battery sales			Battery stocks[3]	End-of-life arisings[3]	Collected for recycling	Collection rate
	(tonnes)	('000s)[1]	(million EBUs)[2]	(tonnes)	(tonnes)	(tonnes)	(%)
Handheld (<5 kg)	21 850	419 330	910	50 170	18 320	2 060	11%
BESS & EV	6 440	190	270	23 820	2 020	1 630	81%
Lead acid (≥5 kg)	153 660	8 480	6 400	362 710	148 980	147 020	99%
Total	**181 960**	**428 000**	**7 580**	**436 690**	**169 320**	**150 710**	**89%**

1. Sales by number of batteries or cells (in thousands).

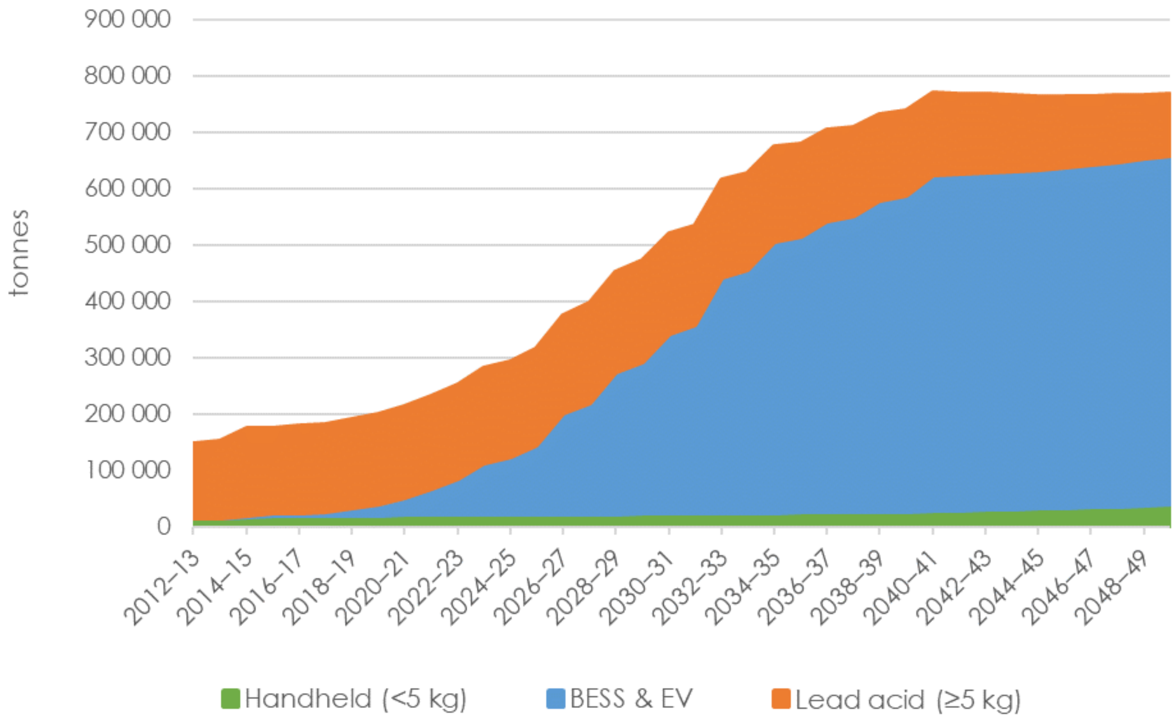
2. Equivalent battery units (EBU), where one EBU = 24 grams. The EBU is a standardised measure for the quantity of end-of-life handheld batteries.

3. The 'use period' applied to determine battery stocks (batteries in use and storage) and the timing of end-of-life arisings includes a retention time allowance for consumer storage prior to disposal.

Note that there is another potential market segment of batteries that could be defined, which are those that are ≥5 kg, are not lead acid, but do not fall into the BESS & EV segment. There were no sales of this group, but small quantities of recovery were reported in 2017–18. These quantities have been allocated into the lead acid (≥5 kg) market segment where market segment-based data is reported.

Presented in Figure E-3 are estimates of battery sales by market segment across the period of 2012–13 to 2049–50. Very significant growth in sales of BESS & EV batteries is currently projected out to 2049–50.

Figure E-3 – Battery sales to 2049–50, by market segment



By the end of the 2029–30 financial year, sales of lithium ion batteries are projected to have grown significantly to 280 000 tonnes. These sales will be primarily into BESS & EV applications.

It is assumed in the modelling that lithium chemistries remain the technology of choice into BESS & EV applications. If any alternative energy storage systems do take significant market share from the lithium chemistries, they may reduce the weight of batteries sold into the market.

By 2050 lithium ion battery sales into BESS & EV applications are projected to be more than 600 000 tonnes per year. This will take significant market share from lead acid chemistries in vehicle related applications, with the anticipated well-advanced transition to battery electric vehicles (as electric vehicles do not require a lead acid battery).

Battery sales by application

On a weight basis, the market is dominated by the automotive lead acid batteries in the weight range of 10–50 kg, as shown in Figure E-4. However, Figure E-5 shows that smaller handheld batteries dominate by number of sales.

Figure E-4 –Battery sales in 2017–18, by weight (tonnes)

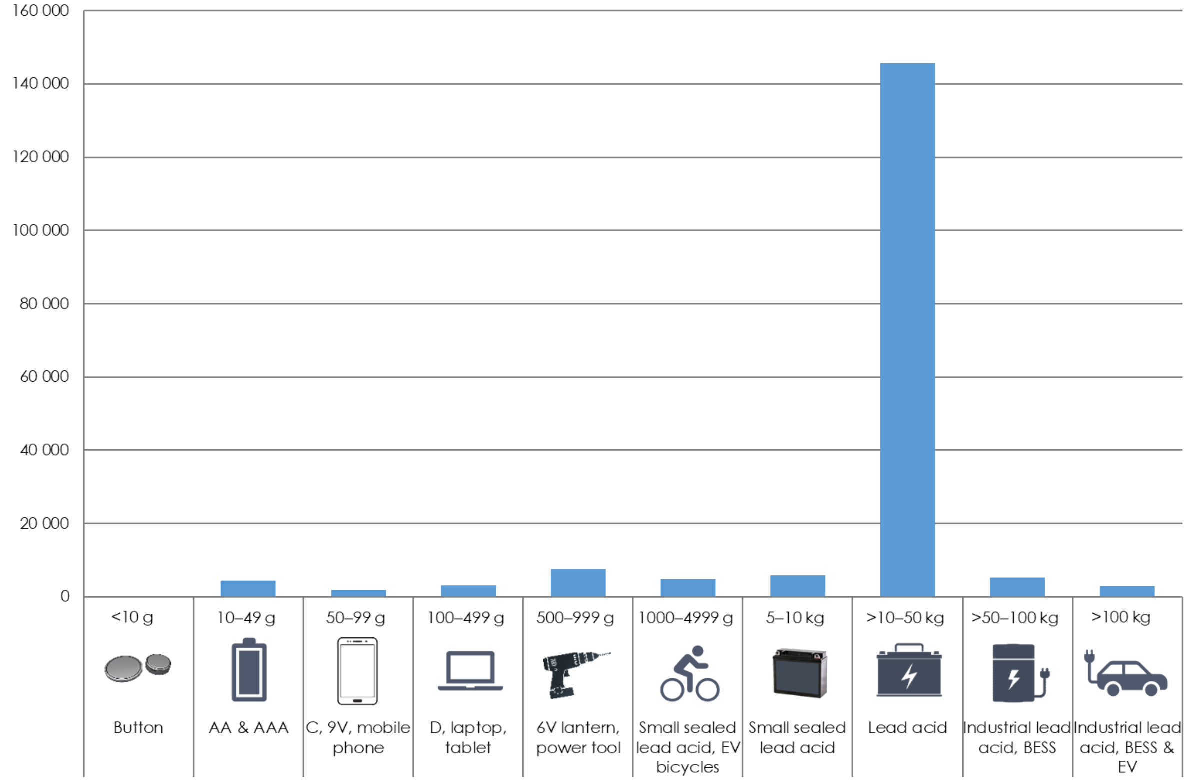
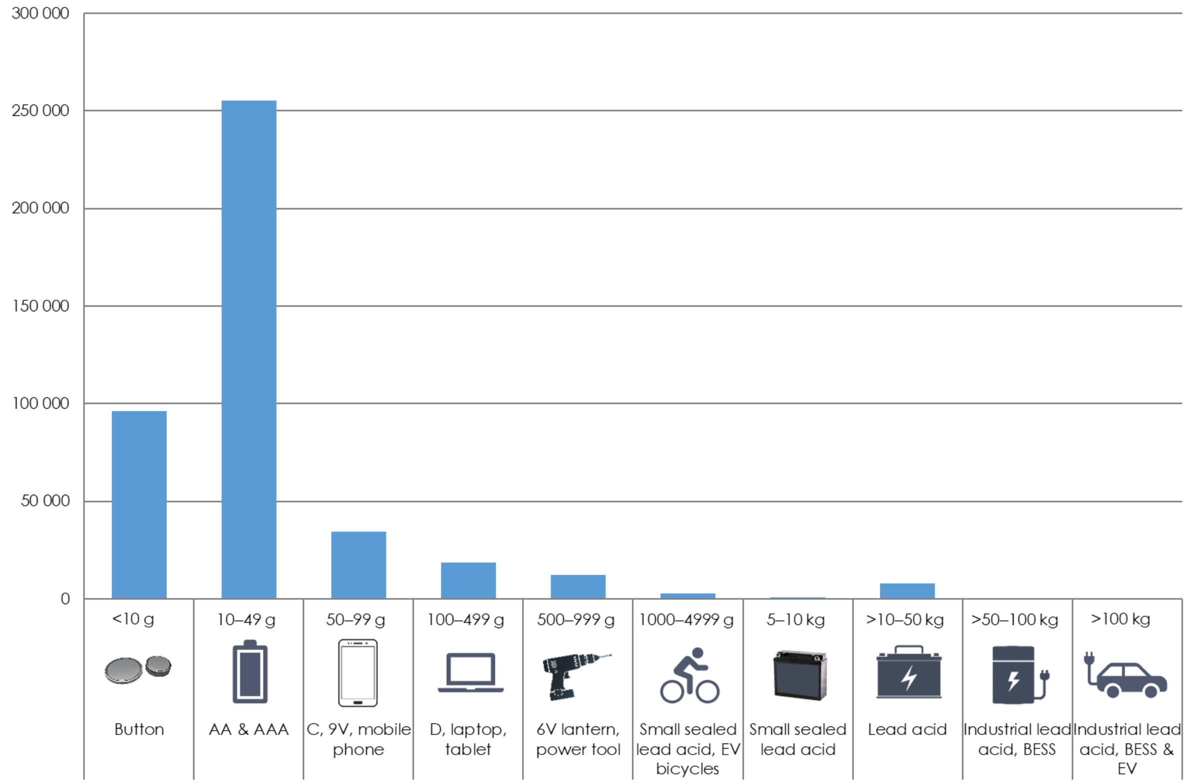


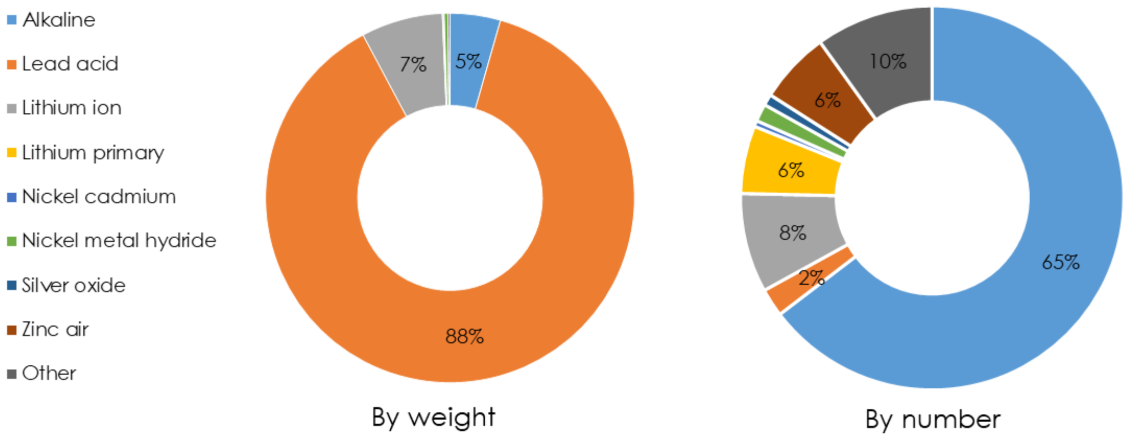
Figure E-5 –Battery sales in 2017–18, by number ('000s)



Battery sales by chemistry

On a weight basis, lead acid batteries made up 88% of the 182 000 tonnes of battery sales in the 2017–18 financial year. By number, alkaline batteries (and cells) made up 65% of the 428 million battery sales.

Figure E-6 –Battery sales in 2017–18, by chemistry



Battery stocks

Battery stocks are the total of all batteries and cells that are in service (use) within the economy. The service period also includes allowances for consumer storage prior to disposal.

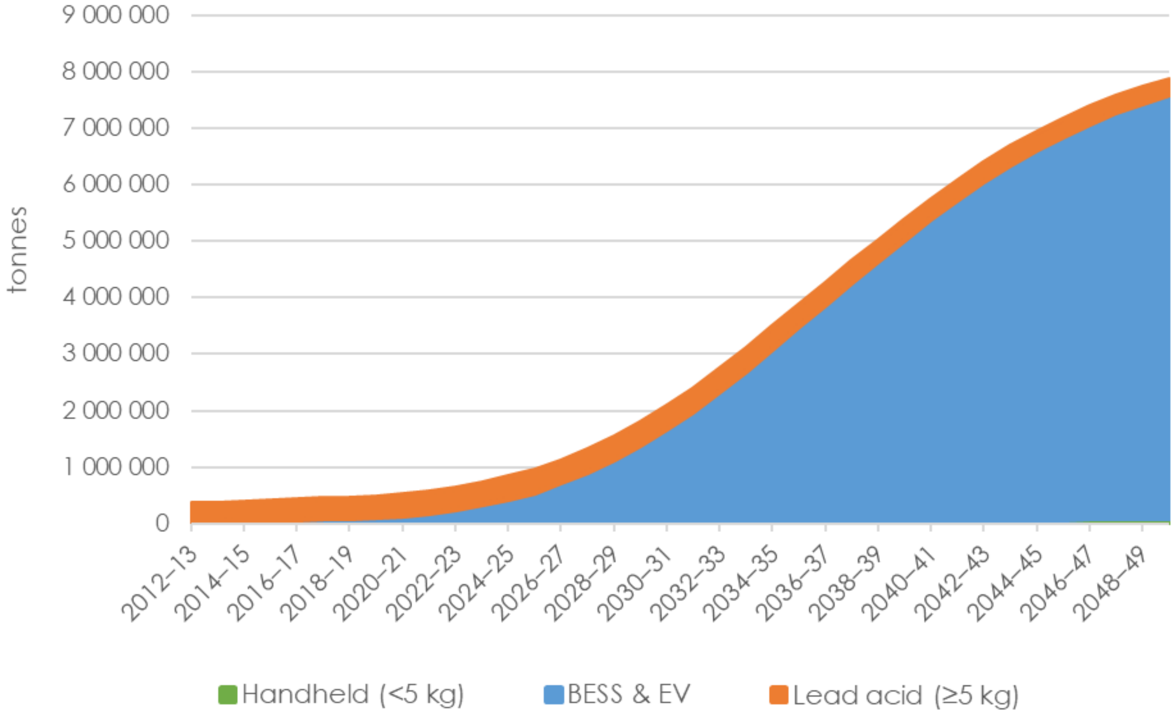
Presented in the following figure are projected battery stocks by market segment across the period of 2012–13 to 2049–50.

At the end of 2017–18 it is estimated that there were 437 000 tonnes of batteries in stocks across the economy. Of this amount, 363 000 tonnes (83.1%) was in the lead acid (≥5 kg) segment, 50 000 tonnes (11.4%) in the handheld (<5 kg) segment and 24 000 tonnes (6.5%) in the BESS & EV segment.

By the end of the 2025–26 financial year, stocks of batteries in the BESS & EV segment are projected to have grown to nearly 0.5 million tonnes, surpassing lead acid (≥5 kg) segment stocks of 0.4 million tonnes.

By 2050, BESS & EV stocks are projected to be 7.5 million tonnes, with lead acid (≥5 kg) stocks falling slightly, to around 0.3 million.

Figure E-7 – Battery stocks to 2049–50, by market segment



Battery end-of-life arisings

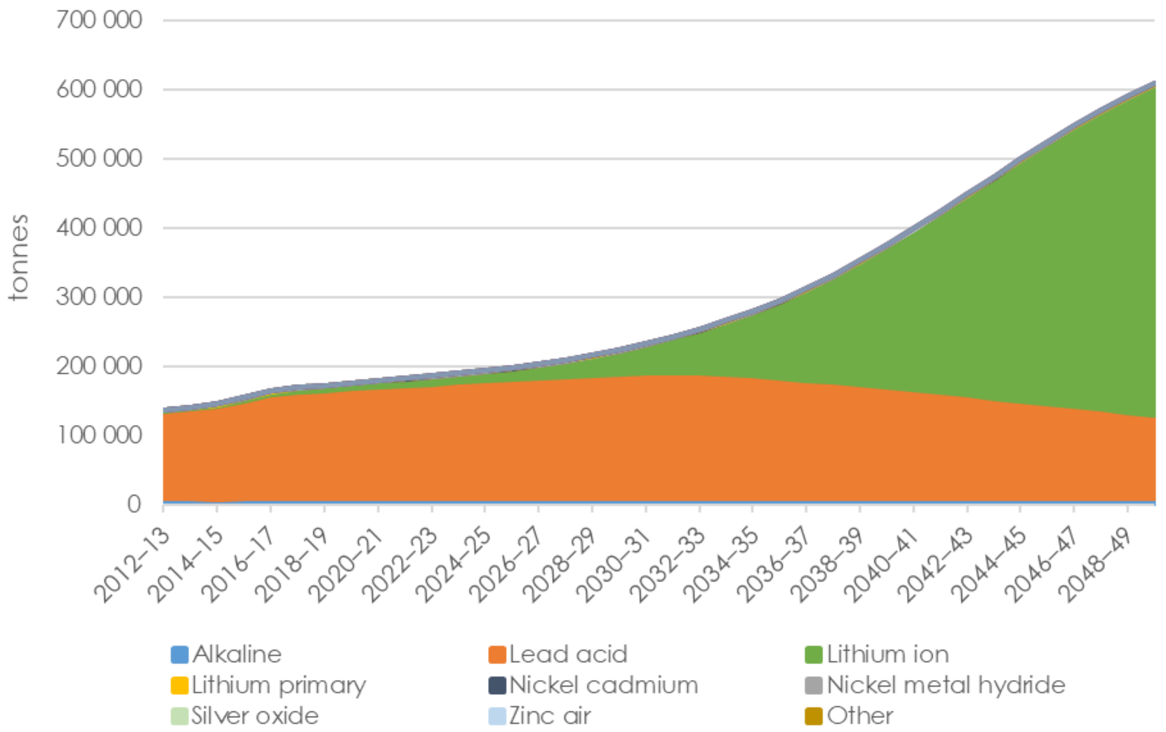
End-of-life (EoL) arisings are batteries that are entering waste streams and are potentially available for recovery. Modelling of EoL arisings suggests that significant changes will be seen in the market out to 2050.

At the end of 2019–20 it is estimated that there will be 176 000 tonnes of batteries reaching end-of-life. By weight this consists of:

- 159 000 tonnes of lead acid batteries (90% of total EoL arisings).
- 7 600 tonnes of lithium chemistry batteries (4% of total EoL arisings).
- 8 000 tonnes of alkaline batteries (5% of total EoL arisings).
- 1 200 tonnes of all other chemistries (1% of total EoL arisings).

End-of-life lead acid battery arisings are projected to increase until the early 2030s, to a maximum of approximately 180 000 tonnes/yr generation. However, it is not until 2040 that lithium ion batteries EoL arisings are projected to exceed lead acid. This is due to the anticipated long average lifespans of lithium chemistry batteries in BESS and EV applications, which are 12 and 16 years, respectively.

Figure E-8 – Battery end-of-life arisings to 2049–50, by chemistry group



Due to the large differences in the scales of battery EoL arisings in different chemistry groups, some chemistry groups are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery EoL arisings at the chemistry group level.

Table E-2 – Battery end-of-life arisings to 2049–50, by chemistry group

Year	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
2014–15	7 430	134 910	2 430	120	230	230	270	**145 630**
2019–20	8 040	159 220	7 600	90	440	350	300	**176 050**
2024–25	8 040	170 760	13 260	100	440	540	320	**193 450**
2029–30	8 040	180 940	33 020	110	310	670	350	**223 440**
2034–35	8 040	177 690	91 700	110	240	770	370	**278 930**
2039–40	8 040	161 590	203 960	120	230	770	400	**375 120**
2044–45	8 040	141 900	347 540	140	220	660	440	**498 940**
2049–50	7 980	120 760	477 890	150	220	550	470	**608 020**

Battery collections

In this report battery 'collection' is the quantity of batteries collected and sent to a reprocessing facility. The project included an extensive survey of end-of-life battery collection service operators, e-waste disassemblers and sorters, and battery reprocessors, including:

- Eight battery reprocessors identified as operating nationally, of which six responded directly to the information request for this project. Reprocessing activity for the other two (both lead acid battery recyclers) was estimated based on discussions with others in the sector.
- Nineteen companies and government agencies identified as operating a battery collection service in some form, excluding local governments.

Presented in Table E-3 are battery collections by chemistry group. Lead acid battery collections far exceed all other chemistries at the current time. Where there is a strong market for the recovered commodity (lead) or commodities, collection solutions emerge, yet where the value of the recovered commodities is insufficient to cover the costs of collection, sorting and processing, markets can't respond with a beneficial recovery outcome.

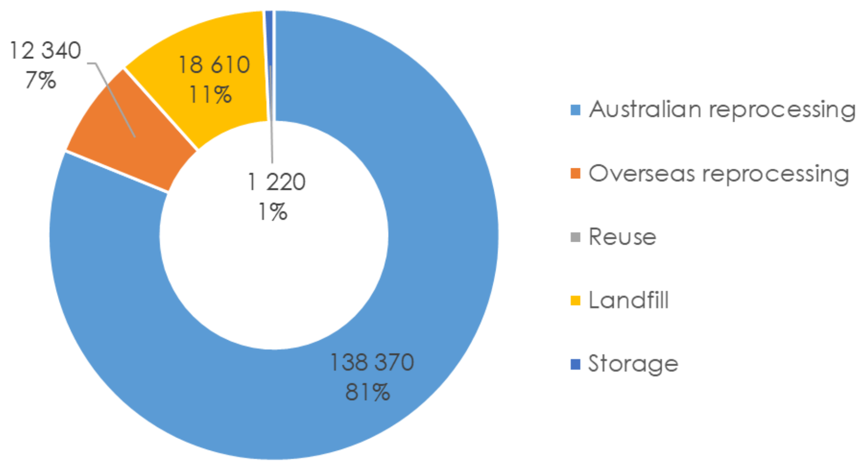
Table E-3 – Battery collection rates in 2017–18, by chemistry group

Weight range	EoL arisings (tonnes)	Collection (tonnes)	Collection rate (tonnes)
Alkaline	8 490	990	**12%**
Lead acid	154 490	148 910	**96%**
Lithium ion	5 290	320	**6%**
Lithium primary	90	20	**20%**
Nickel cadmium	370	290	**77%**
Nickel metal hydride	300	180	**59%**
All other	280	0	**1%**
Total	**169 320**	**150 710**	**89%**

Battery fates

Provided in Figure E-9 is a summary of battery fates in 2017–18. The Australian reprocessing of lead acid batteries dominates the fates of the 169 000 tonnes of batteries reaching end-of-life in Australia in 2017–18.

Figure E-9 – Battery fates in 2017–18



Provided in Table E-4 is a summary of battery fates in 2017–18 by chemistry. In 2017–18 all alkaline batteries that were collected for reprocessing were identified as reprocessed in Australia, as were most lithium ion and nickel cadmium batteries. Nickel metal hydride batteries were largely exported for reprocessing.

The 12 000 tonnes of exported lead acid batteries is an estimate of illegal exports, as there were no permitted lead acid exports in 2017–18.

Table E-4 – Battery fates in 2017–18, by chemistry

Fate	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
Local reproc	990	136 910	260	0	190	20	0	**138 370**
Export reproc.	0	12 000[b]	60	20	100	160	0	**12 340**
Reuse	0	0	0	0	0	0	0	**<50[c]**
Landfill	7 500	5 580	4 970	70	90	130	280	**18 610**
Total EoL	**8 490**	**154 490**	**5 290**	**90**	**390**	**300**	**280**	**169 340**
Storage[d]	*260*	*430*	*200*	*10*	*280*	*50*	*0*	***1 220***

a. Reprocessing quantities are 'in-the-gate' estimates and include any processing losses to landfill.
b. Estimated illegal exports during the 2017–18 period.
c. Some battery reuse reported. Chemistry not reported due to confidentiality constraints.
d. Reported storage by collectors, disassemblers and reprocessors in mid-2019. Mostly stored for less than 6 months but includes a relatively small quantity of batteries stored for more than 12 months.

Reprocessors and electrical and electronic equipment (EEE) disassemblers were also surveyed for estimates on battery processing material yield rates from scrap batteries by chemistry. A summary of this data is provided in Table E-5. Note that these estimates do not include any subsequent downstream material losses, e.g. during smelting operations, and are the estimated yield rates out the gate of battery reprocessing facilities.

Table E-5 – Scrap battery processing material yield rates

Chemistry	Material yield
Alkaline	90%
Lead acid	95%–97%
Lithium ion	90%
Lithium primary	NR
Nickel cadmium	95%
Nickel metal hydride	90%

It is important to note that downstream recovery rates of cathode, anode and electrolyte material are dependent on battery chemistry and processing technology. The actual utilisation rates in new products, of materials recovered from scrap batteries, other than lead acid, may be significantly lower than the 'out-the-gate' yield rate estimates provided in the table above.

Lead acid batteries are the only chemistry for which a significant proportion of end-of life arisings are collected, disassembled and processed into secondary (recovered) materials suitable for use in the manufacture of new products in significant quantities.

Battery level of integration

While batteries almost always operate as part of electrical and electronic equipment (EEE), they have differing levels of integration into the product. This ranges from standalone batteries that are commonly sold separately and are designed for easy replacement by consumers (e.g. single-use AA cells), through to batteries that are embedded within EEE and are not designed to be replaced by consumers (e.g. lithium ion batteries in many laptops and mobile phones, and EV batteries).

In Table E-6 the sales of batteries are presented by the level of integration into products. Standalone battery sales dominated in terms both weight and number of battery sales, followed by batteries that are part of EEE but are easily removed (e.g. power tool batteries).

Embedded batteries are generally only a small proportion of total battery sales. However, applications where they made up more than 10% of total sales in 2017–18 were toys (40% of sales) and consumer electronics (15% of sales).

Table E-6 – Battery sales in 2017–18, by level of integration

Application area	Level of integration			
	Standalone battery	Part of EEE (easily removable)	Part of EEE (embedded)	Total
	(tonnes)	(tonnes)	(tonnes)	(tonnes)
Consumer electronics	7 200	1 000	1 500	**9 700**
Torches/lanterns	0	500	0	**500**
Power tools & gardening equipment	0	6 100	100	**6 200**
Toys	0	600	400	**1 000**
Personal mobility	0	900	0	**900**
Storage, emergency & standby (SES)	31 500	1 700	2 900	**36 100**
Vehicles	106 100	18 400	1 000	**125 500**
Other application area	1 900	0	0	**1 900**
Unknown	300	0	0	**300**
Totals	**146 900**	**29 100**	**6 000**	**182 000**

HANDHELD BATTERIES (<5 KG)

This section of the executive summary provides a detailed examination of the Australian handheld battery (<5 kg) market segment. The segment description is provided in the following table.

Table E-7 – Handheld batteries – Market characteristics

Segment description	All batteries under 5 kg, except for BESS & EV batteries. Includes lead acid batteries under 5 kg.
Weight	<5 kgs.
Applications	All applications except for BESS & EV use.
Chemistries	All chemistries.

Handheld battery flows

A summary of handheld (<5 kg) battery flows in 2017–18 is provided in Table E-8. In 2017–18 there was 21 850 tonnes of handheld batteries sold into the Australian market, with 18 320 tonnes reaching end-of-life, but only 2 100 tonnes collected for reprocessing.

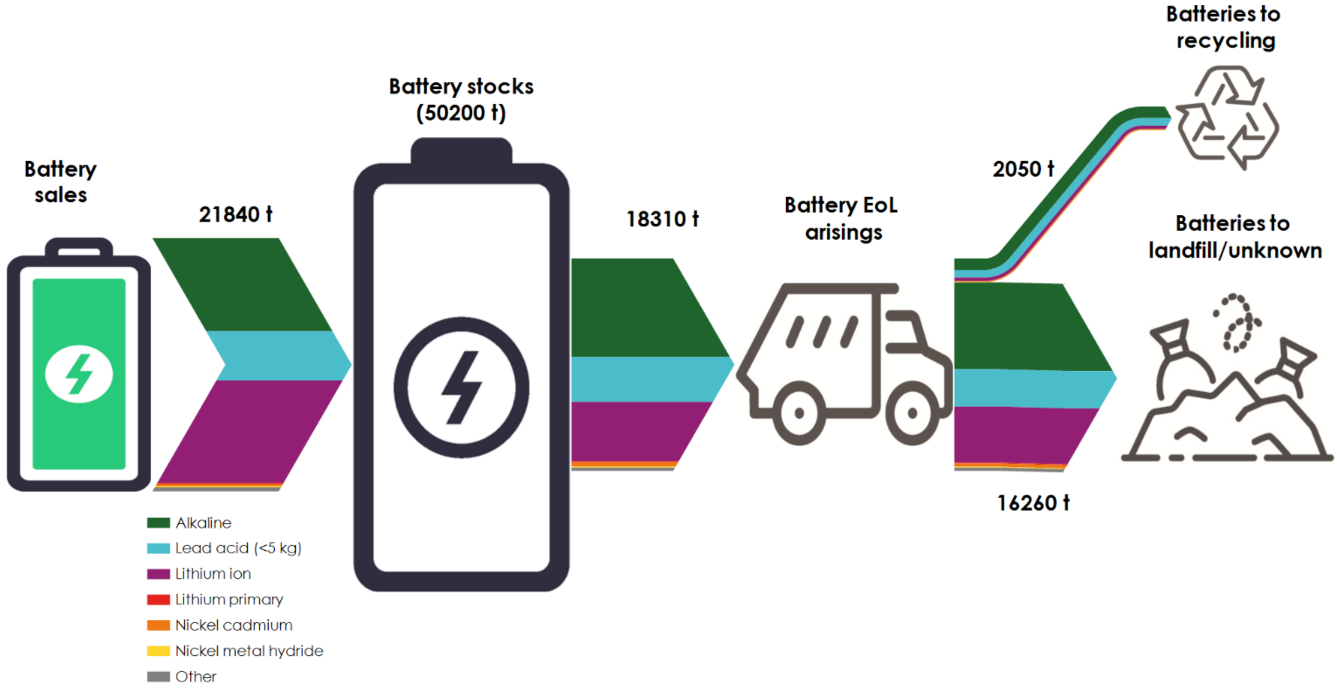
The data highlights the limited recovery that is occurring in this market segment. Nearly 90% of handheld batteries are estimated to be disposed of directly to landfill, with only 11% of end-of-life arisings diverted to recovery pathways.

Table E-8 – Handheld battery flows in 2017–18, by chemistry

Chemistry	Battery sales			Battery stocks	EoL arisings	Collection to recovery	Collection rate
	(tonnes)	('000s)[1]	(million EBUs)[2]	(tonnes)	(tonnes)	(tonnes)	(%)
Alkaline	8 040	276 600	340	6 190	8 490	990	12%
Lead acid	4 230	1 600	180	15 550	3 880	660	17%
Lithium ion	8 850	35 730	370	22 240	5 110	280	6%
Lithium primary	90	24 480	0	70	90	20	20%
Nickel cadmium	190	2 140	10	5 480	370	80	23%
Nickel metal hydride	110	6 310	0	400	90	20	26%
All other	330	72 480	10	250	280	0	1%
Total	**21 850**	**419 330**	**910**	**50 170**	**18 320**	**2 060**	**11%**

1. Sales by number of batteries or cells (in thousands).
2. Equivalent battery units (EBU), where one EBU = 24 grams.

Figure E-10 – Handheld battery flows in 2017–18, by chemistry group



Handheld battery trends

Table E-9 and Figure E-11 provide a summary of the key available time-series data on the trends of handheld battery flows.

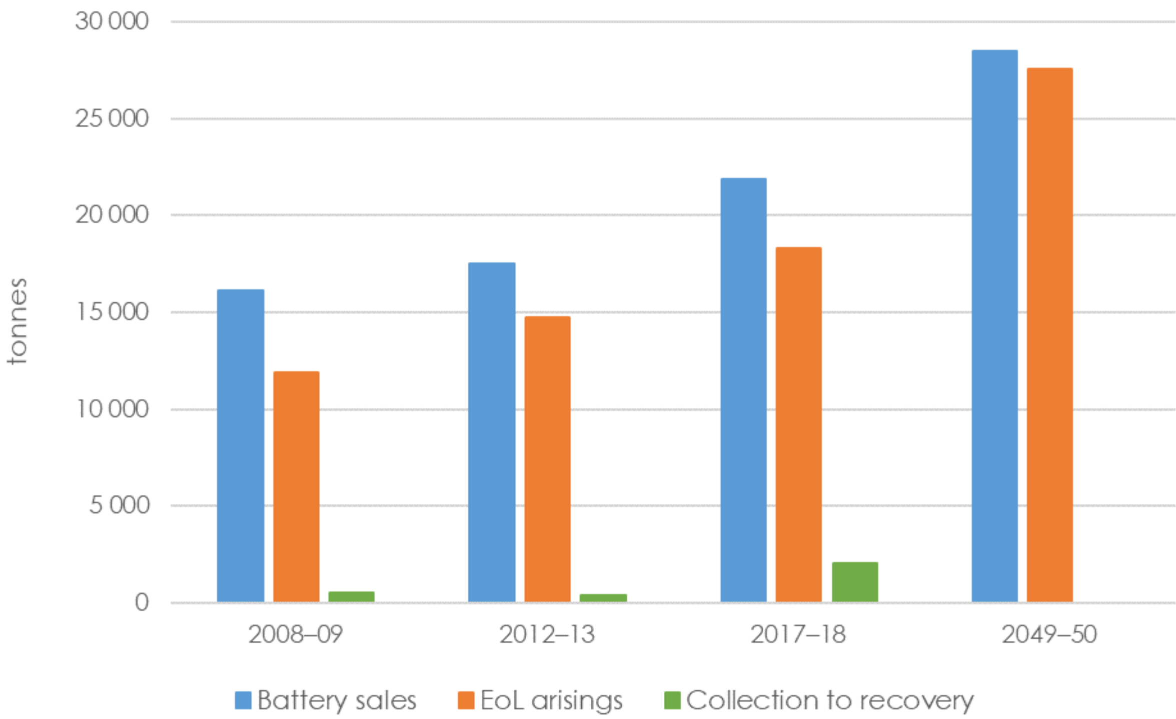
Handheld battery sales are estimated to have grown by 35% between 2008–09 and 2017–18 and are projected to increase by another 30% to 2049–50. Handheld battery collections to recovery have grown by 300% between 2008–09 and 2017–18, to 11% of EoL arisings of handheld batteries.

Table E-9 – Handheld battery trends

Battery flow	Unit	2008–09	2012–13	2017–18	2049–50
Source:	-	Warnken **(2010)**	SRU **(2014)**	This study	This study
Battery sales	(tonnes)	16 140	17 500	21 850	28 490
	number ('000s)	345 270	400 400	419 330	546 620
	(million EBUs)	670	730	910	1 190
EoL arisings	(tonnes)	11 900	14 750	18 320	27 560
Collection to recovery	(tonnes)	510	400	2 060	NR
	(%)	**4%**	**3%**	**11%**	**NR**

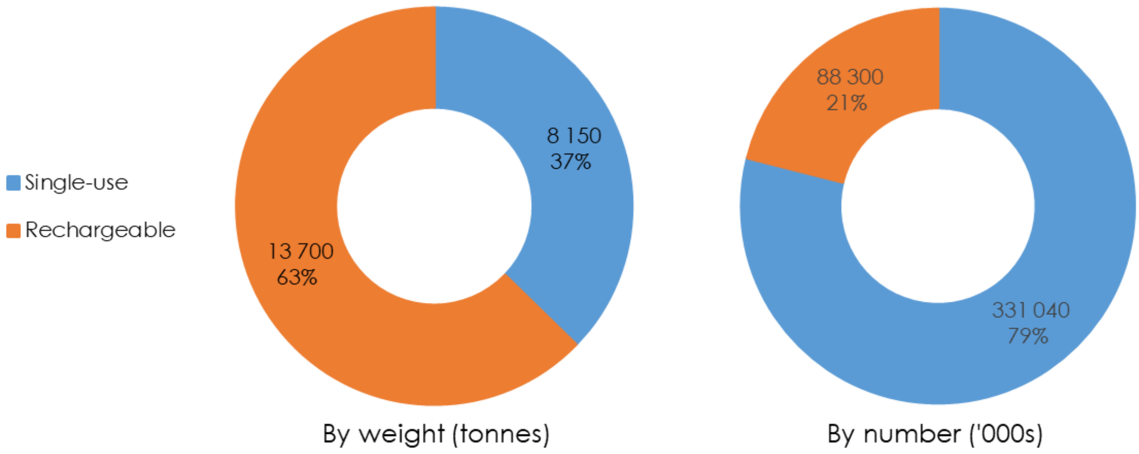
NR – Not reported. Either not reported in the source reference or cannot be projected.

Figure E-11 – Handheld battery trends



In 2017–18 single-use batteries made up 8 150 tonnes (37%) of handheld battery sales, and rechargeable batteries made up 13 700 tonnes (63%) of handheld battery sales.

Figure E-12 – Single-use and rechargeable handheld battery sales in 2017–18



Provided in Table E-10 and Table E-11 are summaries of the available time-series data on the trends of single-use and rechargeable handheld battery flows, respectively.

Single-use handheld batteries include alkaline, lithium primary, silver oxide and zinc air chemistries. In 2017–18 alkaline battery sales made up 98% of single-use handheld battery sales by weight and 84% of sales by number.

Table E-10 – Single-use handheld battery trends

Battery flow	Unit	2008–09	2012–13	2017–18	2049–50
Source:	-	Warnken (2010)	SRU (2014)	This study	This study
Battery sales	(tonnes)	11 350	8 660	8 150	8 240
	number ('000s)	278 850	358 300	331 040	334 530
	(million EBUs)	470	360	340	340
EoL arisings	(tonnes)	8 900	8 910	8 600	8 170
Collection to recovery	(tonnes)	NR	170	1 010	NR
	(%)	**NR**	**2%**	**12%**	**NR**

NR – Not reported. Either not reported in the source reference or cannot be projected.

The market growth for single-use batteries overall is assumed to be flat for the foreseeable future due to ongoing competition by rechargeable chemistries, both in standalone battery sales (e.g. rechargeable nickel metal hydride sales in AA and AAA formats), and devices shifting to inbuilt rechargeable batteries (e.g. torches with lithium-ion batteries).

Rechargeable handheld batteries include lead acid, lithium ion, nickel cadmium and nickel metal hydride chemistries. In 2017–18 lithium ion battery sales made up 65% of rechargeable handheld battery sales by weight, followed by lead acid batteries (<5 kg) of 31%.

Table E-11 – Rechargeable handheld battery trends

Battery flow	Unit	2008–09	2012–13	2017–18	2049–50
Source:	-	Warnken (2010)	SRU (2014)	This study	This study
Battery sales	(tonnes)	4 790	8 830	13 700	20 250
	number ('000s)	66 420	42 000	88 300	130 480
	(million EBUs)	200	370	570	840
EoL arisings	(tonnes)	3 010	5 840	9 720	19 390
Collection to recovery	(tonnes)	NR	230	1 050	NR
	(%)	**NR**	**4%**	**11%**	**NR**

NR – Not reported. Either not reported in the source reference or cannot be projected.

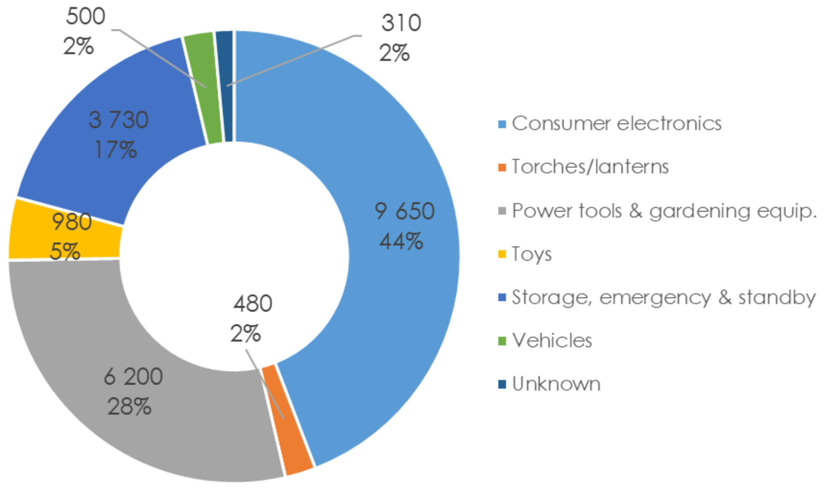
The growth in rechargeable handheld battery sales out to 2049–50 is underpinned by anticipated increasing use of lithium ion chemistries, which are projected to undergo moderate but steady growth for the foreseeable future in the main applications of laptops, mobile phones and power tools. Lithium chemistries have already completely substituted all other chemistries in these applications.

Handheld battery sales by application area

The handheld battery market segment consists of a range of application areas. The main application area is consumer electronics which makes up 44% of this segment by weight of batteries. Consumer electronics includes most single-use battery applications (7 100 tonnes or 74% of consumer electronics batteries) and rechargeable electronic devices such as laptops, tablets and mobile phones (2 200 tonnes or 23% of consumer electronics).

The other significant application areas in the handheld battery market segment are power tools & gardening equipment (6 200 tonnes or 29% of handheld battery sales), and storage, emergency & standby (SES) applications, such as small sealed lead acid batteries (SSLABs) and emergency lighting backup batteries (3 730 tonnes or 17% of handheld battery sales).

Figure E-13 – Handheld battery sales in 2017–18, by application area

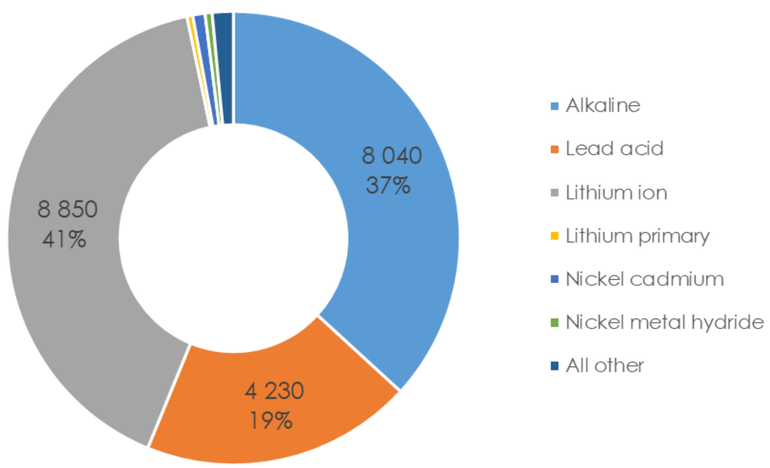


Note: Refer to Appendix B-3 for a detailed listing of the specific battery applications that are allocated to each of the application areas in the figure above.

Handheld battery sales by chemistry group

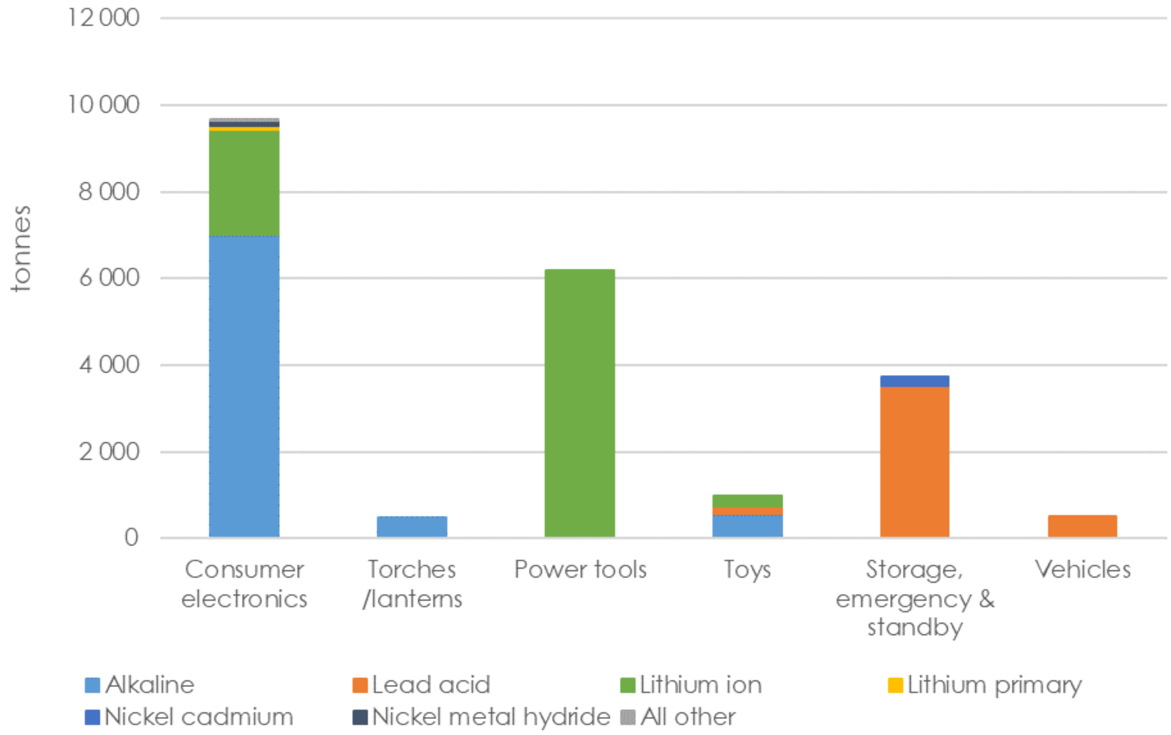
The major battery chemistries sold into the handheld battery market in 2017–18 were lithium ion (8 850 tonnes or 41% of handheld battery sales), alkaline (8 040 tonnes or 37% of handheld battery sales) and lead acid (4 230 tonnes or 19% of handheld battery sales). The remaining 3% (720 tonnes) was sales of lithium primary, nickel cadmium, nickel metal hydride, silver oxide and zinc air batteries.

Figure E-14 – Handheld battery sales in 2017–18, by chemistry group



The following figure presents handheld battery sales in 2017–18 by both chemistry group and application area. Sales of single-use alkaline batteries are almost entirely into consumer electronic devices, torches/lanterns and toys. Lithium ion sales are almost entirely into power tools & garden equipment, and consumer electronic devices.

Figure E-15 – Handheld battery sales in 2017–18, by chemistry group and application area

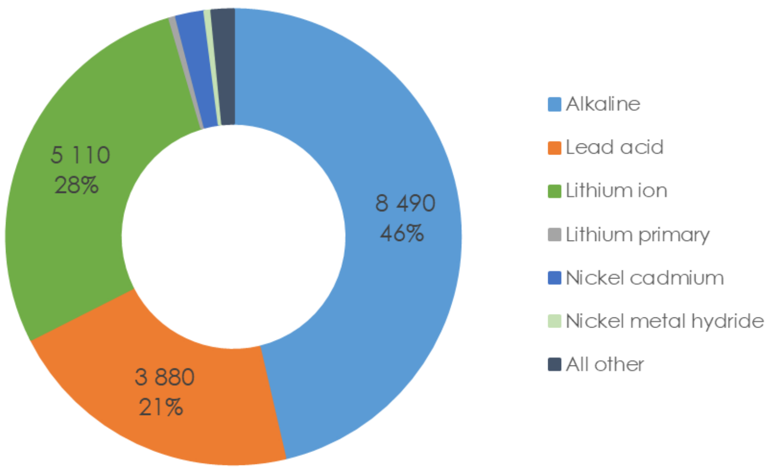


Handheld battery end-of-life arisings

In Figure E-16 are presented estimated handheld battery end-of-life (EoL) arisings by chemistry group in 2017–18. EoL arisings are batteries that are entering waste streams and are potentially available for recovery.

In 2017–18 there were an estimated 18 300 tonnes of handheld batteries reaching end-of-life, with 46% of these alkaline batteries, 28% lithium ion batteries, 21% lead acid batteries, and the remaining 5% made up of all other chemistries.

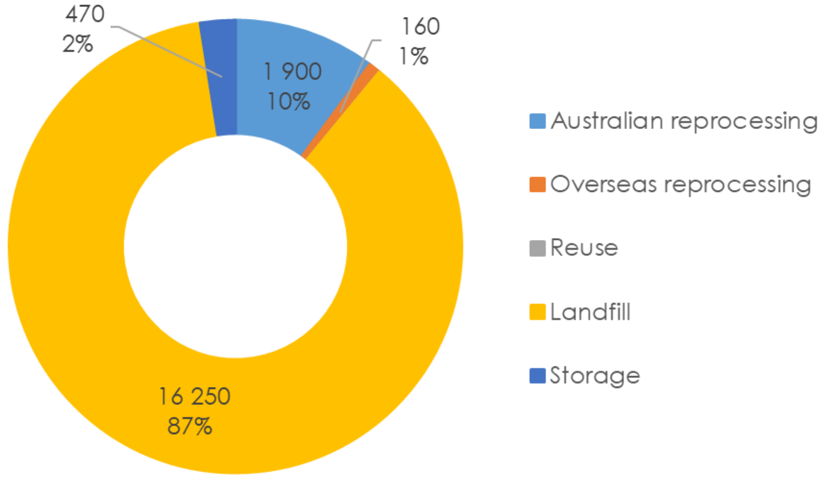
Figure E-16 – Handheld battery EoL arisings in 2017–18, by chemistry group



Handheld battery fates

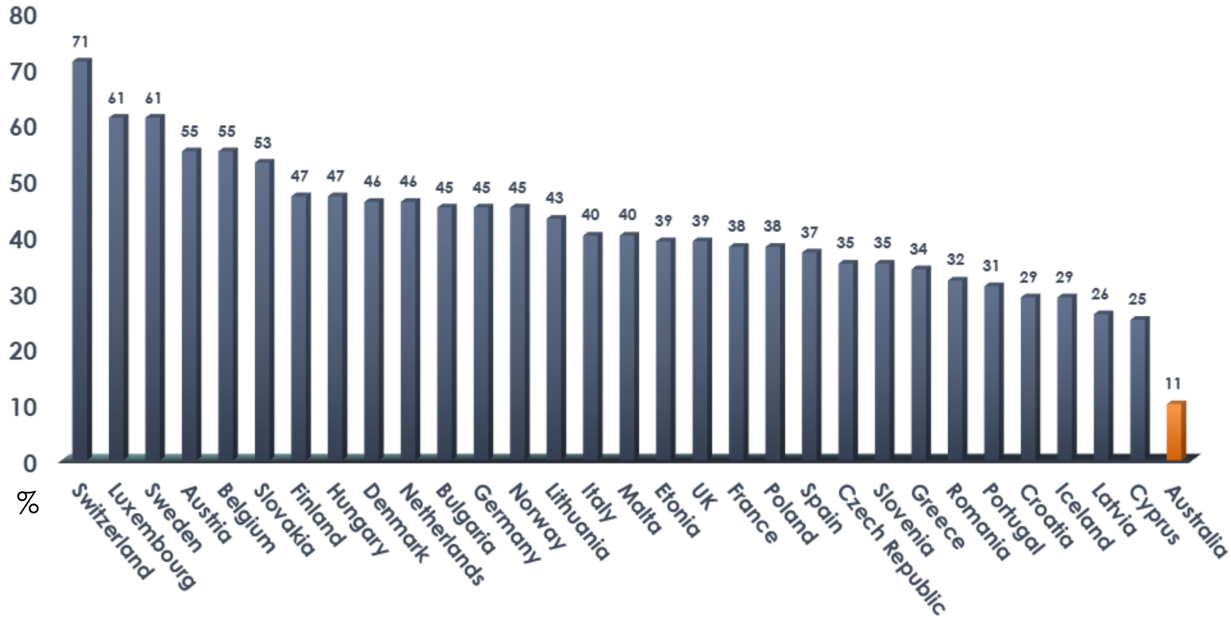
Provided in Figure E-17 is a summary of handheld battery fates in 2017–18. Disposal to landfill dominates the fates of the 18 300 tonnes of handheld batteries reaching end-of-life in Australia in 2017–18, with 87% sent to landfill. Only 11% was sent to downstream reprocessing.

Figure E-17 – Handheld battery fates in 2017–18



Australian collection of handheld batteries for recycling is very low compared with most European countries (Figure E-18). Collection rates in Europe demonstrate the huge opportunity for improvement available to Australia if the appropriate stewardship framework and policy environment are established.

Figure E-18 – Handheld battery collection rates of European Economic Area (EEA) countries and Australia



Sources: Perchards & SagisEPR (2016), and Envisage Works.

BATTERY ENERGY STORAGE SYSTEM AND ELECTRIC VEHICLE BATTERIES

This section of the executive summary provides a detailed examination of the Australian battery energy storage system and electric vehicle (BESS & EV) market segment. The segment description is provided in the following table.

Table E-12 – BESS & EV batteries – Market characteristics

Segment description	BESS are battery systems intended for continual use and are either electricity grid connected, or stand-alone power systems that replace the electricity grid. EV batteries are those that can be used as the primary energy source for vehicles during use.
Weight	All weights.
Applications	BESS & EV use. Also includes batteries in hybrid and plug-in hybrid vehicles, e-bikes, power wheelchairs and golf buggies.
Chemistries	Potentially all chemistries, but in practice dominated by lithium ion chemistries.

BESS & EV battery flows

A summary of BESS & EV battery flows in 2017–18 is provided in Table E-13. In 2017–18 there was 6 440 tonnes of BESS & EV batteries sold into the Australian market, with 2 020 tonnes reaching end-of-life, and 1 630 tonnes reported as collected for reprocessing.

It's worth noting that lead acid batteries in grid-connected and stand-alone power systems have now been largely substituted by lithium ion chemistries, and it is expected that within the next five years 95% or more of BESS sales will be based on non-lead chemistries.

Quantities of BESS & EV lithium ion batteries reaching EoL are still very low. However, these quantities can be expected to grow sharply over the next decade.

Table E-13 – BESS & EV battery flows in 2017–18, by chemistry

Chemistry	Battery sales			Battery stocks	EoL arisings	Collection to recovery	Collection rate
	(tonnes)	('000s)[1]	(million EBUs)[2]	(tonnes)	(tonnes)	(tonnes)	(%)
Lead acid	1 800	90	75	7 020	1 630	1 440	88%
Lithium ion	4 150	90	170	11 880	180	40	21%
Nickel metal hydride	490	10	20	4 920	210	150	73%
All other	0	0	0	0	0	0	N/A
Total	**6 440**	**190**	**270**	**23 820**	**2 020**	**1 630**	**81%**

1. Sales by number of batteries or cells (in thousands).
2. Equivalent battery units (EBU), where one EBU = 24 grams.

BESS & EV battery trends

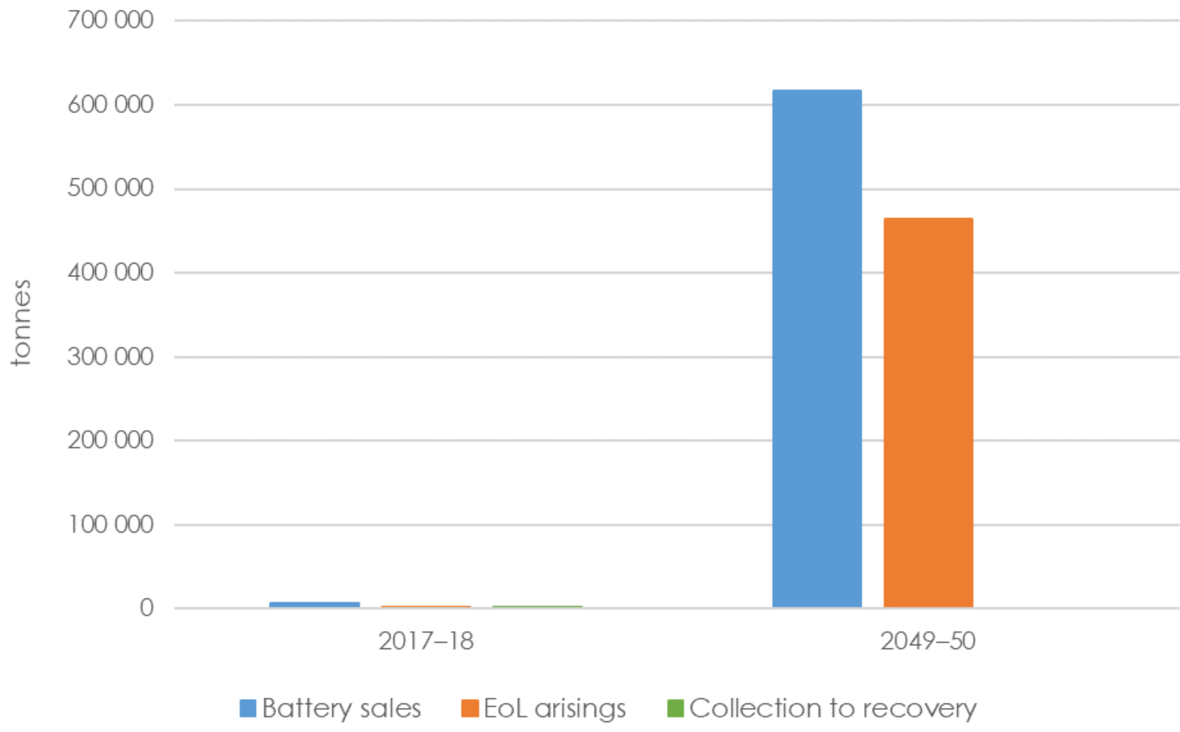
Table E-14 and Figure E-19 provide a summary of the key available time-series data on the trends of BESS & EV battery flows. Battery sales in this market segment are projected to grow one hundredfold between 2017–18 and 2049–50.

Table E-14 – BESS & EV battery trends

Battery flow	Unit	2017–18	2049–50
Battery sales	(tonnes)	6 440	616 350
	number ('000s)	190	18 200
	(million EBUs)	270	25 680
EoL arisings	(tonnes)	2 020	464 440
Collection to recovery	(tonnes)	1 630	NR
	(%)	**81%**	**NR**

NR – Not reported as cannot be projected.

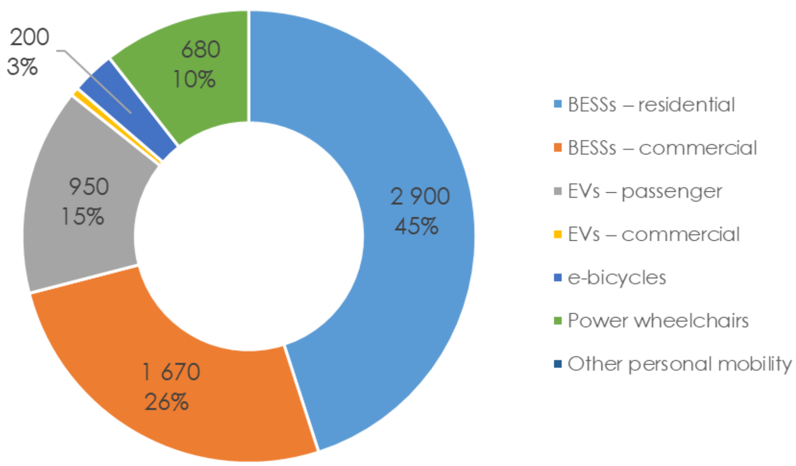
Figure E-19 – BESS & EV battery trends



BESS & EV battery sales by application

Application level BESS & EV battery market segment sales in 2017–18 are presented in Figure E-20. Of the 6 400 tonnes of batteries sold, 71% were into residential and commercial/utility scale BESSs, 15% were into passenger and commercial EVs, and the remainder were into e-bikes, wheelchairs and other personal mobility applications.

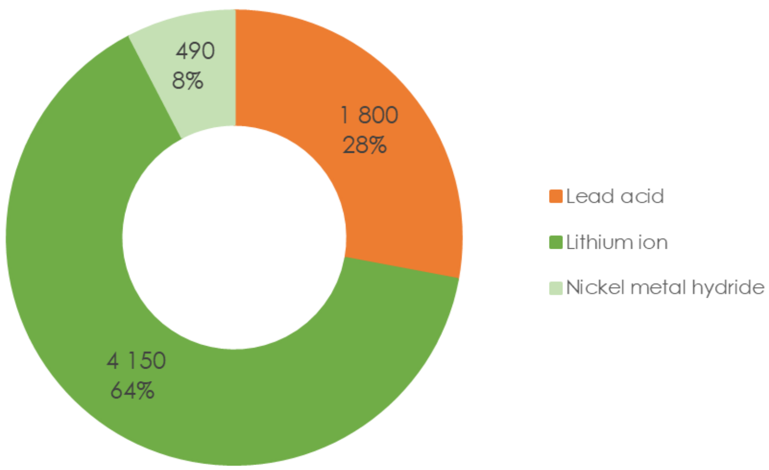
Figure E-20 – BESS & EV battery sales in 2017–18, by application



BESS & EV battery sales by chemistry group

The major battery chemistries sold into the BESS & EV battery market segment in 2017–18 were lithium ion (4 150 tonnes or 64% of sales, lead acid (1 800 tonnes or 28% of sales), and nickel metal hydride (490 tonnes or 8% of sales).

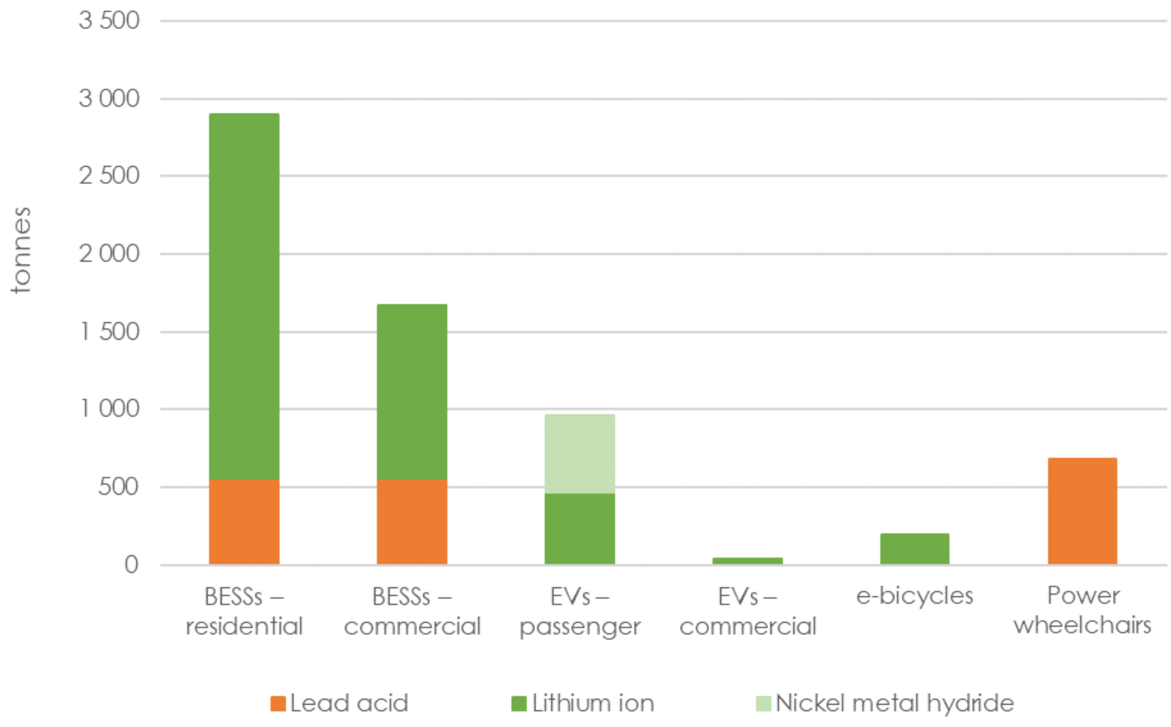
Figure E-21 – BESS & EV battery sales in 2017–18, by chemistry group



The following figure presents BESS & EV battery sales in 2017–18 by both chemistry group and application. There were still some sales of lead acid batteries into BESS applications. However, this will continue its decline as a proportion of BESS sales, and probably in terms of absolute tonnage as well.

The use of nickel metal hydride batteries in EVs is anticipated to cease once Toyota completes its transition from nickel metal hydride to lithium ion chemistries in hybrid and plug-in hybrid vehicles.

Figure E-22 – BESS & EV battery sales in 2017–18, by chemistry group and application

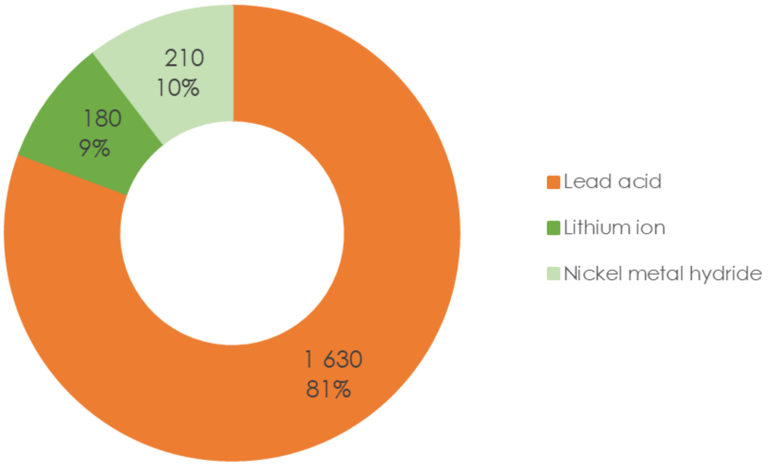


BESS & EV battery end-of-life arisings

Figure E-23 presents estimated BESS & EV battery end-of-life (EoL) arisings by chemistry group in 2017–18. EoL arisings are batteries that are entering waste streams and are potentially available for recovery.

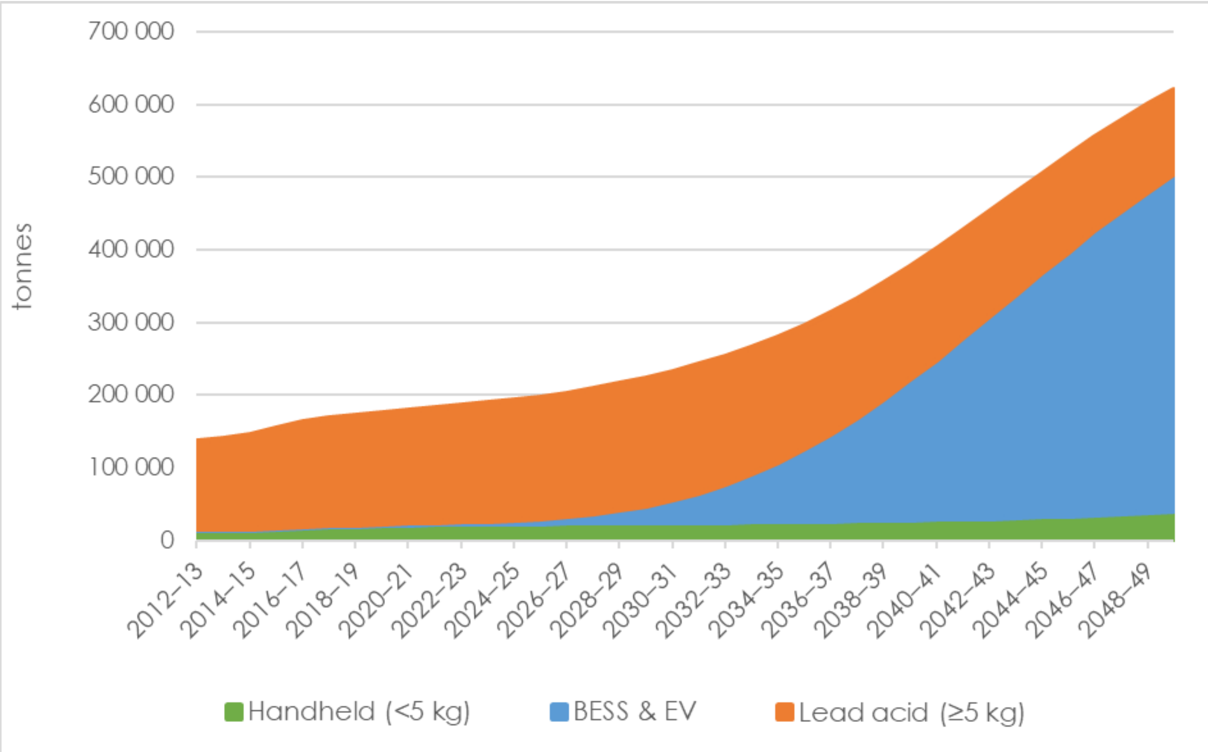
In 2017–18 there was an estimated 2 020 tonnes of BESS & EV batteries reaching end-of-life, with 81% of these lead acid batteries, 10% nickel metal hydride and 9% lithium ion chemistries.

Figure E-23 – BESS & EV battery EoL arisings in 2017–18, by chemistry group



Presented in Figure E-24 are estimates of ***all*** batteries (not just BESS & EV) EoL arisings by market segment across the period of 2012–13 to 2049–50. This figure illustrates the massive anticipated increase in BESS & EV batteries reaching end-of-life over the next 30 years compared to the other market segments. BESS & EV batteries EoL arisings (almost entirely lithium ion chemistries) are projected to exceed lead acid battery EoL arisings before 2040.

Figure E-24 – Battery EoL arisings to 2049–50, by market segment



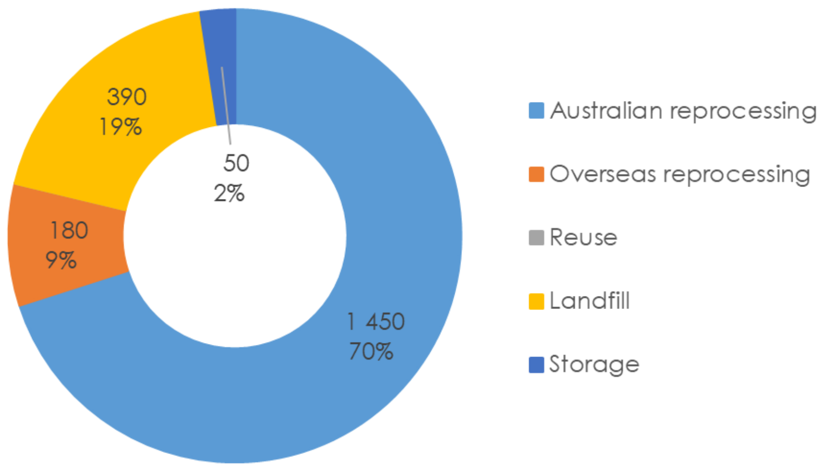
The economics of recovery of these (non-lead based) battery types, particularly in the BESS & EV market segment, is highly uncertain. Without significant planning there is substantial risk that large and quickly growing quantities of batteries and battery reprocessing waste products will be disposed to landfill over the foreseeable future.

BESS & EV battery fates

Provided in Figure E-25 is a summary of fates of the 2 020 tonnes of BESS & EV batteries reaching EoL in 2017–18. Australian reprocessing dominates the fates due to the high proportion of larger lead acid batteries reaching EoL in this market segment.

As outlined previously the battery chemistry profile is rapidly shifting in the BESS & EV segment to lithium ion chemistries and a continued high collection rate to reprocessing is not certain.

Figure E-25 – BESS & EV battery fates in 2017–18



LEAD ACID BATTERIES (≥5 KG)

This section of the executive summary provides a detailed examination of the Australian lead acid (≥5 kg) market segment. The segment description is provided in the following table.

Table E-15 – Lead acid (≥5 kg) batteries – Market characteristics

Segment description	Lead acid batteries of 5 kg or more, except for lead acid batteries going into BESS & EV applications.
Weight	≥5 kg.
Applications	All applications except for BESS & EV use.
Chemistries	Lead acid only.

Lead acid battery flows

A summary of lead acid battery flows in 2017–18 is provided in Table E-16. In 2017–18 there was nearly 154 000 tonnes of lead acid batteries (≥5 kg) sold into the Australian market (84% of all batteries sales). During the same period, it is estimated that 149 000 tonnes reached end-of-life, with 146 800 tonnes subsequently collected for reprocessing.

Table E-16 – Lead acid (≥5 kg) battery flows in 2017–18, by chemistry

Chemistry	Battery sales			Battery stocks	EoL arisings	Collection to recovery[3]	Collection rate
	(tonnes)	('000s)[1]	(million EBUs)[2]	(tonnes)	(tonnes)	(tonnes)	(%)
Lead acid	153 660	8 480	6 400	362 710	148 980	147 020	99%

1. Sales by number of batteries or cells (in thousands).
2. Equivalent battery units (EBU), where one EBU = 24 grams.
3. Collection includes a small amount of nickel cadmium batteries which are not reported separately for confidentiality reasons.

Lead acid battery trends

Table E-17 and Figure E-26 provide a summary of the key available time-series data on the trends of lead acid (≥5 kg) battery flows.

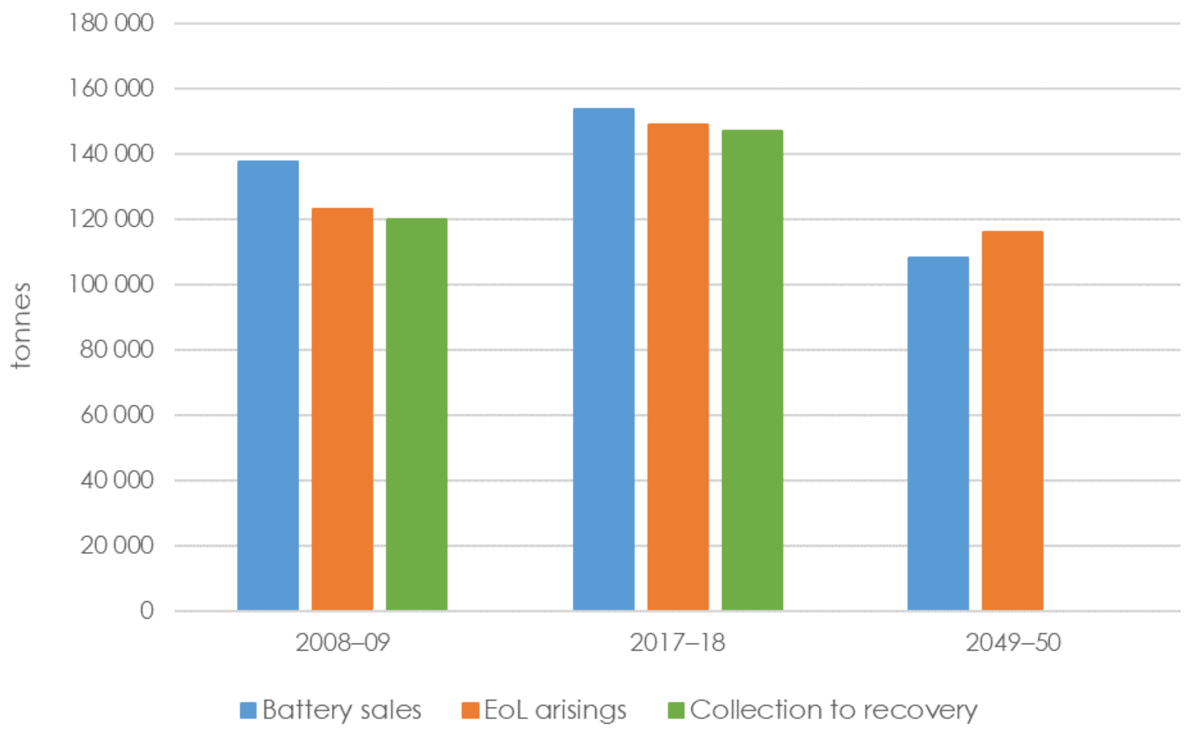
Table E-17 – Lead acid (≥5 kg) battery trends

Battery flow	Unit	2008–09	2017–18	2049–50
Source:	-	Warnken **(2010)**	This study	This study
Battery sales	(tonnes)	137 350	153 660	108 210
	number ('000s)	7 590	8 480	5 970
	(million EBUs)	5 720	6 400	4 510
EoL arisings	(tonnes)	123 050	148 980	116 020
Collection to recovery	(tonnes)	119 700	147 020	NR
	(%)	**97%**	**99%**	**NR**

NR – Not reported as cannot be projected.

Note that the apparent increase in the collection rate between 2008–09 (97%) and 2017–18 (99%) should not be interpreted as significant, due to inherent uncertainties in estimating the EoL arisings quantity.

Figure E-26 – Lead acid (≥5 kg) battery trends



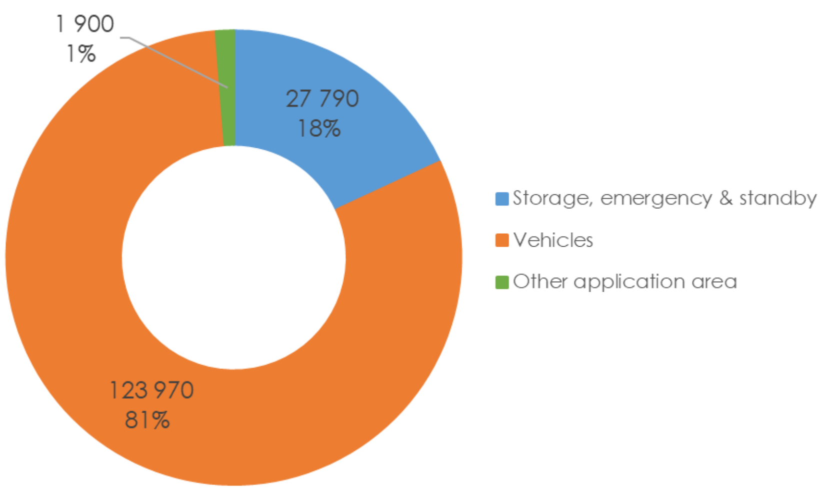
Lead acid battery sales are projected to peak around 2030, then fall steadily over the next two decades to approximately 110 000 tonnes of sales in 2049–50. This is a projected fall of 30% from 2017–18 sales. This is primarily due to the projected shift to electric vehicles over the coming decades.

Lead acid battery sales by application area

Lead acid battery market sales in 2017–18 are presented in Figure E-27, at the application level.

Of the 154 000 tonnes of batteries sold, 81% were into engine starting applications in vehicles, and the other 30 000 tonnes (19%) were into storage, emergency & standby (SES) applications such as commercial and industrial uninterruptible power supplies (UPS), and many other industrial, mining and farming applications.

Figure E-27 – Lead acid (≥5 kg) battery sales in 2017–18, by application area

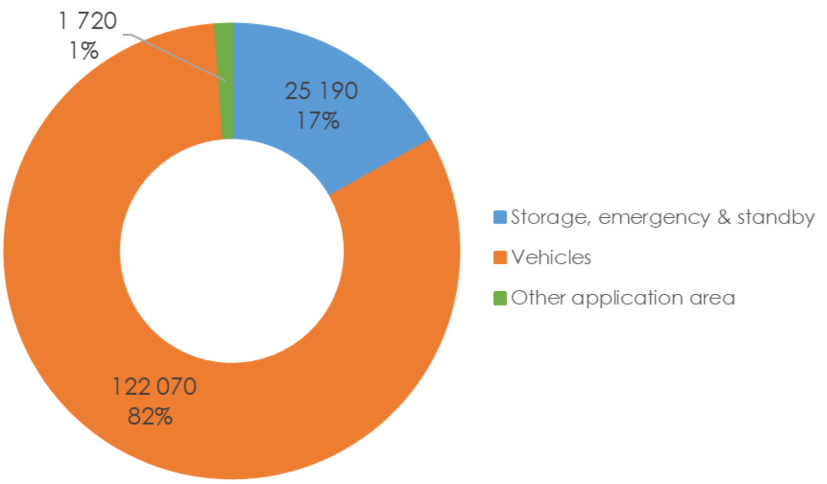


Lead acid battery end-of-life arisings

Figure E-28 presents estimated lead acid (≥5 kg) battery end-of-life (EoL) arisings by application area in 2017–18. EoL arisings are batteries that are entering waste streams and are potentially available for recovery.

In 2017–18 there were an estimated 149 000 tonnes of lead acid (≥5 kg) batteries reaching end-of-life.

Figure E-28 – Lead acid (≥5 kg) battery EoL arisings in 2017–18, by application area

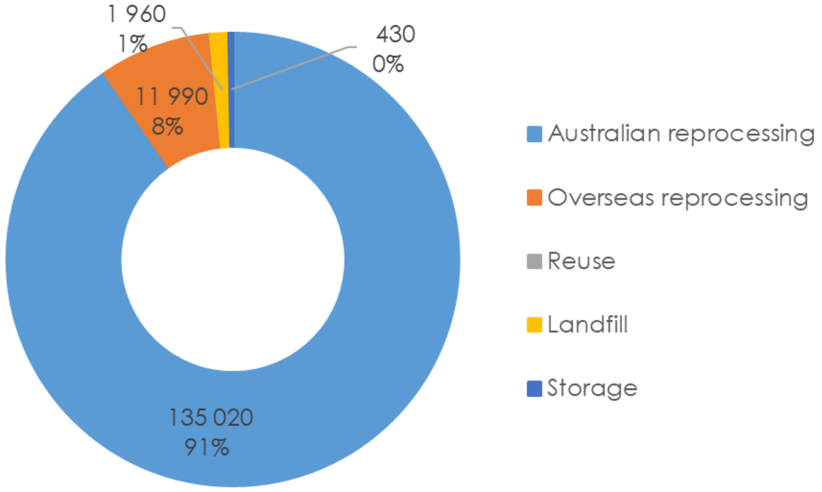


Lead acid battery fates

Provided in Figure E-29 is a summary of fates of the 149 000 tonnes of lead acid (≥5 kg) batteries reaching EoL in 2017–18. Australian reprocessing dominates the fates due to the very high collection rates, and strong local reprocessing industry coupled with tight requirements on exports.

Only 12 000 tonnes were identified as exported. This is an approximate estimate of illegal exports in 2017–18, as no export permits were issued or used during the period.

Figure E-29 – Lead acid (≥5 kg) battery fates in 2017–18



BATTERY RECOVERY MARKET ECONOMIC ASSESSMENT

As part of the project, a market assessment of the Australian end-of-life battery collection, sorting and processing sector has been undertaken. Its purpose is to explore the market characteristics and cost structures within the current battery recovery sector, and consider the implications for recovery of the increasing flows of end-of-life batteries in the future.

Summary statistics on the sector

A number of EEE disassembler and battery reprocessor survey respondents provided estimates of both employment and turnover for battery reprocessing activities. These have been scaled up to whole of reprocessing market estimates.

Table E-18 – Indicative employment and turnover

Activity	Employment (FTE)	Turnover ($m)
Reprocessing	400	$71.3m

The estimate for employment suggests a ratio of 26.4 (equivalent) full time employees (FTEs) per 10,000 tonnes of reprocessed batteries. This compares with the Access Economics (2009) estimate of 9.2 FTEs per 10 000 tonnes of recycled waste.

Figure E-30 highlights the grouping of reprocessing firms. Over half of the firms undertaking processing employ fewer than 20 employees in those processes. The remainder have at least 20 employees undertaking reprocessing activities.

This split is more evident when looking at turnover. The smaller firms have significantly lower revenues from reprocessing compared with that earned by those employing 20 or more in reprocessing.

Figure E-30 – Size of reprocessing firms by number of employees

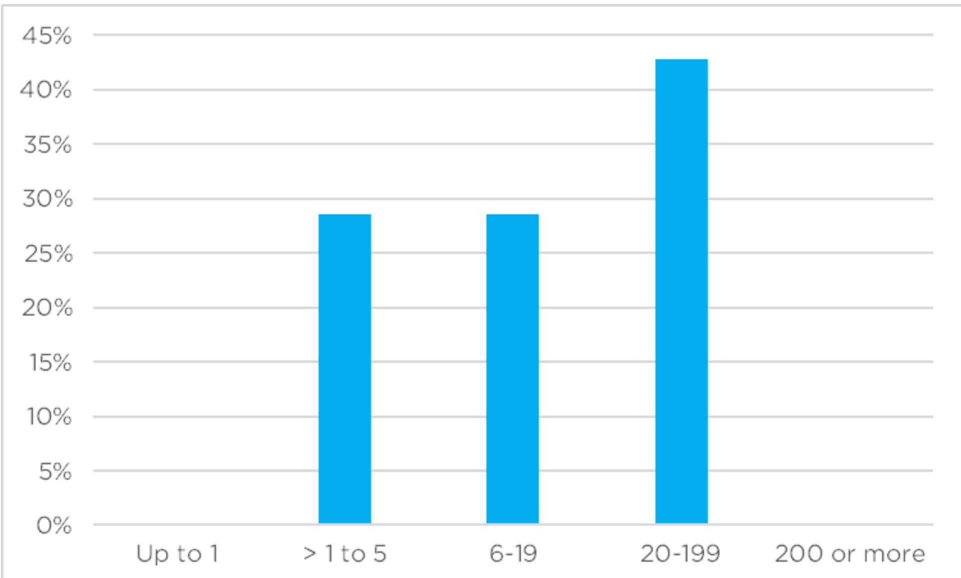
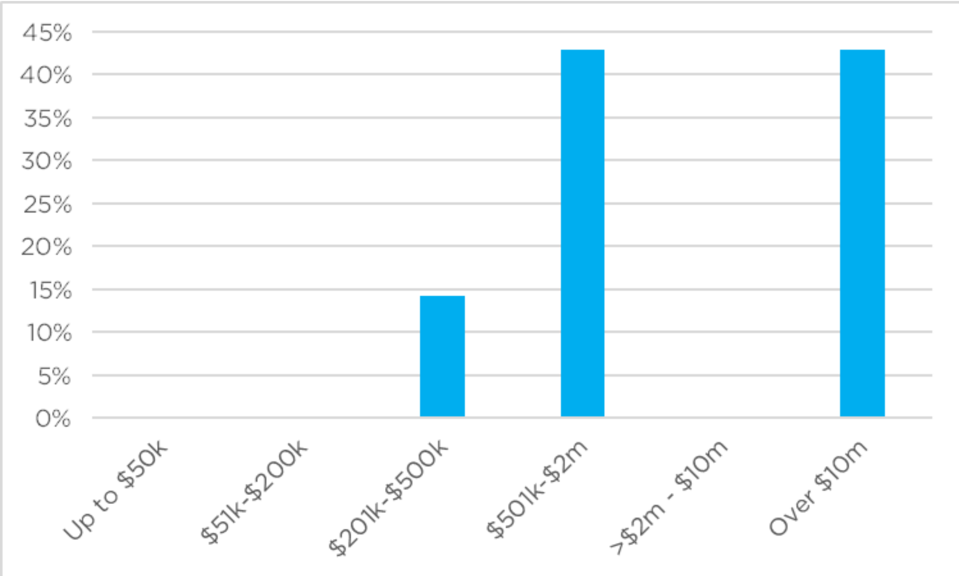


Figure E-31 – Turnover of reprocessing firms



Separate estimates of the contribution of battery recycling and general recycling to Australian GDP are not available. We have therefore applied the factors used for waste industries in general.

The estimate is based on the battery related turnover of the sector and estimates of the total value of waste activity of $15.5b in Australia, of which $6.9b contributed to Australia's GDP (The CIE, 2017, p. 33).

The indicative estimated contribution of battery recycling to Australian GDP is $31m.

Recycling industry financial assessment

Table E-19 presents a summary of the financial assessment undertaken for this project which has been structured across four battery groups. These groups have been selected in part to meet confidentiality constraints due to the small number of battery reprocessors operating in Australia.

After lead acid batteries, alkaline batteries represent the second most significant weight of batteries collected for reprocessing in Australia. The collection and reprocessing market for alkaline batteries is not independently viable in Australia and needs significant funding support to operate.

The other major chemistry group is lithium ion batteries. This group is also not independently self-funding for the collection, EEE disassembly and reprocessing of these chemistries.

Table E-19 – Indicative financial assessment of collection and onshore reprocessing

Chemistry group	Quantity collected (tonnes)	Collection and EEE disassembling ($/tonne)	Reprocessing ($/tonne)	Total local costs ($/tonne)	Comments on collection and reprocessing market
Alkaline	990	$200	$490	$690	Not viable without significant funding support.
Non-alkaline single-use[1]	22	CIC	CIC	CIC	Marginal or not viable due to very low quantities. Silver only valuable output.
Lead acid	148 910	$189	–$481	–$292	Generally viable but vulnerable to lower cost overseas reprocessors.
Li-ion, NiCd and NiMH[3]	787	$860	–$1,308	–$448	Generally viable for NiCd and NiMH chemistries. Not viable for Li-ion chemistries.

Source: Marsden Jacob Associates

Note: In the table above positive values are costs and negative values are income.

1. Non-alkaline single-use includes lithium primary, silver oxide and zinc air button cells.

2. Commercial in confidence (CIC) – Financial data not-reportable due to confidentiality constraints.

3. Lithium ion, nickel cadmium and nickel metal hydride batteries grouped for confidentiality reasons. Minimal cost information was available for this group and the estimated costs may be understated.

Excluding the lead acid reprocessing sector, the financial viability of the collection and intermediate (disassembling) stages of battery recovery are very uncertain. Preliminary analysis suggests that the collection and disassembling stages are not viable financially if they are considered in isolation.

Furthermore, financial analysis of the battery reprocessing stage indicates that to recover material from the major battery types, alkaline and lithium ion, is generally not financially viable. The value of recovered materials is significantly exceeded by reprocessing and other associated costs (e.g. disposal of residual waste).

Another key factor holding back recycling is ensuring an adequate supply of sorted batteries provided through the intermediate processing stage.

This all underlines the need for investment in the sector either through a stewardship scheme or regulation. Ensuring that the costs of collection, sorting, reprocessing and disposal of residual waste are funded, would help avoid the financial, environmental and social externalities associated with the loss of large quantities of EoL batteries to landfill.

Potential interventions

The low recovery rates of most battery types, excluding lead acid batteries, is partly due to the marginal financial viability of battery recycling, especially at the collection and disassembling stages of recycling.

A key pathway forward is ensuring an adequate supply of sorted batteries through the intermediate processing stage. This, in turn, would require active intervention in the form of a range of policies and programs. These include:

- Introduce a battery product stewardship scheme.
- Investment in infrastructure for sorting and reprocessing facilities to ensure security of onshore processing.
- Enhanced community information and educations programs.
- Improvement of import code reporting requirements to support the operation of any product stewardship scheme.
- Regular data collection and industry market analysis.

GLOSSARY AND ABBREVIATIONS

ABRI	Australian Battery Recycling Initiative
ABS	Australian Bureau of Statistics
Accumulator	Rechargeable battery
Act (the)	Product Stewardship Act 2011
Alkaline battery or cell	The term 'Alkaline' has been adopted in this report as the chemistry group name for single-use batteries with zinc manganese dioxide based chemistry. Common types are 'alkaline', 'zinc carbon' or 'zinc chloride' cells or batteries. See Appendix B-1 for the listing of all battery chemistries covered in this report.
ANZSCC	Australian and New Zealand Standard Commodity Classification
ANZSIC	Australian and New Zealand Standard Industrial Classification
Arisings	Batteries that have reached the end of their service life (or are unwanted for any other purpose) within the Australian economy and require a resource recovery or waste management solution
Battery inputs	Batteries that are purchased for use in Australia
Battery Product Stewardship Scheme (Scheme)	The overarching framework that provides the means by which parties in the battery supply chain can share responsibility for the long-term management of end-of-life batteries in Australia.
Battery recycler	A business or organisation recovering the component materials from batteries.
Battery retailer	A retailer that sells loose batteries or a product containing batteries that is in a Designated Product category.
BESS	Battery energy storage systems (BESS) are battery systems intended for continual use and are either electricity grid connected, or stand-alone power systems that replace the electricity grid.
Brand owner	(a) a person who is the owner or licensee in Australia of a trademark or brand under which a battery is sold or otherwise distributed in Australia, whether the trademark or brand is registered or not; or (b) a manufacturer of a product containing a battery.
BRG	The Battery Reference Group.
BSC	Battery Stewardship Council.
Button cell battery	Small, thin energy cells that are commonly used in watches, hearing aids, and other electronic devices requiring a thin profile.
C&D waste	Construction and Demolition waste: Materials generated during construction or demolition of buildings, often containing significant quantities of sand, bricks, concrete, steel, plastic pipes, plasterboard, timber and also packaging materials.
C&I waste	Commercial and industrial (C&I) waste: Comprises solid waste generated by the business sector as well as solid waste created by state and federal government entities, schools and tertiary institutions. Unless otherwise noted, C&I waste does not include waste from the construction and demolition (C&D) sector.
Collection	(a) collection of loose used batteries from consumers; or (b) separation of batteries from used electrical and electronic equipment for the purposes of Recycling
Collector	An individual, business or organisation that collects and/or transports end-of-life batteries from anywhere in Australia for Recycling as part of the Battery Product Stewardship Scheme.
Consumer	The final purchaser of the battery, whether as a loose replacement battery or as a battery sold with or contained in a product.
Data year	The year defined for reporting purposes.

Easily removable battery	'Easily removable' means readily detachable by a person without the use of tools, or designed with the intent that the battery is easily removed with the use of common household tools.
EEE	Electrical and electronic equipment.
EV battery	Electric vehicle (EV) batteries are those that can be used as the primary energy source for vehicles during use. Also includes batteries in hybrid and plug-in hybrid vehicles.
Embedded battery	A battery that is an integral part of a product and cannot be easily removed without rendering the product inoperable.
End-of-life (EoL)	An item which is no longer deemed to be capable of performing the function for which it was originally intended.
EoL arisings	Batteries leaving stocks, entering waste streams, and are potentially available for recovery.
Equivalent Battery Unit (EBU)	A standardised measure for the quantity of end-of-life handheld batteries. One EBU is equivalent to 24 grams.
Export	Export from Australia.
Formal stockpiles	Batteries that are stored in accordance with relevant regulations prior to transport or processing.
Free-rider	An Importer that is not a signatory to the Agreement or otherwise not fulfilling the commitments of a Steward.
Handheld battery	A battery or cell of any chemistry that weighs less than 5kg.
HTISC	The *Harmonized Tariff Item Statistical Code*. An Australian extension of the international *Harmonized Commodity Description and Coding System* (HS), to provide a finer level of detail than the international HS system. The HTISC relates to imports, but not to exports. The *Combined Australian Customs Tariff Nomenclature and Statistical Classification* (the Customs Tariff) is the broader Australian extension of the HS which covers both imports and exports. The HTISC is a subset of the Customs Tariff.
Import	Import into Australia, which includes bringing in with or as part of another product.
Individual Producer Responsibility (IPR)	Each producer is responsible for financing the operations relating to the waste from their own products, rather than collective responsibility through a shared product stewardship scheme.
Industrial battery	A large battery used in industrial applications for standby or motive power.
Informal stockpiles	Storage of batteries by consumers prior to reuse at a later stage or disposal into formal waste streams/disposal routes. This storage could be, for example, in a disused piece of equipment within a household, or separately in rural and regional settings.
Lead acid battery	A battery with lead electrodes and using dilute sulphuric acid as the electrolyte.
Lithium batteries	Disposable (primary) batteries that have lithium metal or compounds as an anode and manganese dioxide typically as a cathode. They are widely used in portable consumer electronic devices.
$LiCoO_2$	Lithium cobalt oxide.
LIB	Lithium ion battery, a member of a family of rechargeable batteries. Lithium ion batteries are typically found in a range of uses from pacemakers, power tools, cameras, smoke alarms and security systems and are increasingly replacing Lead Acid Batteries for use in golf carts. Chemistry, performance, cost and safety characteristics vary across LIB types—for example, LiCoO2, NMC and LMO.
LMO	Lithium manganese oxide.
Material flow analysis (MFA)	Material flow analysis (MFA) is a mass balanced based analytical method to quantify flows and stocks of materials or substances for a well-defined system and timeframe. MFA is also referred to as substance flow analysis (SFA).

Municipal waste	Household wastes plus material from public place collection.
NiCd	Nickel cadmium.
NiMH	Nickel-metal hydride.
NMC	Lithium nickel manganese cobalt oxide, a chemistry typically found in batteries for power tools and medical equipment.
NTCRS	National Television and Computer Recycling Scheme.
OEM	Original equipment manufacturer.
Orphan product	A battery or a product containing a battery that was manufactured or imported by a company that no longer exists.
Parallel import	A non-counterfeit, legitimate product imported from another country without the permission of the intellectual property owner.
Primary battery	A battery not intended for recharging.
Primary Product List	The list of products, published each year by the Australian Government under the Product Stewardship Act 2011 that are being considered for product stewardship approaches.
Product Stewardship	An approach to reducing the environmental and other impacts of products by encouraging or requiring manufacturers, importers, distributors and other persons to take responsibility for those products.
Recyclable	Material that can be collected separately from the general waste and sent for recycling. The precise definition will vary, depending upon location (i.e. systems exist for the recycling of some materials in some areas and not in others).
Recycle	A process to recover constituent materials and use these materials to produce other products.
Recycling	Where a material or product undergoes a form of processing to produce a feedstock suitable for the manufacture of new products.
Recycling efficiency	The percentage of a battery that is recycled by weight.
Recovery	End-of-life products or materials collected for either recycling or energy recovery.
Reuse	The transfer of a product to another user, with no major dismantling or processing required.
Secondary battery	A battery intended for recharging.
SES	Storage, emergency & storage (SES) battery application area.
SLAB	Sealed lead acid battery. A type of lead acid battery that is sealed and contains no free liquid electrolyte. These are commonly used for portable electrical devices, emergency lighting and alarm systems.
SLI	Starting, lighting and ignition batteries.
Sorting	To categorise batteries by their chemical composition to determine the most appropriate management process.
SSLA	Small sealed lead acid (battery).
Standalone batteries	Batteries sold separately, and not with an EEE product.
Steward	A Signatory to the Battery Stewardship Agreement.
Stocks	Batteries in service within the economy.
ULAB	Used lead acid battery.
UNLAB	Used non-lead acid battery.
UPS	Uninterruptible power supply.
Waste arising	The estimate of batteries in a particular year that have reached the end of their useful life or that are unwanted for any reason and require disposal through any route.

1 INTRODUCTON

1.1 THIS PROJECT

The Battery Stewardship Council (BSC) and the Queensland Department of Environment and Science (DES) commissioned this study to analyse the Australian battery market, and undertake a stocks and flows analysis of all battery consumption, use and end-of-life, by battery chemistry, format/size and application.

The BSC was established in May 2018 to facilitate the design and deployment of a national stewardship scheme for all batteries, across all chemistry types and applications. This project will inform development of the preferred product stewardship design to ensure that the selected scheme is practical, recovery effective, cost effective and future focused.

The requirements and objectives of this project are to:

- Inform the design of the consultation phase of the national product stewardship scheme for batteries.
- Support the identification of recommendations for inclusion in the scheme design.
- Provide a robust information base on quantitative flows of batteries through the Australian economy, information that is of interest more widely to industry, government and the community.
- Assess the financial characteristics of the battery recycling sector, which will inform on the current status of the sector, and may support future work in assessing the regulatory impact of short-listed options for the national product stewardship scheme for batteries.

The material flow analysis (MFA) component of the project is a significant update and expansion of prior MFA work with battery flow modelling forecasts out to 2049–50. Time series data across a period of time (i.e. 2012–13 to 2049–2050) is required to better understand the flow and market share of batteries in Australia, and the potential future implications of any short-listed product stewardship scheme designs.

The MFA scope covers batteries of all sizes, including those sold embedded within products, with the analysis splits including:

- Battery market segment.
- Battery size/format.
- Battery chemistry type (e.g. used lead-acid batteries).
- Both single-use (primary) and rechargeable (secondary or accumulator) battery types.
- Batteries that are separately purchased (standalone) batteries, e.g. alkaline AA cells, and embedded batteries sold in electrical and electronic equipment (EEE).
- Batteries in energy storage systems (BESSs) and electric vehicles (EVs).

The MFA quantifies the consumption of different battery types in different applications, so includes batteries that are already covered by existing product stewardship schemes (e.g. the co-regulatory National Television and Computer Recycling Scheme).

It is anticipated this study will contribute to an improved understanding of the issues and opportunities for battery product stewardship in Australia. Further to this, it is expected to contribute to a strong evidence base, to inform the work of the BSC on assessing designs for a voluntary or co-regulatory battery product stewardship scheme for Australia.

1.2 THIS REPORT

This report consists of seven sections.

Executive summary

Overview of the project purpose and results.

Section 1 – Introduction

Description of the project background and purpose.

Section 2 – Study scope and method

Description of the project scope and method.

Section 3 – Battery sales in 2017–18

Estimates of batteries sold onto the Australian market in 2017–18, reported at following levels:

- Sales by market segment.
- Sales by application area.
- Sales by chemistry group.
- Sales by unit weight range.
- Sales by single-use or rechargeable type.
- Sales by level of integration in products.
- Sales by end-user type.
- Sales by jurisdiction.

Section 4 – Project battery flows to 2049–50

In this section of the report annual battery sales, stocks (batteries that are in use), and end-of-life arisings (battery disposal) across the period of 2012–13 to 2049–50 are estimated.

Section 5 – Battery collection in 2017–18

Estimates of batteries recovered for reprocessing in 2017–18, reported at the following levels:

- Collection by market segment.
- Collection by chemistry group and weight range.
- Collection by chemistry group and applications area.

- Collection rates by chemistry group and application area.
- Collection by chemistry and collection route.

Section 6 – Battery recovery market assessment

Undertaken in this section of the report is a market assessment of the Australian battery recovery and recycling sector. The purpose of this assessment is to explore the market characteristics and cost structures within which the battery recovery sector currently operates, and consider the implications for the recovery of increasing flows of end-of-life batteries in the future.

Section 7 – Local government activity review

Local governments nationally contributed to the study through an online survey on council battery recycling programs.

2 STUDY SCOPE AND METHOD

This section provides an overview of the study scope and method as developed during the project planning phase of the project.

2.1 STUDY SCOPE

2.1.1 Classifications and definitions

For the purpose of data collection, description and analysis, batteries were classified and defined in line with the classifications and definitions outlined below, with additional detail provided in Appendix B. A summary of the main battery classifications and definitions applied is provided below:

- **Market segment** – handheld batteries (<5 kg); battery energy storage system and electric vehicle batteries (BESS & EV); lead acid batteries (≥5 kg).
- **Application area** – consumer electronics; torches/lanterns; power tools & gardening equipment; toys; personal mobility; storage, emergency & standby; vehicles; and other application area.
- **Chemistry group** – alkaline; lead acid; lithium ion; lithium primary; nickel cadmium; nickel metal hydride; silver oxide; zinc air; and other chemistries.
- **Battery size or weight range** – common sizes and other application specific sizes.
- Single-use or rechargeable.
- **Level of integration in products** – separately sold batteries; batteries sold as part of electrical and electronic equipment (EEE) and easily removable by consumers; and batteries sold as part of EEE and not user removable ('embedded' batteries).
- **End user type** – household and commercial; and large and industrial.

Also see the Glossary and Abbreviations section (page 38) for additional detail on the definitions provided above.

2.1.2 Data sources

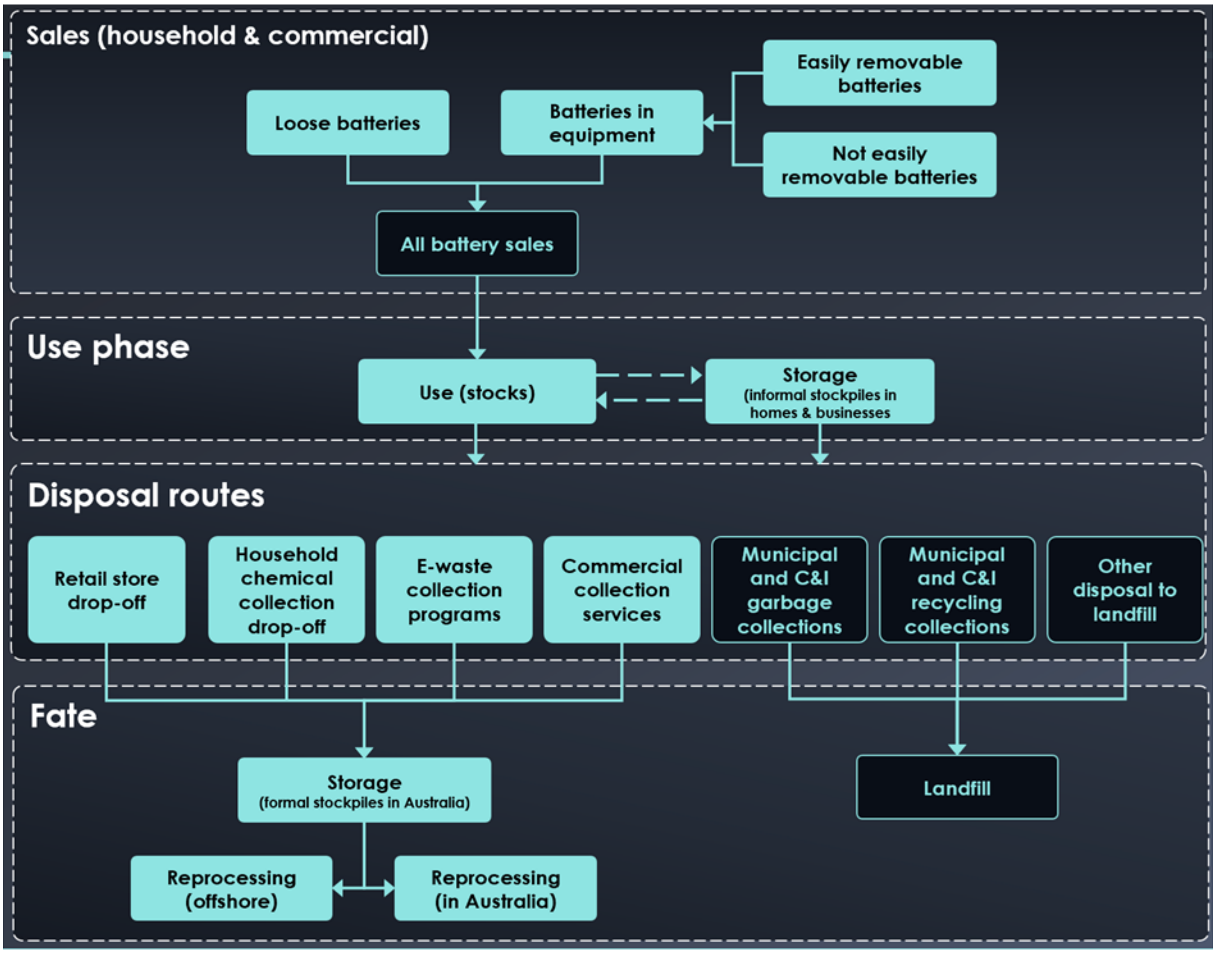
Battery sales, collection and processing data was obtained from a combination of sources, primarily:

- Battery related brand-owners and retailers – National survey undertaken as part of this project.
- Battery collection service operators, e-waste disassemblers and sorters, and battery reprocessors – National survey undertaken as part of this project.
- Extensive review of Australian import and export data (Australian Customs import/export Harmonized Tariff Item Statistical Code (HTISC) data extracts) across the period of 2012–13 to 2018–19.

2.1.3 MFA system

The 'MFA system map' is presented on the following page. It details the general structure that the MFA adopts.

Figure 1 – Australian battery MFA system map



2.1.4 MFA boundaries

2.1.4.1 Battery

The physical scope of a battery (or cell) is defined as the battery unit only, and excludes any other components of a product that a battery component may be attached to or embedded within.

An exception to this is with respect to battery energy storage systems (BESSs), for which the cabinet or housing immediately containing the grouped batteries is also included in the weight estimates of batteries for those applications.

2.1.4.2 Temporal

The MFA modelling time boundary has been undertaken on a financial year basis across the period of 2003–04 to 2049–50. The adopted approaches to estimating of future sales trends are outlined in detail in Appendix D.

2.1.4.3 Geographic

The MFA geographic boundary is mainland Australia and Tasmania.

2.1.4.4 Sales

Annual sales have been quantified through determination of:

- Imported batteries (contributing to sales).
- Locally manufactured batteries (contributing to sales).
- Exported batteries (subtracted from sales).

2.1.4.5 Use phase

- **Use (stocks)** – Batteries in use
- **Storage (informal)** – Stockpiles of batteries (stand alone or in waste EEE) in households and businesses. These batteries may re-enter use or be disposed of directly from storage.

2.1.4.6 Recovery routes

- Retail store drop-off.
- Hazardous household chemical collection (HHCC) – both permanent and temporary sites.
- E-waste collection programs (including the TVs/computers scheme, MobileMuster, other phone collections schemes, Cartridges for Planet Ark, etc.).
- Commercial collection services.
- Institutional collection programs (e.g. schools, universities, government, hospitals).
- Receival by battery processors.

2.1.4.7 Disposal routes

- Municipal and C&I garbage collections
- Municipal and C&I recycling collections
- Other disposal to landfill.
- Illegal dumping/illegal export.

The general types of disposal to landfill routes for end-of-life batteries are summarised above. Battery disposal to landfill has not been quantified separately via each of these routes, as the available audit data of each of the waste streams does not provide the required level of detail and data quality.

Aggregated disposal of batteries to landfill have been calculated as the difference between the estimated quantities of batteries reaching end-of-life in any given year, minus the known or estimated recovery.

2.1.5 Fate (of batteries)

1. **Reprocessing (local)** – Battery reprocessing which substantially takes place in Australia.
2. **Reprocessing (overseas)** – Battery reprocessing which substantially takes place overseas.

2.2 STUDY METHOD

2.2.1 Data collection and stakeholder consultation

Survey forms were prepared for the two main stakeholder groups, which were sales or recovery related. An extensive stakeholder consultation plan was also developed for the project which was documented in the project plan.

Battery sales and recovery related stakeholders were identified through previous survey contacts (SRU, 2014), ABRI and BSC membership lists, and the project team's industry knowledge. A listing of the stakeholders contacted during the course of the project is provided in Appendix A.

2.2.2 Determination of battery sales

With few exceptions almost all batteries are now imported into Australia either as standalone batteries or as part of electrical and electronic equipment (EEE). For this reason Australian Border Force (ABF) Customs import and export data is a valuable source of information on net battery consumption in Australia.

However, Customs data typically does not provide the level of detail required to allocate battery sales at the level of detail required for this project, and therefore an extensive survey of Australian battery brand-owners and retailers was also undertaken to inform and supplement the import and export data analysis.

The survey of local brand-owners and retailers also assisted in identifying and managing any gaps in the battery related import and export dataset.

In summary, battery sales have been estimated based on:

- Analysis of import and export data across the period of 2012–13 to 2018–19 (DFAT, 2019a; DFAT, 2019b) to determine net unit imports of batteries by chemistry group and application.
- Industry reported sales data in 2012–13 (SRU, 2014) and 2017–18 (Envisage, 2019c) to inform the analysis of the DFAT data, and quantify local manufacturing.
- Research and audits of battery weights by chemistry group and application area. See Appendix C for the average battery weights (g/battery) that have been adopted throughout the modelling undertaken for this study.
- Projected battery sales are based on brand-owner and manufacturer surveys, prior studies, and review of published reports.

The adopted approaches to estimating future sales at the battery chemistry and application levels are outlined in detail in Appendix D. Of particular note has been the extensive work undertaken over the last couple of years on battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) uptake (Energeia, 2019; BITRE, 2019; CSIRO, 2019), and residential and commercial/utility battery energy storage system (BESS) take-up rates in Australia (Energeia, 2019; CSIRO, 2019).

Where high, medium/neutral, and low projections have been reported in any source references and subsequently adopted into the modelling undertaken for this study the projections in this report are based on the 'medium' or 'neutral' scenario in the source material.

The projections of battery stocks and end-of-life arisings incorporate average lifespans estimated for each battery chemistry group and application area. These are largely drawn from the SRU (2014) report and the latest round of battery brand-owners and manufacturer surveys (Envisage, 2019c). The adopted lifespans at the battery chemistry and application area levels are outlined in detail in Appendix E.

The stocks phase (while the batteries are in-use) and end-of-life arisings have modelled assuming that the period of battery use follows a normal distribution prior to end-of-life.

2.2.3 Determination of battery collection and local/export processing

Australian battery collection and local/export processing has been determined through a survey of battery recovery chain participants across the following groups:

- Collection service operators – Organisations providing a collection service only, some disassembly of battery-containing devices, and sorting into battery types. The sorted batteries are then sent to another local processor to extract recoverable materials.
- EEE disassemblers – Organisations undertaking some degree of disassembly of battery-containing devices, and sorting into battery types. These organisations may also operate a collection service. The sorted batteries are then sent to a local or overseas reprocessor to extract recoverable materials.
- Reprocessors – Organisations undertaking the disassembly or shredding of batteries or cells to facilitate the subsequent recovery of materials from batteries. These organisations may also operate as collection service operator and or disassemblers.

A quantity of potentially illegal direct scrap lead acid battery export activity by others was also estimated by local reprocessors. This quantity has also been included in recovery estimates.

2.2.4 Material flow analysis modelling

The approach to modelling the flow of batteries through sales (consumption), stocks (in use), and end-of-life arisings, is that of material flow analysis (MFA). Material flow analysis is an analytical method of quantifying flows and stocks of materials or substances in a well-defined system, in this case for batteries. MFA is based on two principles, system mapping and mass balance.

The MFA system developed for this project was a model of Australian flows of standalone and embedded batteries, built up from estimated flows of historical and current battery sales, use and disposal, differentiated by application of use, size/format and weight, end-of-life fate, jurisdiction of use, and the other required attributes.

The MFA model built on baseline 2017–18 financial year data, with time series estimates of the key model outputs out to 2049–50. The MFA model was built in MS Excel and is an extension of a model initially created in 2014 (SRU, 2014) covering all handheld batteries (<5 kg) nationally.

2.3 ASSUMPTIONS

Provided here are some of the key assumptions adopted in modelling undertaken for this study, that are not discussed elsewhere in the report.

EV battery reuse

After life electric vehicle batteries are not modelled as having a second life as residential storage batteries, and so reducing sales to a degree of batteries into residential BESSs across the 2040s in particular. It is considered unlikely that functional batteries will be removed from EVs, checked, and rebuilt into a BESS, at any scale, at a competitive price, and with a marketable warranty. There is no real precedence for reuse of 10–15 year old (or more) e-goods in this manner. Also refer to CSIRO (2019, p. 39) for a more detailed discussion on the reasons that study excluded the reuse of electric vehicle batteries after their on-vehicle life.

Self-driving autonomous electric vehicles

The impact of the introduction of self-driving autonomous electric vehicles used to deliver 'Transport as a service' (TaaS) on private vehicle sales may be significant. However, the modelling does not incorporate changes in vehicle ownership patterns in the Australian market. The relative cost of private car ownership is anticipated to be high relative to TaaS, and place downward pressure on passenger car sales generally.

Lithium based chemistries as the technology of choice

It is assumed in the modelling that lithium chemistries remain the technology of choice into vehicle and BESS applications. If any alternative energy storage systems do take significant market share from the lithium chemistries they may reduce the weight of batteries sold into the market, assuming that they have an improved energy density over lithium-ion chemistries.

2.4 CONFIDENTIALITY

Assurances were provided to stakeholders surveyed as part of this project on the confidentiality and security of their responses. This report does not include any company specific data from survey responses. All survey data published in this report has been aggregated to the level of general battery chemistry groups, application areas, and other general battery attributes.

2.5 REPORT AND DATA LIMITATIONS

Envisage Works has prepared this report with a high-level of care and thoroughness, and recommends that it is read in full. This report is based on generally accepted practices and standards at the time it was prepared. It is prepared in accordance with the scope of work and for the purpose outlined in the project brief. The method adopted and sources of information used by Envisage Works are outlined in this report, except where provided to Envisage Works on a confidential basis.

This report has been prepared for use by the *Battery Stewardship Council*, and only other third parties who have been authorised in writing by Envisage Works. Envisage Works is not liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

This report does not purport to give legal or financial advice. No other warranty, expressed or implied, is made as to the professional advice included in this report.

This report was prepared to end of December 2019 and is based on the conditions encountered and information reviewed at the time of preparation. Envisage Works disclaims responsibility for any changes that may have occurred after this time.

Where conclusions have been drawn, these have been based upon information provided to Envisage Works by stakeholders and other identified sources. Envisage Works has taken reasonable steps to verify the accuracy of the information provided within the boundaries of the agreed project scope and resources available. It is noted that the data presented in this study is reliant on a wide range of data sources, which vary in terms of quality and reliability.

Envisage Works has attempted to source the best available data for this study, however, in some instances, data was not readily available and it was necessary to make assumptions. Where assumptions were necessary, Envisage Works has based these on a reputable source or reasonable first principle basis. Some of the assumptions potentially have a significant impact on the analysis outcomes.

In the tables presented in this report, minor discrepancies may occur between summed totals presented in tables, and the apparent sums of the component items in tables, as summed totals are calculated using component item values prior to rounding.

3 BATTERY SALES IN 2017–18

3.1 SALES BY MARKET SEGMENT

The Australian battery market consists of the following three market segments as defined for this study:

- **Handheld batteries (<5 kg)** – All batteries under 5 kg, except for BESS & EV batteries. Includes all lead acid batteries under 5 kg.
- **Battery energy storage system and electric vehicle batteries (BESS & EV)** – Battery energy storage system (BESS) are battery systems intended for continual use and are either electricity grid connected, or stand-alone power systems that replace the electricity grid. Electric vehicle (EV) batteries are those that can be used as the primary energy source for vehicles during use. The BESS & EV segment includes a relatively small quantity of lead acid batteries of 5 kg or more.
- **Lead acid batteries (≥5 kg)** – All lead acid batteries of 5 kg or more, except for lead acid batteries going into BESS & EV applications.

A summary of 2017–18 Australian battery sales by market segment is provided in Figure 2 and Table 1. By weight, lead acid batteries (≥5 kg) made up 84% of the total sales of 182 000 tonnes, but only 2% of sales by number. Handheld batteries (predominately alkaline batteries) made up 98% of sales by number but only 12% by weight.

Figure 2 – Battery sales in 2017–18, by market segment

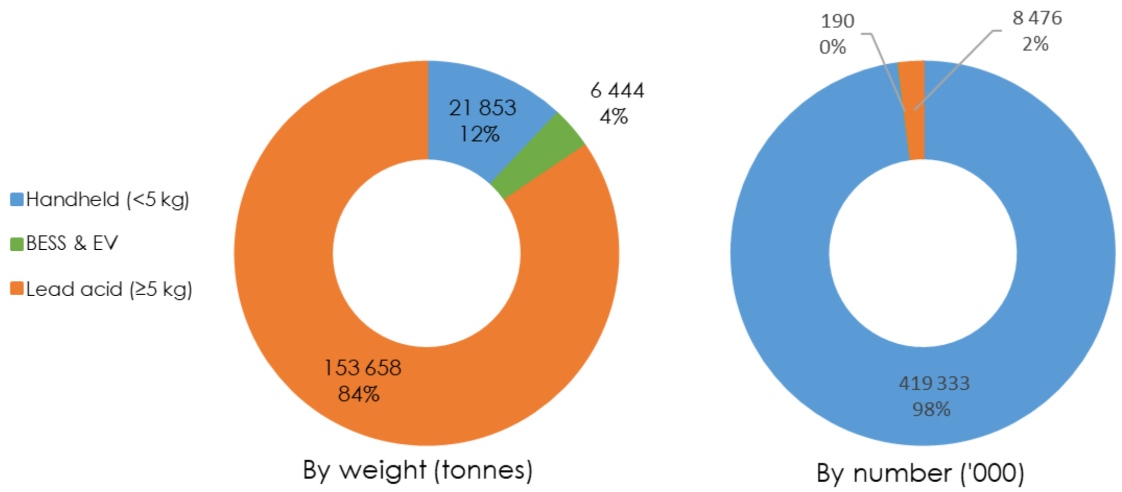


Table 1 –Battery sales in 2017–18, by market segment

Market segment	Battery sales		
	(tonnes)	('000s)[1]	(million EBUs)[2]
Handheld (<5 kg)	21 850	419 330	910
BESS & EV	6 440	190	270
Lead acid (≥5 kg)	153 660	8 480	6 400
Total	**181 960**	**428 000**	**7 580**

1. Sales by number of batteries or cells (in thousands).
2. Equivalent battery units (EBU), where one EBU = 24 grams. The EBU is a standardised measure for the quantity of end-of-life handheld batteries.

Note that there is another potential market segment of batteries that could be defined, which are those that are ≥5 kg, are not lead acid, but do not fall into the BESS & EV segment. There were no sales of this group reported but small quantities of recovery were reported in 2017–18. These quantities have been allocated into the lead acid (≥5 kg) market segment where market segment-based data is reported.

3.2 SALES BY APPLICATION AREA

In Table 2 and Figure 3 the sales of batteries are presented by application area. Three application areas account for most battery sales by number, which are: Consumer electronics (73%); Torches/lanterns (5%); and Toys (6%).

By weight, the application area of vehicles made up 69% of battery sales, and the storage, emergency & standby (SES) applications consisted of 20%. This was followed by consumer electronics and power tool applications, which made up 5% and 3% of battery sales respectively. All other application areas made up the remaining 3% of battery sales.

Laptops and mobile phones are the most significant battery applications in the consumer electronics application area. While battery use in the cordless power tools & gardening equipment application area is spread across sales of drills, circular saws, sanders, routers, grinders, blowers, edgers, vacuums, and mowers. Later in this section more detailed analysis of these two application areas is provided.

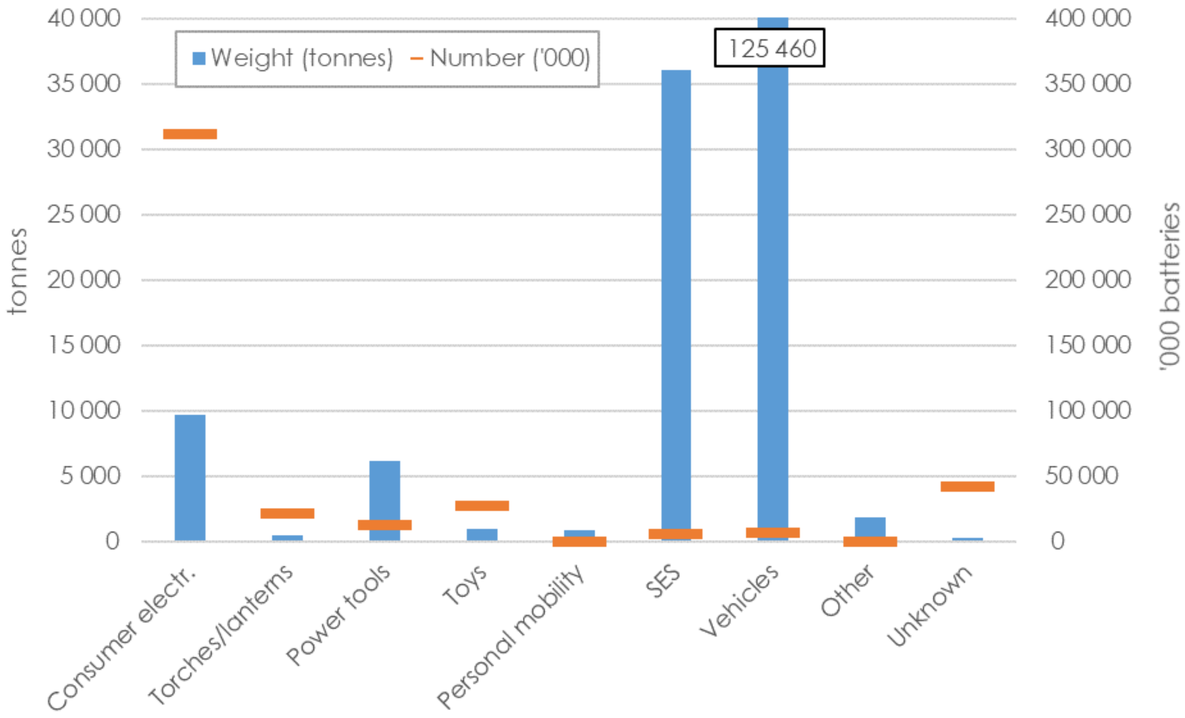
Many batteries sold into the power tool market are used across multiple tools types, and a proportion of these batteries are sold separately as replacements or spares.

Sales of consumer electronics have continued to grow strongly over recent years, and battery power tool sales have also climbed strongly due to convenience of use, and improved safety on building sites through the avoidance of running electricity across work areas. It is estimated that the DIY/tradesperson power tool market is moving to be almost completely cordless. That market is now 85% cordless compared to 15% corded.

Table 2 – Battery sales in 2017–18, by application area

Application area	Weight (tonnes)	Number ('000 batteries)
Consumer electronics	9 650	311 630
Torches/lanterns	480	21 780
Power tools	6 200	12 560
Toys	980	27 250
Personal mobility	880	150
Storage, emergency & standby	36 090	5 310
Vehicles	125 460	6 770
Other application area	1 900	100
Unknown	310	42 460
Totals	**181 960**	**428 000**

Figure 3 – Battery sales in 2017–18, by application area



Note: SES – Storage, emergency & standby.

Presented in Table 3 and Figure 4 are 2017–18 battery sales by market segment, chemistry group and application area. Note that Figure 4 only presents handheld battery sales.

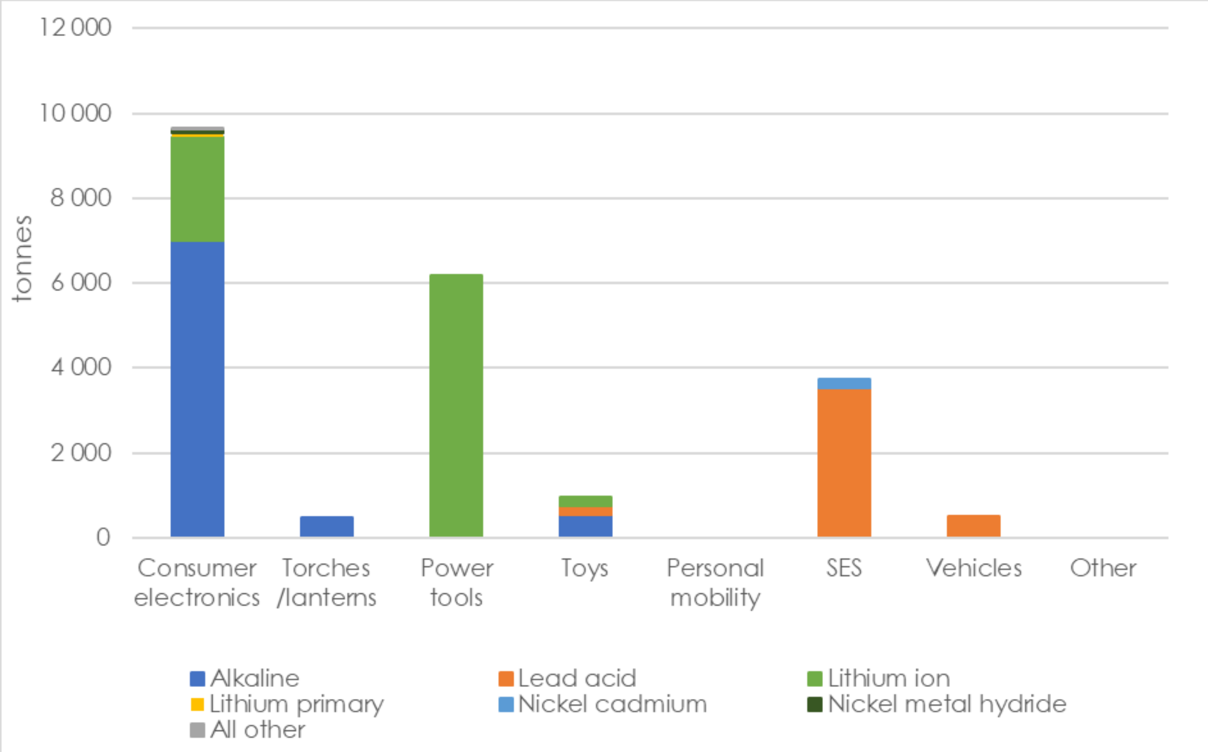
In the market segment of handheld (<5 kg), there were 9 650 tonnes of batteries sold into consumer electronics applications (44% of <5 kg sales), 6 200 tonnes of batteries sold into power tool applications (28% of <5 kg sales), and 3 730 tonnes of batteries sold into storage, emergency & standby related applications (17% of <5 kg sales).

Table 3 – Battery sales in 2017–18, by chemistry group and application area

	Application area	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
Handheld (<5 kg)	Consumer electronics	7 010	0	2 430	90	0	110	20	9 650
	Torches/lanterns	480	0	0	0	0	0	0	480
	Power tools	0	0	6 200	0	0	0	0	6 200
	Toys	560	200	220	0	0	0	0	980
	Personal mobility	0	0	0	0	0	0	0	0
	SES[1]	0	3 540	0	0	190	0	0	3 730
	Vehicles	0	500	0	0	0	0	0	500
	Other applications	0	0	0	0	0	0	0	0
	Unknown	0	0	0	0	0	0	310	310
	Total handheld	***8 040***	***4 230***	***8 850***	***90***	***190***	***110***	***330***	***21 850***
BESS & EV	Consumer electronics	0	0	0	0	0	0	0	0
	Torches/lanterns	0	0	0	0	0	0	0	0
	Power tools	0	0	0	0	0	0	0	0
	Toys	0	0	0	0	0	0	0	0
	Personal mobility	0	680	200	0	0	0	0	880
	SES[1]	0	1 120	3 450	0	0	0	0	4 570
	Vehicles	0	0	500	0	0	490	0	990
	Other applications	0	0	0	0	0	0	0	0
	Unknown	0	0	0	0	0	0	0	0
	Total BESS & EV	***0***	***1 800***	***4 150***	***0***	***0***	***490***	***0***	***6 440***
Lead acid (≥5 kg)	Consumer electronics	0	0	0	0	0	0	0	0
	Torches/lanterns	0	0	0	0	0	0	0	0
	Power tools	0	0	0	0	0	0	0	0
	Toys	0	0	0	0	0	0	0	0
	Personal mobility	0	0	0	0	0	0	0	0
	SES[1]	0	27 790	0	0	0	0	0	27 790
	Vehicles	0	123 970	0	0	0	0	0	123 970
	Other applications	0	1 900	0	0	0	0	0	1 900
	Unknown	0	0	0	0	0	0	0	0
	Total lead acid	***0***	***153 660***	***0***	***0***	***0***	***0***	***0***	***153 660***
	Total	**8 040**	**159 690**	**13 010**	**90**	**190**	**600**	**330**	**181 960**

1. SES – Storage, emergency & standby.

Figure 4 – Battery sales in 2017–18, by chemistry group and application area – Handheld (<5 kg) only



Note: SES – Storage, emergency & standby.

The two application areas of 'Consumer electronics' and 'Power tools & gardening equipment' are of particular interest given the large contributions they make to handheld battery sales by both weight and number. Note that the 'Vehicles' handheld batteries (<5 kg) primarily consisted of motorcycle engine starting small sealed lead acid batteries (SSLABs).

Provided in Table 4 and Figure 5 are the estimated 2017–18 sales of batteries into the consumer electronics application area at the contributing application level (see Appendix B-3 for a full listing of the applications and application areas applied throughout the MFA).

Provided in Table 5 and Figure 6 are the estimated 2017–18 sales of batteries into the Power tools & gardening equipment application area at the contributing application level.

Table 4 – Battery sales in 2017–18, by consumer electronics applications

Application area	Weight (tonnes)	Number ('000 batt.)	Comments
Standalone single-use sales	6 990	226 540	Almost entirely alkaline batteries.
Cameras	240	3 830	Lithium ion batteries.
Cordless phones and answering machines	30	1 450	Nickel metal hydride batteries.
Health / hygiene and wearable devices	20	29 960	Silver oxide and zinc air cells.
Laptops	1 230	7 220	Lithium ion batteries and lithium primary (CMOS[1]) cells.
Mobile phones	610	12 240	Lithium ion batteries.
Remote controls	40	1 820	Alkaline batteries.
Tablets	370	2 960	Lithium ion batteries.
Watches and calculators	50	19 000	Lithium primary and alkaline batteries.
Other consumer electronic devices	90	6 610	Mostly nickel metal hydride and lithium primary batteries.
Totals	**9 650**	**311 630**	-

1. Complementary metal oxide semiconductor (CMOS) cell for retaining computer system settings in both desktop and laptop systems.

Figure 5 – Battery sales in 2017–18, by consumer electronics applications

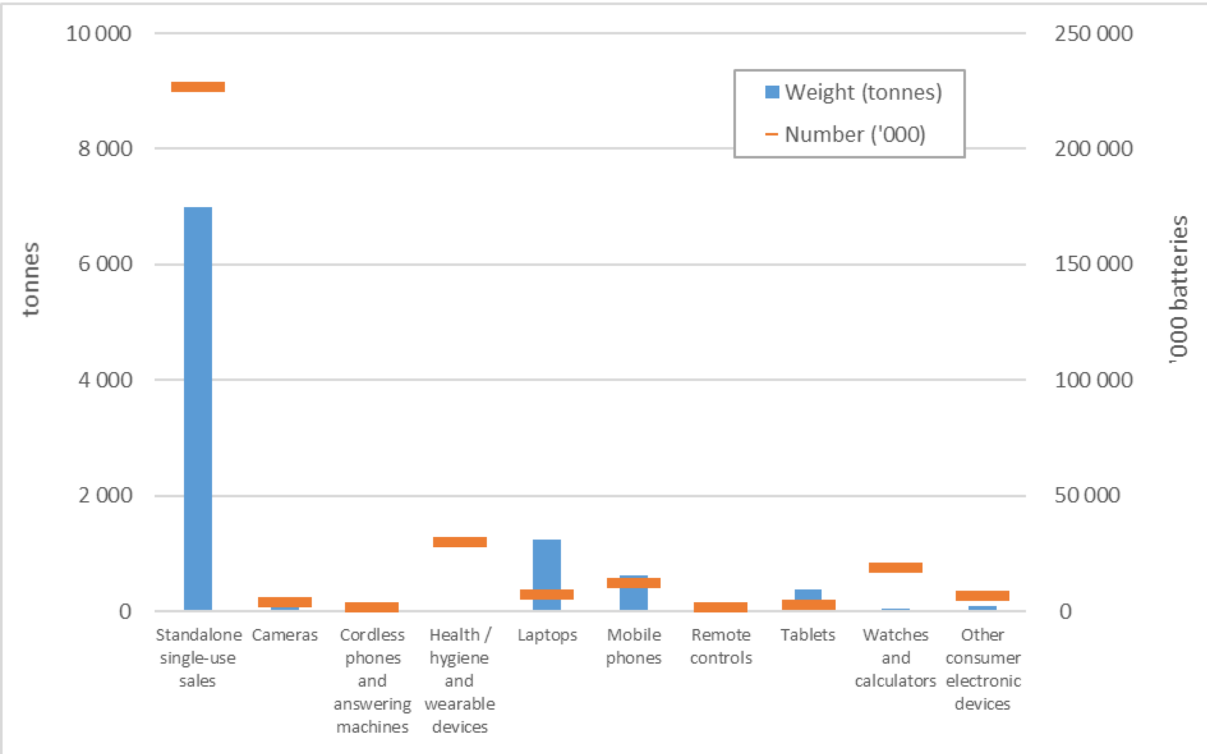
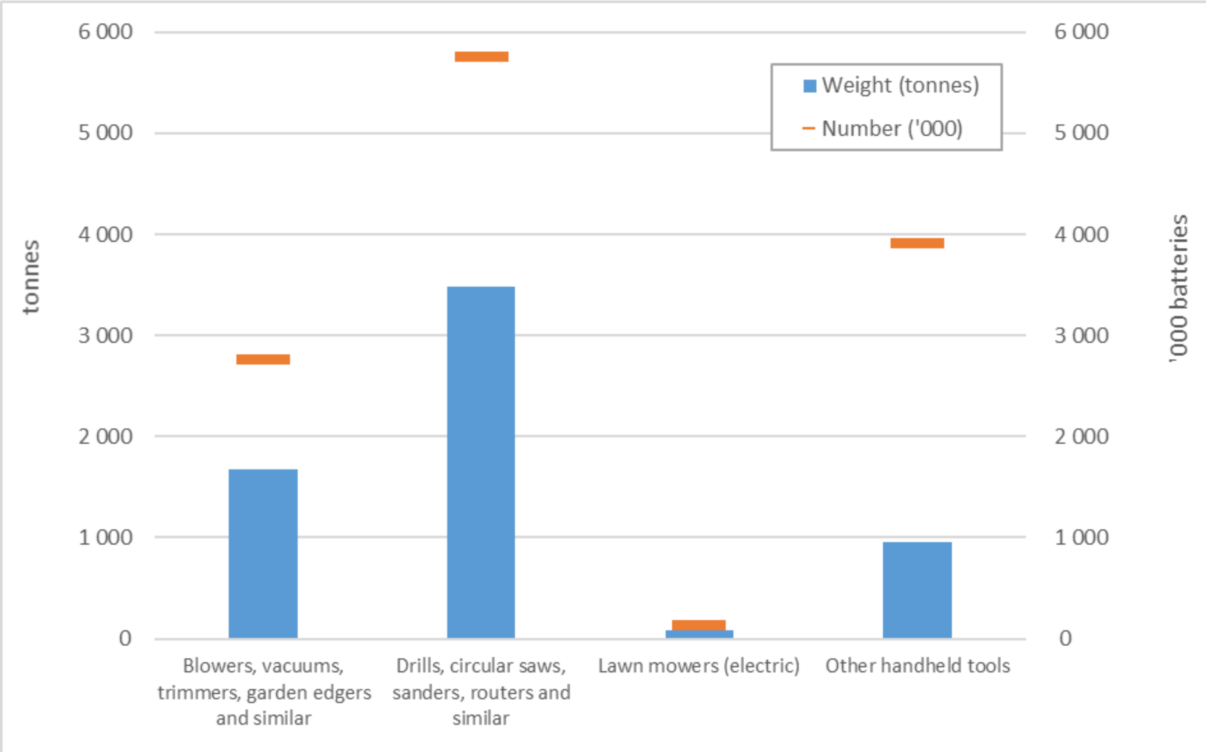


Table 5 – Battery sales in 2017–18, by Power tools & gardening equipment applications

Application area	Weight (tonnes)	Number ('000 batt.)	Comments
Blowers, vacuums, trimmers, garden edgers and similar	1 670	2 760	Lithium ion batteries.
Drills, circular saws, sanders, routers and similar	3 480	5 750	Lithium ion batteries.
Lawn mowers (electric)	80	140	Lithium ion batteries.
Other handheld tools	960	3 910	Lithium ion batteries.
Totals	**6 200**	**12 560**	-

Figure 6 – Battery sales in 2017–18, by Power tools & gardening equipment applications



3.3 SALES BY CHEMISTRY GROUP

Presented in Table 6 and Figure 7 are summary estimates of battery sales in 2017–18 by chemistry group on both a weight and number basis.

Sales of all batteries in Australia during the 2017–18 financial year are estimated at a nearly 182 000 tonnes or 428 million individual batteries or cells.

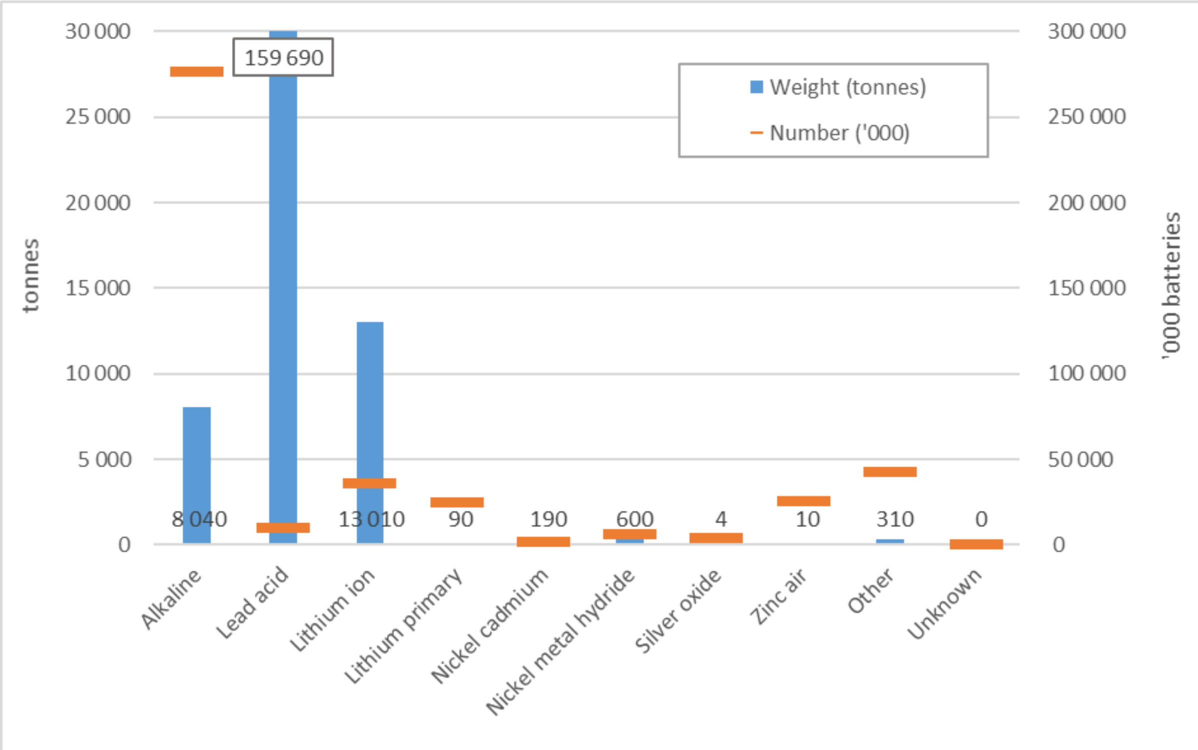
Of the total weight of batteries sold onto the market, 160 000 tonnes were lead acid chemistries (88%), of which more than 97% were batteries weighing 5 kg or more. The remaining 12% of batteries sold by weight were primarily lithium ion chemistries at 7% of sales, and the alkaline group at 4% (includes alkaline, zinc carbon and zinc chloride batteries).

Table 6 – Battery sales in 2017–18, by chemistry group

Battery chemistry	Weight (tonnes)	Number ('000 batteries)
Alkaline	8 040	276 600
Lead acid	159 690	10 160
Lithium ion	13 010	35 830
Lithium primary	90	24 480
Nickel cadmium	190	2 140
Nickel metal hydride	600	6 320
Silver oxide	4	4 050
Zinc air	10	25 910
Other	310	42 520
Totals	**181 960**	**428 000**

Of the 428 million batteries or cells sold onto the market in 2017–18 nearly 277 million (65%) were in the alkaline group across formats such as AA, AAA and button cells. The remaining 35% of batteries sold by number were primarily lithium ion chemistries of nearly 36 million batteries (8%), zinc air button cells of nearly 26 million cells (6%), and lithium primary cells (i.e. single-use button cells) of 24 million cells (6%).

Figure 7 – Battery sales in 2017–18, by chemistry group



Analysis of battery sales by chemistry shows that the alkaline and zinc carbon batteries are dominant in units but far less dominant by weight. Lead acid and lithium ion are linked to larger battery applications and therefore have a more significant share of battery sales by weight.

3.4 SALES BY WEIGHT RANGE

Presented in Table 7 and Figure 8 are summary estimates of battery sales in 2017–18 on a unit weight range basis. Descriptions of the typical battery types that fall into each weight range are provided in Table 7, and refer to Appendix C for the average battery weights (g/battery) that have been adopted throughout the modelling undertaken for this study.

In Table 7 it is clear that the smaller battery sizes dominate sales in number, but the heavier battery sizes are much more significant in total weight, especially engine starting batteries in the weight range of >10–50 kg.

There were 170 million AA cells sold in 2017–18, which was 40% of all battery sales by number, but was only 2% of sales by weight. This was followed by button cells at 22% of sales by number (but only 0.1% of sales by weight), and AAA cells at 19% of sales by number (but only 0.5% of sales by weight).

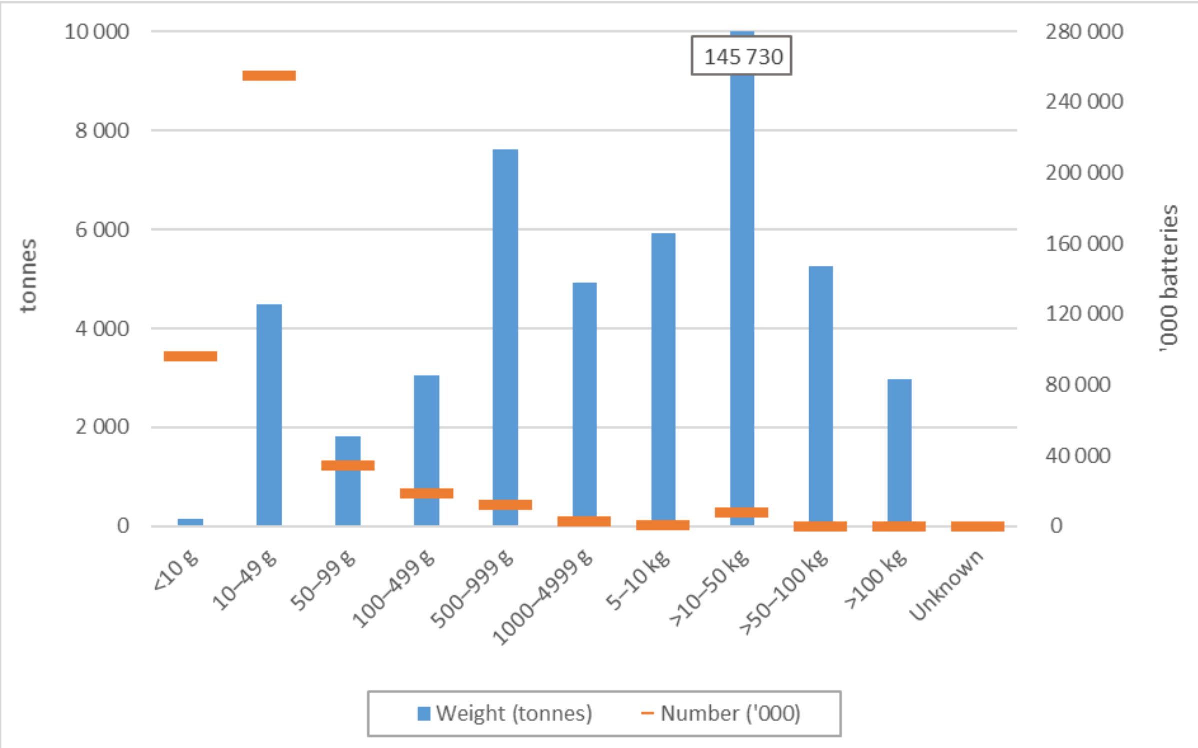
Batteries in the weight range of >10–50 kg, which are almost entirely lead acid batteries, were 2% of sales by number but 80% of sales by weight.

Table 7 – Battery sales in 2017–18, by weight range

Weight range (per battery)	Typical battery types	Weight (tonnes)	Number ('000)
<10 g	Buttons cell	150	95 990
10–49 g	AA cell, AAA cell	4 480	255 390
50–99 g	C cell, 9V battery, mobile phone battery	1 830	34 460
100–499 g	D cell, laptop battery, tablet battery	3 130	18 630
500–999 g	6V lantern battery, power tool battery	7 620	12 300
1000–4999 g	General purpose SSLAB[1], EV bicycle lithium-ion battery	4 920	2 630
5–10 kg	General purpose SSLAB[1]	5 930	740
>10–50 kg	Automotive lead-acid battery	145 730	7 780
>50–100 kg	Industrial lead acid battery, Home BESS[2] battery	5 270	70
>100 kg	Industrial lead acid battery, EV battery system	2 980	10
Totals		**181 960**	**428 000**

1. Small sealed lead-acid battery.
2. Battery energy storage system.

Figure 8 – Battery sales in 2017–18, by weight range



Presented in Table 8 and Figure 9 are 2017–18 battery sales by chemistry group and weight range. Note that Figure 9 only presents battery sales for when the battery weight is <5 kg.

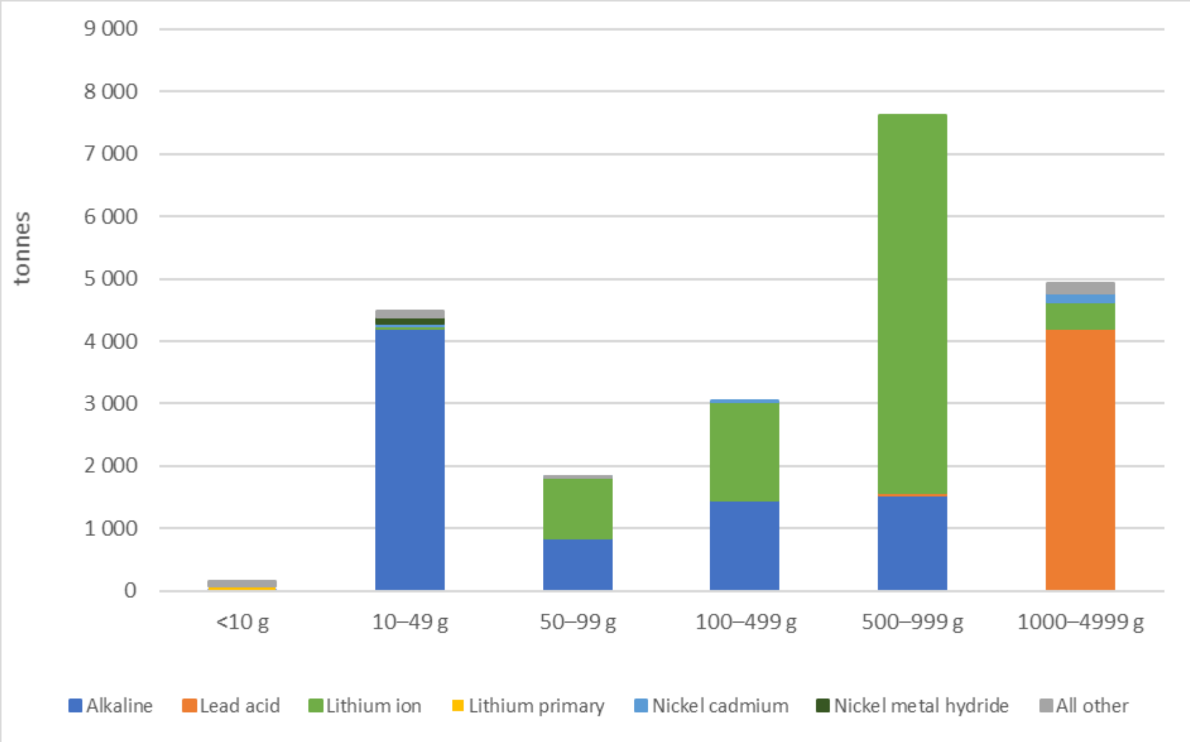
In the weight ranges that are less than 5 kg, there were 9 050 tonnes of lithium ion battery sales (41% of <5 kg sales), 8 040 tonnes of alkaline battery sales (36% of <5 kg sales), and 4 230 tonnes of lead acid battery sales (19% of <5 kg sales).

Table 8 – Battery sales in 2017–18, by chemistry group and weight range

Weight range (per battery)	Typical battery types	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
<10 g	Buttons cell	10	0	0	60	0	0	70	**150**
10–49 g	AA cell, AAA cell	4 200	0	20	20	30	110	90	**4 480**
50–99 g	C cell, 9V battery, mobile phone battery	840	0	970	0	10	0	10	**1 830**
100–499 g	D cell, laptop battery, tablet battery	1 450	0	1 590	0	10	0	0	**3 040**
500–999 g	6V lantern battery, power tool battery	1 540	30	6 050	0	0	0	0	**7 620**
1000–4999 g	General purpose SSLAB[1], EV bicycle lithium-ion battery	0	4 200	420	0	150	0	150	**4 920**
Total <5 kg		**8 040**	**4 230**	**9 050**	**90**	**190**	**110**	**330**	**22 050**
5–10 kg	General purpose SSLAB[1]	0	5 930	0	0	0	0	0	**5 930**
>10–50 kg	Automotive lead-acid battery	0	145 240	0	0	0	490	0	**145 730**
>50–100 kg	Industrial lead acid battery, Home BESS[2] battery	0	3 170	2 100	0	0	0	0	**5 270**
>100 kg	Industrial lead acid battery, EV battery system	0	1 120	1 860	0	0	0	0	**2 980**
Total ≥5 kg		0	155 460	3 950	0	0	490	0	**159 900**
Total		**8 040**	**159 690**	**13 010**	**90**	**190**	**600**	**330**	**181 960**

1. Small sealed lead-acid battery.
2. Battery energy storage system.

Figure 9 – Battery sales in 2017–18, by chemistry group and weight range (<5 kg only)



3.5 SALES BY SINGLE-USE OR RECHARGEABLE TYPE

In Table 9 and Table 10 the sales of batteries are presented by single-use and rechargeable battery chemistry respectively.

Rechargeable batteries make up nearly 97% of all batteries sold in 2017–18 by weight, with single-use batteries making up the other 3%. However, if lead acid batteries are excluded there were 8 460 tonnes of single-use battery sales in 2017–18 (38% by weight) and 13 800 tonnes of rechargeable battery sales (62% by weight). 95% of single-use batteries were alkaline chemistries by weight, and 94% of rechargeable batteries (excluding lead acid) were lithium ion chemistries.

The increased sales in products utilising rechargeable batteries has been a transitional market feature for many years. In addition, rechargeable batteries are also increasing market share in smaller battery sizes, such as AA and AAA nickel metal hydride battery sales. These trends are expected to continue into the future.

Table 9 – Single-use battery sales in 2017–18, by chemistry and application area

Application area	Alkaline (tonnes)	Lithium primary (tonnes)	Silver oxide (tonnes)	Zinc air (tonnes)	Other (tonnes)	Total (tonnes)
Consumer electronics	7 010	90	4	14	0	**7 110**
Torches/lanterns	480	0	0	0	0	**480**
Power tools & gardening equipment	0	0	0	0	0	**0**
Toys	560	0	0	0	0	**560**
Personal mobility	0	0	0	0	0	**0**
Storage, emergency & standby	0	0	0	0	0	**0**
Vehicles	0	0	0	0	0	**0**
Other application area	0	0	0	0	0	**0**
Unknown	0	0	0	0	310	**310**
Total	**8 040**	**90**	**4**	**14**	**310**	**8 460**

Table 10 – Rechargeable battery sales in 2017–18, by chemistry and application area

Application area	Lead acid (tonnes)	Lithium ion (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	Total (tonnes)
Consumer electronics	0	2 430	0	110	**2 540**
Torches/lanterns	0	0	0	0	**0**
Power tools & gardening equipment	0	6 200	0	0	**6 200**
Toys	200	220	0	0	**420**
Personal mobility	680	200	0	0	**880**
Storage, emergency & standby	32 450	3 450	190	0	**36 090**
Vehicles	124 470	500	0	490	**125 460**
Other application area	1 900	0	0	0	**1 900**
Unknown	0	0	0	0	**0**
Total	**159 690**	**13 010**	**190**	**600**	**173 490**

3.6 SALES BY LEVEL OF INTEGRATION IN PRODUCTS

While batteries almost always operate as part of electrical and electronic equipment (EEE), they have differing levels of integration into the product. This ranges from standalone batteries that are commonly sold separately and are designed for easy replacement by consumers (e.g. single-use AA cells), through to batteries that are embedded within EEE and are not designed to be replaced by consumers (e.g. lithium ion batteries in many laptops and mobile phones).

The level of integration of battery sales has been analysed using the following categories in this study:

- Batteries sold separately – Standalone batteries that are commonly sold separately and are designed for easy replacement by consumers – Examples include car batteries, alkaline AA and AAA cells, and button cells.
- Easily removable batteries (user separable) for sale as part of an E&E product – Examples include power tools, some laptops and mobile phones (particularly older models), and most torches with an integrated battery.
- Embedded batteries (not user separable) for sale as part of an E&E product – Examples include many laptops and mobile phones (particularly newer models), and tablets.

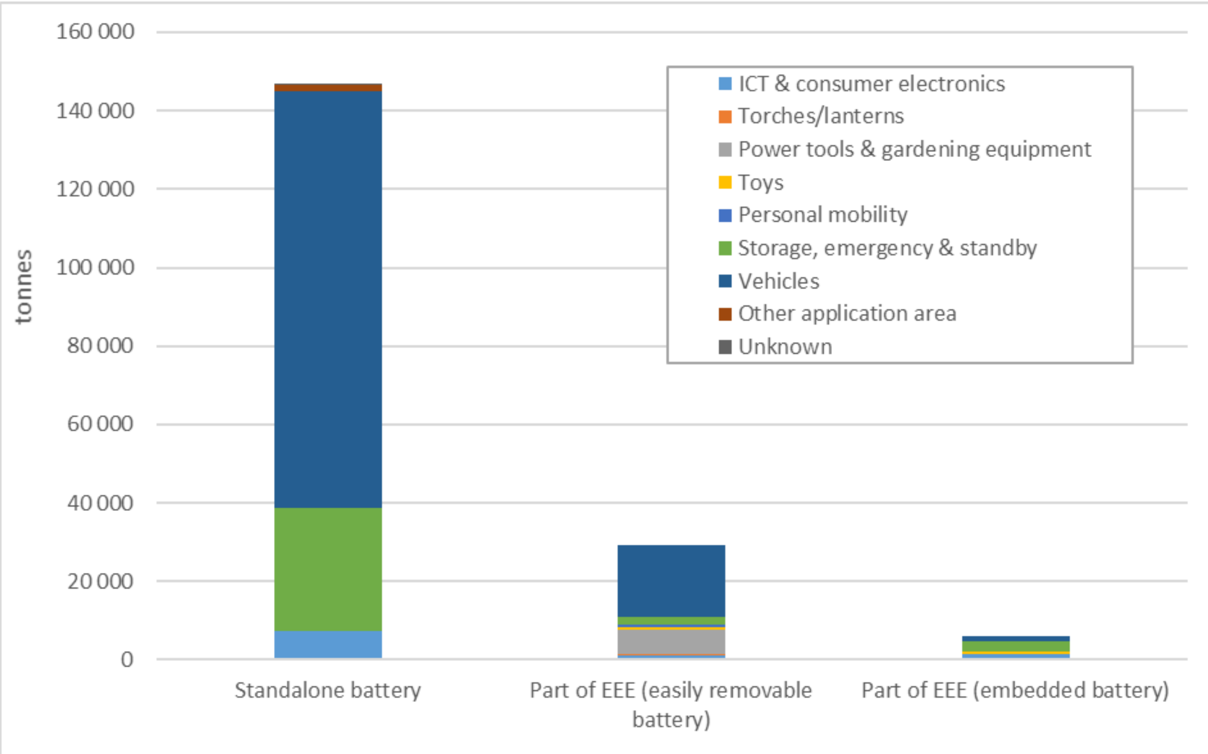
In Table 11 and Figure 10 the sales of batteries are presented by the level of integration into products. Standalone battery sales dominated in terms both weight and number of battery sales, followed by batteries that are part of EEE but are easily removed (e.g. power tool batteries).

Embedded batteries are only a small proportion of total battery sales, however, this category is growing in a number of applications such as mobile phones and laptops.

Table 11 – Battery sales in 2017–18, by level of integration

Application area	Level of integration			
	Standalone battery	Part of EEE (easily removable)	Part of EEE (embedded)	Total
	(tonnes)	(tonnes)	(tonnes)	(tonnes)
Consumer electronics	7 200	1 000	1 500	**9 700**
Torches/lanterns	0	500	0	**500**
Power tools & gardening equipment	0	6 100	100	**6 200**
Toys	0	600	400	**1 000**
Personal mobility	0	900	0	**900**
Storage, emergency & standby	31 500	1 700	2 900	**36 100**
Vehicles	106 100	18 400	1 000	**125 500**
Other application area	1 900	0	0	**1 900**
Unknown	300	0	0	**300**
Totals	**146 900**	**29 100**	**6 000**	**182 000**

Figure 10 – Battery sales in 2017–18, by level of integration



3.7 SALES BY END-USER TYPE

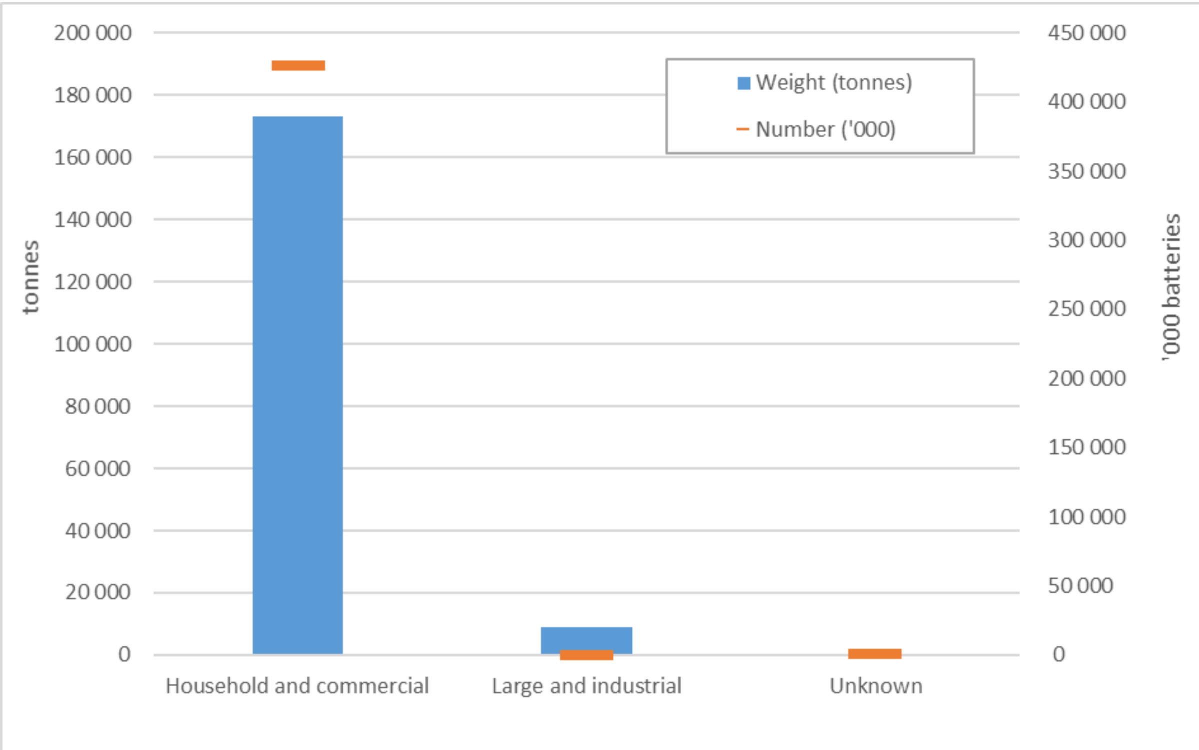
In Table 12 and Figure 11 the sales of batteries are presented in terms of the typical end-users for each battery type, categorised into household & commercial, and large & industrial end-user types.

Household and commercial destinations make up nearly 94% of battery use, and nearly 100% of battery use by number, reflecting the very large format batteries that can be used in industrial settings.

Table 12 – Battery sales in 2017–18, by end-user type

End-user type	Weight (tonnes)	Number ('000)
Household and commercial	173 010	426 820
Large and industrial	8 790	290
Unknown	0	0
Totals	**150**	**880**

Figure 11 – Battery sales in 2017–18, by end-user type



3.8 SALES BY JURISDICTION

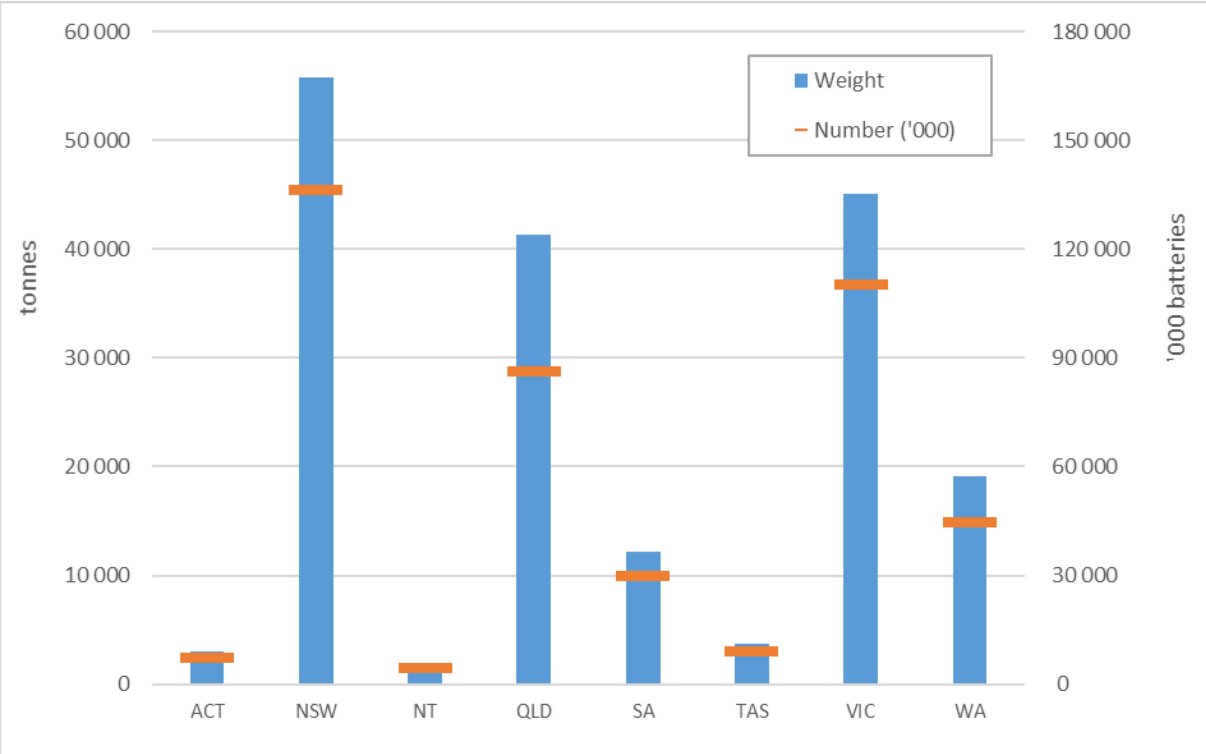
Presented in Table 13 and Figure 12 are estimated battery sales by state and territory. Brand-owner and retailer reported sales of batteries at the jurisdictional level have been combined with Customs import data estimates to derive these values. Where Customs import data has been adopted, the jurisdictional level sales are based on per capita consumption splits.

Table 13 – Battery sales in 2017–18, by jurisdiction

Jurisdiction	Single-use		Rechargeable		Total	
	(tonnes)	('000)[1]	(tonnes)	('000)[1]	(tonnes)	('000)[1]
ACT	140	6 300	2 870	920	3 020	7 220
NSW	2 700	119 170	53 040	17 280	55 740	136 450
NT	80	3 730	1 820	540	1 900	4 280
QLD	1 700	75 130	39 600	11 200	41 300	86 330
SA	590	26 010	11 550	3 760	12 130	29 770
TAS	180	7 910	3 480	1 140	3 660	9 050
VIC	2 180	96 380	42 850	13 930	45 040	110 310
WA	880	38 920	18 280	5 680	19 160	44 590
Totals	**8 460**	**373 560**	**173 490**	**54 440**	**181 960**	**428 000**

1. Sales by number of batteries or cells (in thousands).

Figure 12 – Battery sales in 2017–18, by jurisdiction

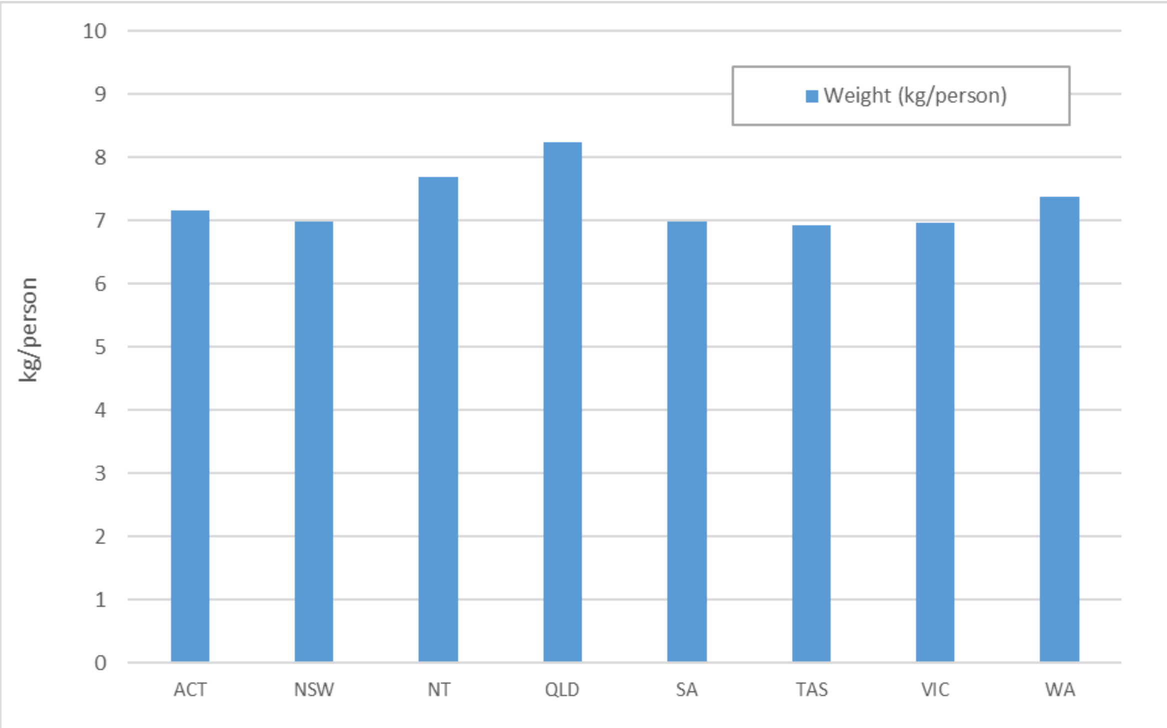


Presented in Table 14 and Figure 13 are per capita battery sales by jurisdiction. Consumption of batteries is relatively high in Queensland, which is primarily driven by higher sales of lead acid batteries. The reason for higher consumption in Queensland is reportedly due to temperature. Higher average temperatures decrease the lifespan of lead-acid batteries through an increased rate of sulphating. Lead acid batteries that last three years in Victoria may only last 2.0–2.5 years in hot and humid climates.

Table 14 – Battery per capita sales in 2017–18, by jurisdiction

Jurisdiction	Weight (kg/person)	Number (batteries/person)
ACT	7.2	17.2
NSW	7.0	17.1
NT	7.7	17.3
QLD	8.2	17.2
SA	7.0	17.1
TAS	6.9	17.1
VIC	7.0	17.1
WA	7.4	17.2
Australia	**7.2**	**17.1**

Figure 13 – Battery per capita sales in 2017–18, by jurisdiction



3.9 MAJOR BRAND-OWNERS AND DISTRIBUTORS

Provided in this section of the report is a summary of major Australian battery brand-owners and major local distributors by product application area.

The Australian battery market is highly diverse across many different applications and chemistries. However, the companies identified in the table below are anticipated to be responsible for 95% or more of battery sales by weight into the Australian market.

Table 15 – Current major brand-owners and distributors – by product application area

Application area	Single-use batteries & NiMH[1]	Rechargeable batteries
Consumer electronics	Energizer (Energizer/Eveready/Varta) Duracell Company (Berkshire Hathaway Group) IKEA Panasonic (Panasonic) Woolworths (Essentials) Coles (Coles) ALDI (Ultracell/Activ Energy) Metcash (IGA Signature/Black and Gold) Fuji (Fuji) Battery World (Battery World) Others: Sony, Maxell, Rocket, Toshiba, Philips, GP and Kodak.	Acer Apple Asus Canon Dell Dyson Hewlett Packard Kogan Lenovo LG Electronics Motorola Nokia Panasonic Samsung Sony Toshiba Others: Google, HTC, Fujitsu, Huawei Technologies, Mitsubishi, NEC, Nikon, Olympus, Uniden.
Torches/lanterns	Arlec Cat Eye Coleman Duracell Energizer (Energizer/Eveready/Dolphin) LED Lenser Maglite Panasonic Primus Spinifex Tactical Tioga Varta Wild Country Other: BBB, Blackburn, Blackfire, Coast, Cryo-Lite, Dune, Knog, Lezyne, Meteor, Moon, Planet Bike, and many other torch/lantern brand-names.	Arlec Cat Eye Coleman LED Lenser Primus Spinifex Varta Wild Country Other: Cryo-Lite, Knog, Lezyne, Moon, Planet Bike, and many other torch/lantern brand-names.
Power tools & gardening equipment	N/A	Black & Decker Bosch DeWALT Hitachi Makita Ozito Panasonic Positec (Rockwell, Worx)

Application area	Single-use batteries & NiMH[1]	Rechargeable batteries
		Techtronic Industries / TTI (Milwaukee/AEG/Ryobi/Homelite) Tooltechnic Systems (Australia) Pty Ltd (Festool/Fein) Others: Wesco, Stihl, Husqvarna Group (Gardena), Briggs and Stratton (Victa), Ramset.
Toys		Insufficient information (many brand-owners, distributors and brands)
Personal mobility	N/A	Century Yuasa Batteries (Century/Yuasa) Federal Batteries (Federal) Marshall Batteries (Exide) MPower (Sonnenschein /Powerblock) Premier Batteries (Premier) Ramcar (Supercharge and Motolite Batteries.
Storage, emergency & standby (including BESSs)	N/A	Alpha Ampetus Aquion Battery Specialties Australia (Sonnenschein/ Power-Sonic/CYB/SAFT/Eaton UPS) BYD CALB Century Yuasa Batteries (Century/Yuasa) Clevertronics (Clevertronics) EcoUlt Enersys (PowerSafe/Genesis/Cyclon/Datasafe) Enphase Federal Batteries (Federal) GNB Sonnenschein Kokam LG Chem Marshall Batteries (Exide) MPower (Sonnenschein /Powerblock) Premier Batteries (Premier) R&J Batteries (Fullriver) Ramcar (Supercharge and Motolite Batteries. Redflow. Samsung. SimpliPhi. Sony. YHI Power (CSB/Vision/C&D/Neuton Power).
Vehicles	N/A	Audi Battery Specialties Australia (Sonnenschein/ Power-Sonic/CYB/SAFT/Eaton UPS) Century Yuasa Batteries (Century/Yuasa) BMW Federal Batteries (Federal) Fonzarelli Hyundai Jaguar Kai Marshall Batteries (Exide) Mercedes Mitsubishi MG

Application area	Single-use batteries & NiMH[1]	Rechargeable batteries
		MPower (Sonnenschein /Powerblock) Nissan Polestar Premier Batteries (Premier) R&J Batteries (Fullriver) Ramcar (Supercharge) Tesla YHI Power (CSB/Vision/C&D/Neuton Power) Toyota

Note: brand-names in brackets as required

1. Rechargeable nickel metal hydride AA and AAA cells only.

4 BATTERY FLOWS TO 2049–50

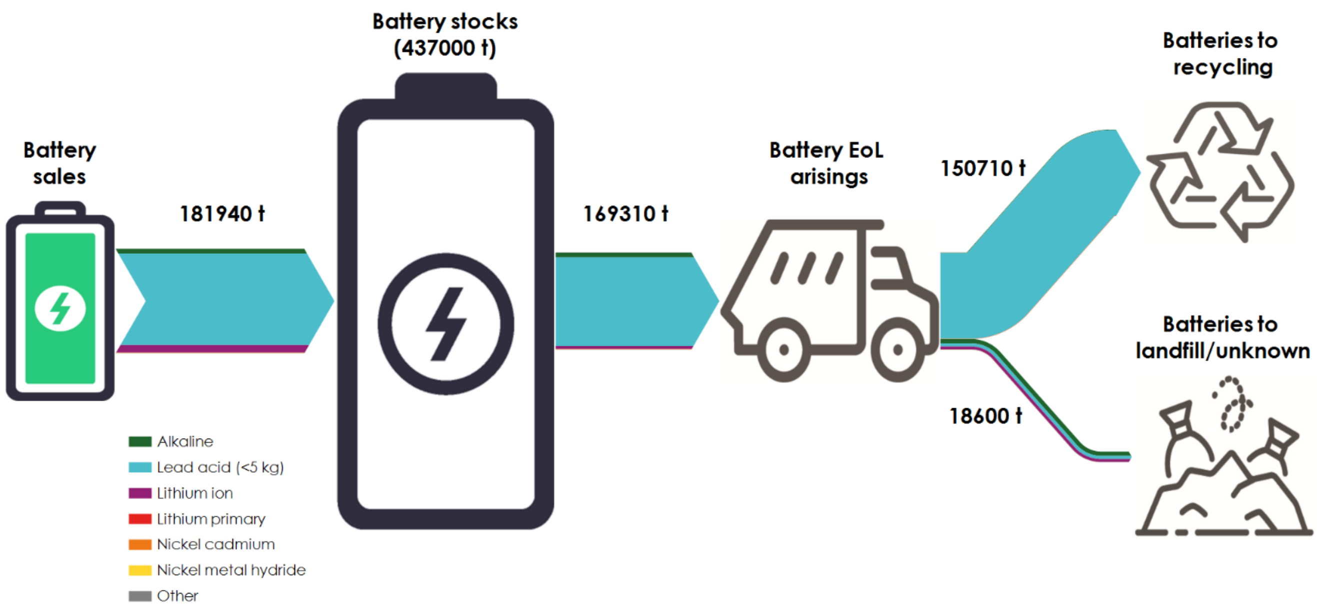
This section of the report presents estimated historical and projected sales, stocks and end-of-life (EoL) battery arisings across the period of 2012–13 to 2049–50.

Provided in Figure 14 is an overview of battery flows across sales, stocks, EoL arisings and fates in 2017–18.

There were 182 000 tonnes batteries sold onto the market, with stocks of batteries in use totalling 437 000 tonnes. It is estimated that during 2017–18 169 000 tonnes of batteries were disposed of, and of these 151 000 tonnes were collected for reprocessing, giving a collection rate across all batteries of 89%.

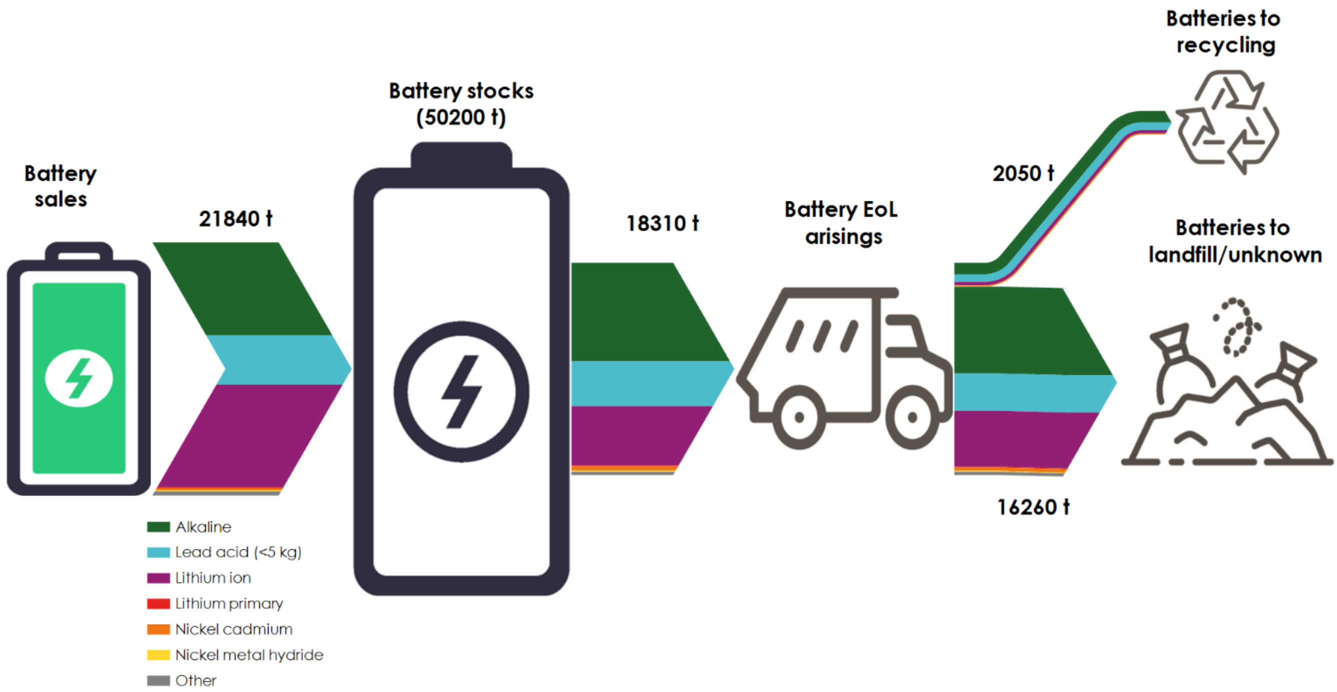
Most of remaining 18 600 tonnes of batteries reaching EoL were probably sent to landfill. This 18 600 tonnes largely consists of handheld (<5 kg) batteries with non-lead acid chemistries, and is the focus of Figure 15.

Figure 14 – Battery flows in 2017–18 by chemistry group



Provided in Figure 15 is an overview of battery flows across sales, stocks, EoL arisings and fates in 2017–18 for handheld (<5 kg) batteries only. With larger lead acid batteries removed the picture is very different, and a collection rate of only 11% was achieved in 2017–18.

Figure 15 – Handheld (<5 kg) battery flows in 2017–18 by chemistry group



Across the rest of this section of the report battery sales, stocks and EoL arisings are assessed in detail across the period of 2012–13 to 2049–50.

4.1 BATTERY SALES

4.1.1 Sales by market segment

Presented in Figure 16 are estimates of battery sales by market segment across the period of 2012–13 to 2049–50. Very significant growth in sales of BESS & EV batteries is currently projected out to 2049–50.

Figure 16 – Battery sales to 2049–50, by market segment

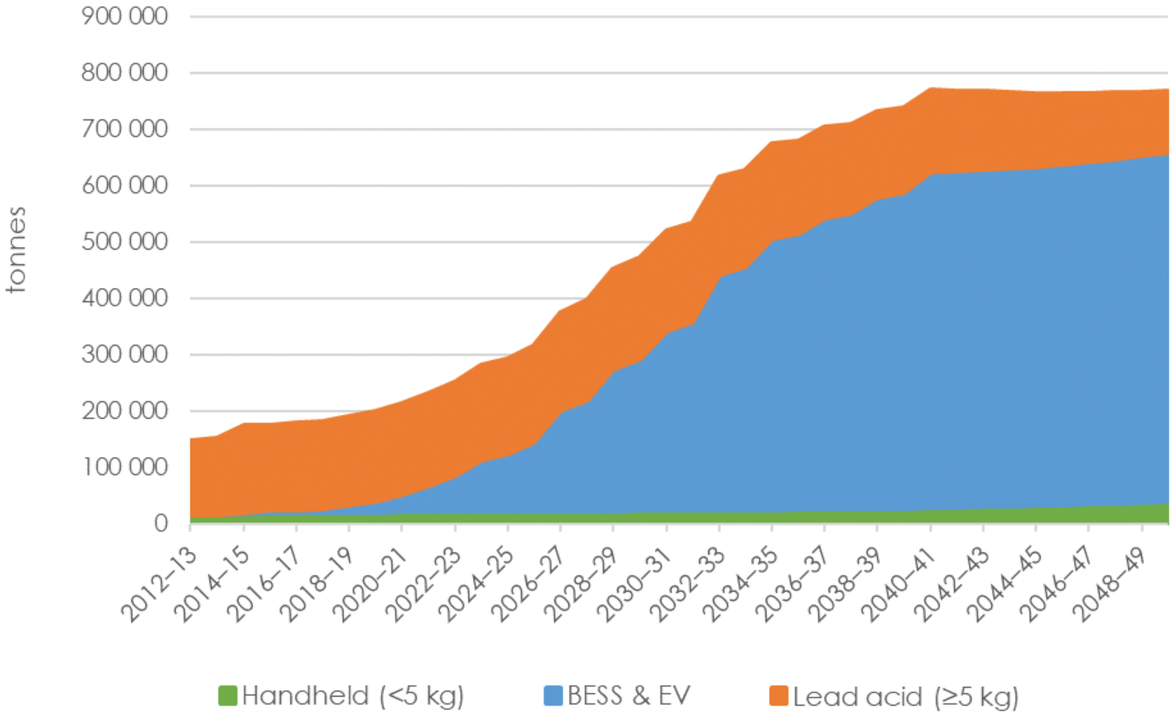


Table 16 – Battery sales to 2049–50, by market segment

Year	Handheld (<5 kg) (tonnes)	BESS & EV (tonnes)	Lead acid (≥5 kg) (tonnes)	Total (tonnes
2014–15	18 170	2 360	155 930	**176 460**
2019–20	22 300	19 550	158 410	**200 260**
2024–25	23 230	101 120	169 990	**294 340**
2029–30	24 270	269 760	179 190	**473 220**
2034–35	25 210	480 530	166 830	**672 570**
2039–40	26 220	559 820	149 430	**735 460**
2044–45	27 300	601 130	128 820	**757 250**
2049–50	28 490	616 350	108 210	**753 050**

1. Storage, emergency & standby

By the end of the 2029–30 financial year, sales of lithium ion batteries are projected to have grown significantly to 280 000 tonnes. These sales will be primarily into BESS & EV applications.

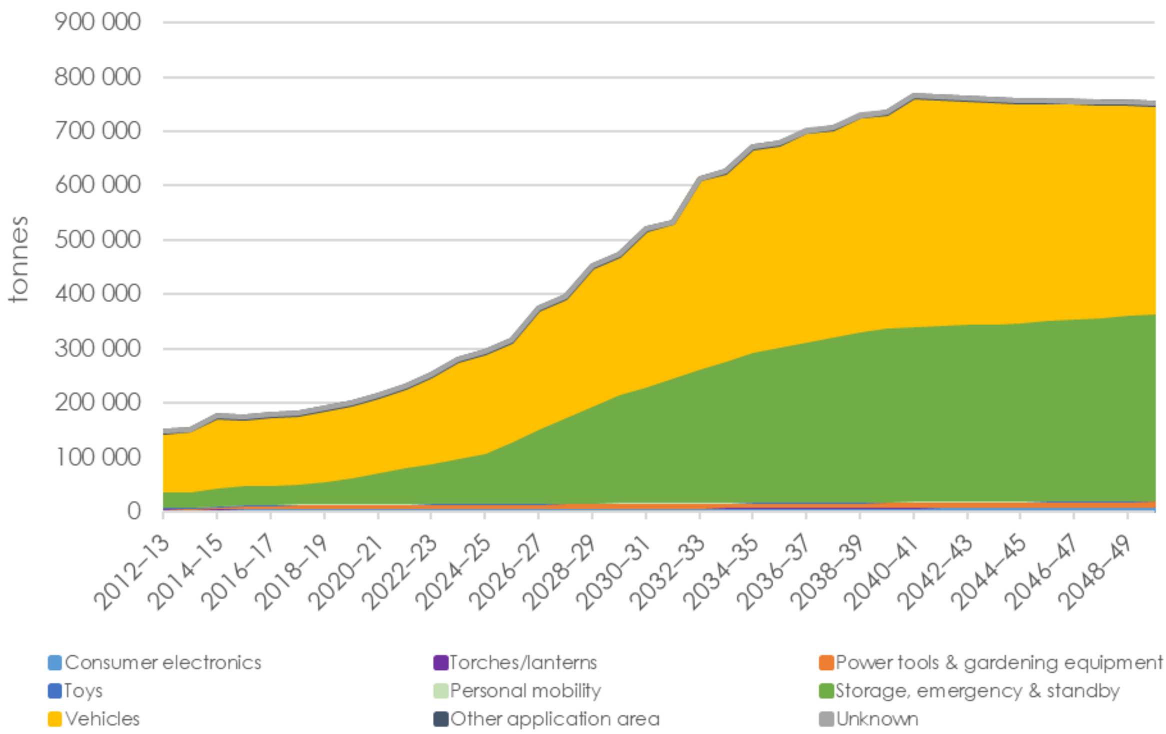
It is assumed in the modelling that lithium chemistries remain the technology of choice into BESS & EV applications. If any alternative energy storage systems do take significant market share from the lithium chemistries, they may reduce the weight of batteries sold into the market.

4.1.2 Sales by application area

In Figure 17 and Table 17 are presented projected battery sales by application area across the period of 2012–13 to 2049–50. This data includes batteries <5 kg and ≥5 kg.

Battery use in vehicles and BESSs is projected to undergo significant growth out to 2050. This growth is anticipated to almost entirely be rechargeable lithium chemistries, which will also start to significantly reduce demand for lead acid engine starting batteries from the late 2020s.

Figure 17 – Battery sales to 2049–50, by application area



Due to the large differences in the scales of battery sales into different application areas, some application areas are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery sales at the application area level.

Table 17 – Battery sales to 2049–50, by application area

Year	Consumer electronics (tonnes)	Torches /lanterns (tonnes)	Power tools (tonnes)	Toys (tonnes)	Personal mobility (tonnes)	SES[1] (tonnes)	Vehicles (tonnes)	Other / unknown (tonnes)	Total (tonnes
2014–15	8 470	470	3 660	880	810	33 270	126 720	2 180	**176 460**
2019–20	9 850	480	6 420	980	900	47 100	132 340	2 180	**200 260**
2024–25	10 100	480	7 020	1 000	960	92 400	180 170	2 200	**294 340**
2029–30	10 360	480	7 710	1 020	1 040	198 840	251 540	2 230	**473 220**
2034–35	10 650	480	8 370	1 050	1 070	274 880	373 820	2 250	**672 570**
2039–40	10 960	480	9 080	1 070	1 100	320 500	389 980	2 280	**735 460**
2044–45	11 300	480	9 860	1 100	1 140	328 110	402 950	2 310	**757 250**
2049–50	11 680	480	10 700	1 130	1 180	343 320	382 230	2 340	**753 050**

1. Storage, emergency & standby

In Table 18 are presented projected battery sales by application area on an equivalent battery unit (EBU) basis across the period of 2014–15 to 2049–50 for all batteries excluding lead acid batteries.

Table 18 – Battery sales to 2049–50, by application area (excluding lead acid) – EBU basis

Year	Consumer electronics (million EBUs)	Torches /lanterns (million EBUs)	Power tools (million EBUs)	Toys (million EBUs)	Personal mobility (million EBUs)	SES[1] (million EBUs)	Vehicles (million EBUs)	Other / unknown (million EBUs)	Total (million EBUs)
2014–15	353	20	153	28	5	14	17	0	**590**
2019–20	410	20	268	33	9	643	129	0	**1 512**
2024–25	421	20	293	33	12	2 544	1 638	0	**4 960**
2029–30	432	20	321	34	15	6 980	4 226	0	**12 028**
2034–35	444	20	349	35	16	10 148	9 839	0	**20 851**
2039–40	457	20	378	36	18	12 049	11 240	0	**24 199**
2044–45	471	20	411	37	19	12 366	12 643	0	**25 967**
2049–50	486	20	446	39	21	13 000	12 642	0	**26 653**

4.1.3 Sales by chemistry group

Presented in Figure 18 are estimates of battery sales by chemistry group across the period of 2012–13 to 2049–50 by weight.

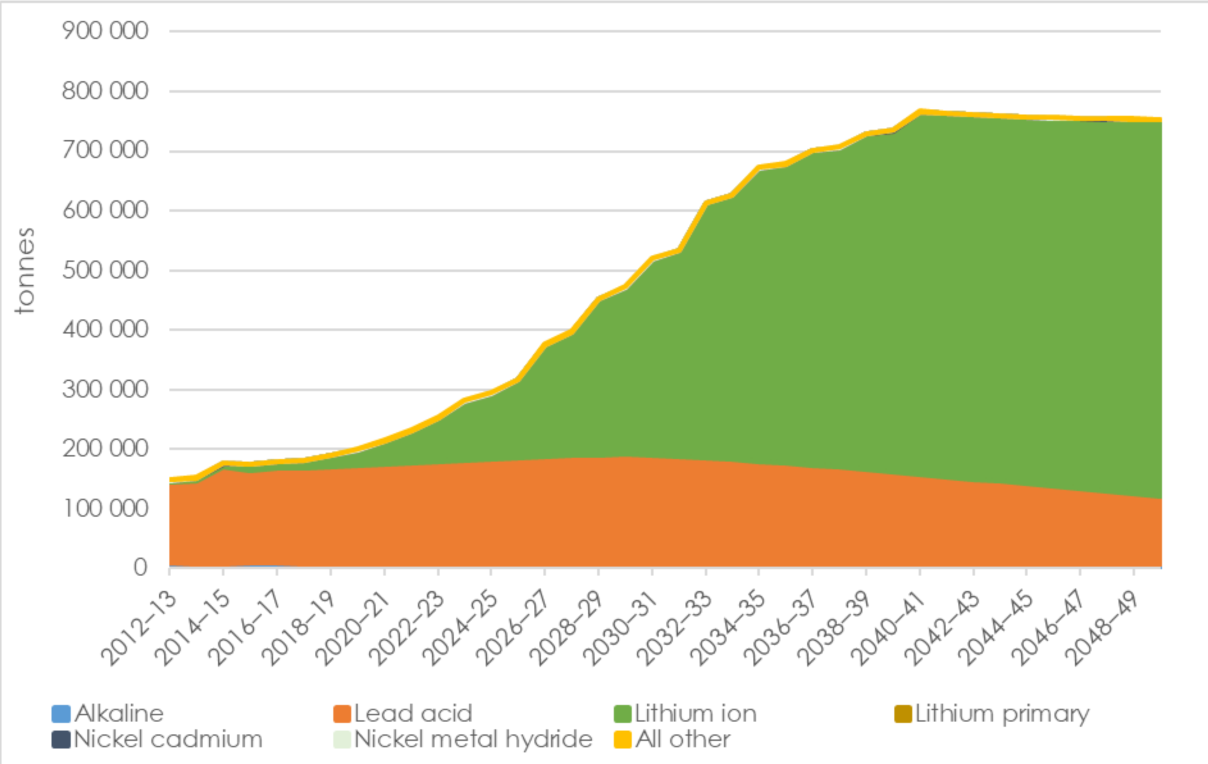
In 2019–20 lead acid batteries sales into all applications are estimated to be 164 000 tonnes of batteries nationally, which is 82% of all batteries. This is followed by lithium ion sales of nearly 27 000 tonnes or 13% of all batteries.

By the end of the 2029–30 financial year sales of lithium ion batteries is projected to have grown very significantly to 280 000 tonnes. These sales will be primarily into vehicle and battery energy storage system (BESS) related applications.

Note that it is assumed that lithium chemistries remain the technology of choice into vehicle and BESS applications. If any alternative pre and early commercialisation energy storage systems do take significant market share from the lithium chemistries they may reduce the weight of batteries sold into the market.

By 2050 lithium ion battery sales are projected to be 630 000 tonnes/yr. Into the 2030s lithium ion will be taking significant market share from lead acid chemistries in vehicle related applications, with the anticipated well-advanced transition to battery electric vehicles (as electric vehicles do not require a lead acid battery).

Figure 18 – Battery sales to 2049–50, by chemistry group



Due to the large differences in the scales of battery sales into different chemistry groups, some chemistry groups are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery sales at the chemistry group level.

Table 19 – Battery sales to 2049–50, by chemistry group

Year	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
2014–15	7 900	162 050	5 650	110	340	140	260	**176 460**
2019–20	8 040	163 680	26 810	90	220	1 110	300	**200 260**
2024–25	8 040	174 990	109 900	100	220	760	320	**294 340**
2029–30	8 040	184 210	279 710	110	220	570	350	**473 220**
2034–35	8 040	171 790	491 540	120	220	470	380	**672 570**
2039–40	8 040	154 320	571 920	130	220	420	410	**735 460**
2044–45	8 040	133 630	614 370	140	220	400	440	**757 250**
2049–50	8 040	112 930	630 810	150	220	400	480	**753 050**

It is important to note that the current projections do not consider the impact of the introduction of self-driving autonomous electric vehicles used to deliver 'Transport as a service' (TaaS). The relative cost of private car ownership may be high relative to TaaS, and place downward pressure on passenger car sales generally.

In Table 20 are presented projected battery sales by chemistry group on an equivalent battery unit (EBU) basis across the period of 2014–15 to 2049–50 for all batteries, but excluding lead acid batteries.

Table 20 – Battery sales to 2049–50, by chemistry group (excluding lead acid) – EBU basis

Year	Alkaline (million EBUs)	Lithium ion (million EBUs)	Lithium primary (million EBUs)	Nickel cadmium (million EBUs)	Nickel metal hydride (million EBUs)	All other (million EBUs)	Total (million EBUs)
2014–15	329	235	5	14	6	11	**600**
2019–20	335	1 117	4	9	46	12	**1 524**
2024–25	335	4 579	4	9	32	13	**4 973**
2029–30	335	11 655	4	9	24	15	**12 042**
2034–35	335	20 481	5	9	20	16	**20 866**
2039–40	335	23 830	5	9	17	17	**24 214**
2044–45	335	25 599	6	9	17	18	**25 984**
2049–50	335	26 284	6	9	17	20	**26 671**

Lithium ion chemistries are anticipated to undergo moderate but steady growth for the foreseeable future in the main applications of laptops, mobile phones and power tools. Lithium chemistries have already effectively completely substituted for all other chemistries in these applications.

Alkaline batteries market growth is assumed to be flat for the foreseeable future due to ongoing competition by rechargeable chemistries, both in standalone battery sales (e.g. rechargeable nickel metal hydride sales in AA and AAA formats), and devices shifting to inbuilt rechargeable batteries (e.g. torches with lithium-ion batteries).

It is anticipated that there may be some further substitution for lead acid and nickel cadmium chemistries in applications such as motorcycle engine starting and smaller storage, emergency & standby applications (e.g. UPSs and emergency lighting), however, the quantities are reasonably small.

4.2 BATTERY STOCKS

4.2.1 Stocks by market segment

Battery stocks are the total of all batteries and cells that are in service (use) within the economy. The service period also includes allowances for consumer storage prior to disposal.

Presented in Figure 19 and Table 21 are projected battery stocks by market segment across the period of 2012–13 to 2049–50.

Figure 19 – Battery stocks to 2049–50, by market segment

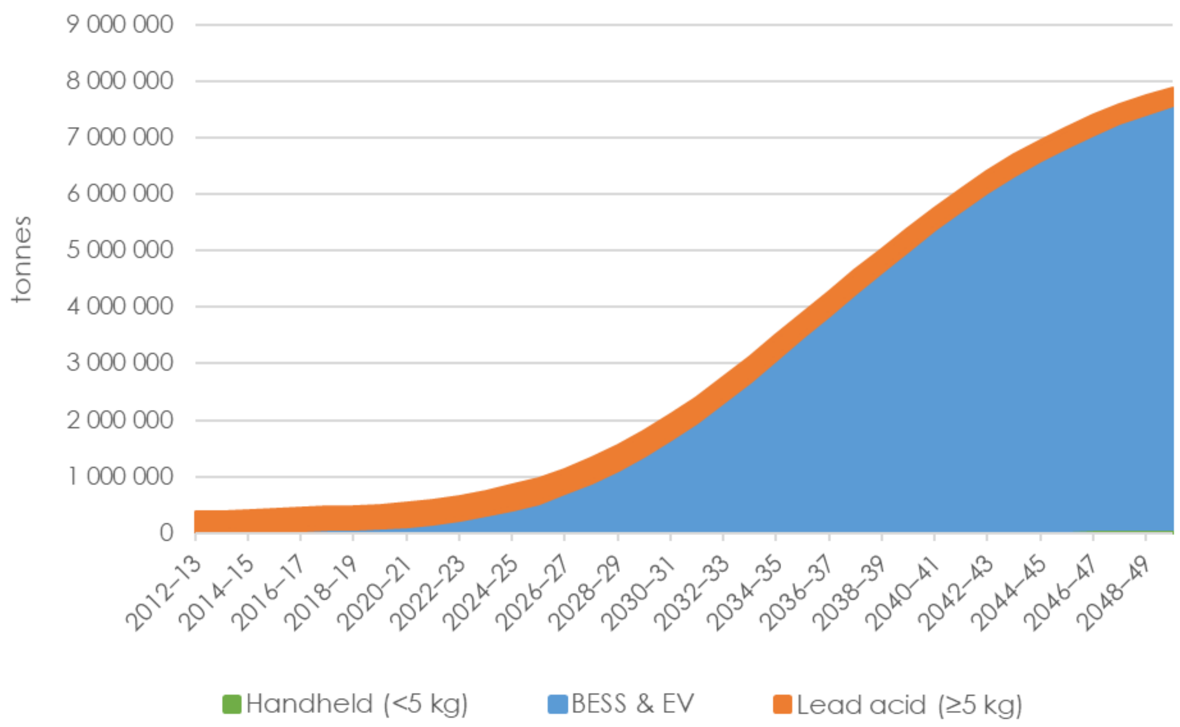


Table 21 – Battery stocks to 2049–50, by market segment

Year	Handheld (<5 kg) (tonnes)	BESS & EV (tonnes)	Lead acid (≥5 kg) (tonnes)	Total (tonnes
2014–15	38 240	12 470	337 210	**387 920**
2019–20	55 170	51 250	372 570	**478 990**
2024–25	59 500	366 750	396 470	**822 720**
2029–30	62 080	1 312 900	415 840	**1 790 820**
2034–35	64 970	3 021 890	398 090	**3 484 950**
2039–40	68 200	4 940 390	364 160	**5 372 750**
2044–45	71 710	6 542 920	323 650	**6 938 270**
2049–50	75 680	7 516 050	282 890	**7 874 620**

At the end of 2017–18 it is estimated that there was 440 000 tonnes of batteries in stocks across the economy. Of this 363 000 tonnes (83%) was in the lead acid (≥5 kg) segment, 50 000 tonnes (11%) in the handheld (<5 kg) segment and 24 000 tonnes (5%) in the BESS & EV segment.

By the end of the 2025–26 financial year, stocks of batteries in the BESS & EV segment are projected to have grown to nearly 0.5 million tonnes, surpassing lead acid (≥5 kg) segment stocks of 0.4 million tonnes.

By 2050, BESS & EV stocks are projected to be 7.5 million tonnes, with lead acid (≥5 kg) stocks falling slightly, to around 0.3 million.

4.2.2 Stocks by application area

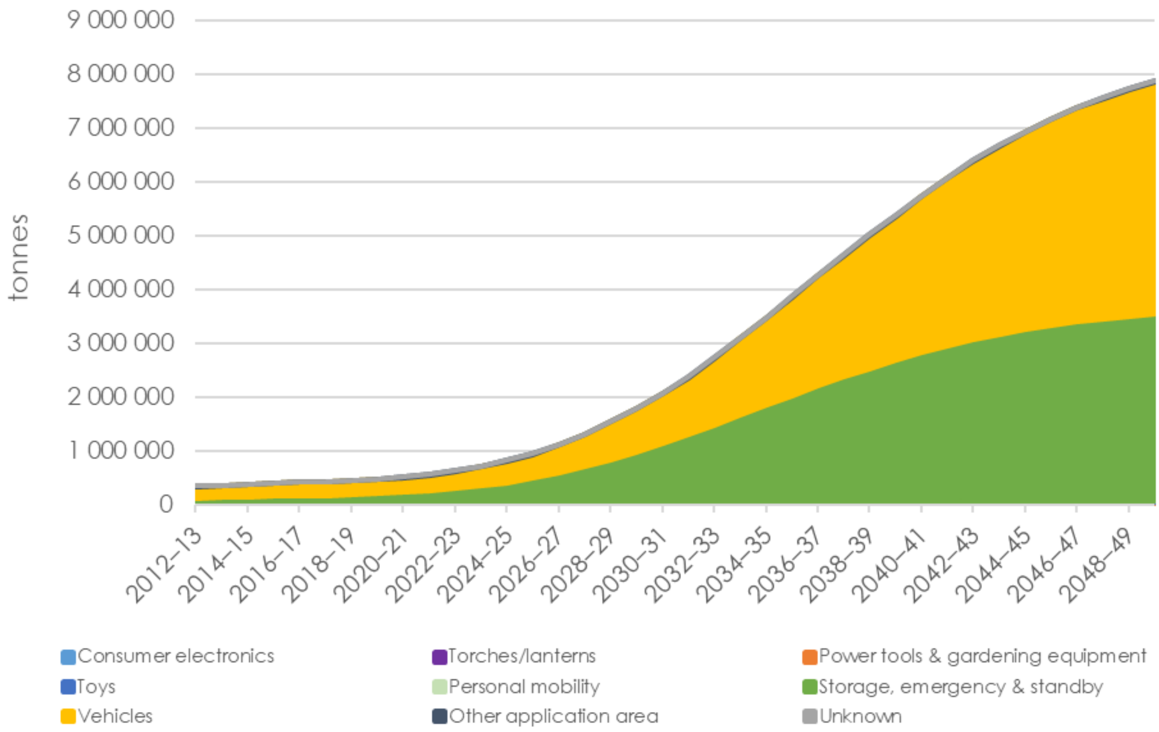
In Figure 20 and Table 22 are presented projected battery stocks (***all*** batteries in use or in storage prior to disposal) by application area across the period of 2012–13 to 2049–50.

At the end of 2019–20 it is estimated that there will be around 270 000 tonnes of batteries in vehicle related applications and nearly 170 000 tonnes of batteries in storage, emergency & standby related applications, which is 58% and 35% of all batteries in use respectively.

By the end of the 2029–30 financial year stocks of batteries in vehicle related applications are projected to have grown to around 0.8 million tonnes, with BESS related applications of more than 0.9 million tonnes.

By 2050 vehicle battery stocks are projected to be 4.3 million tonnes, with BESS related applications of 3.5 million tonnes.

Figure 20 – Battery stocks to 2049–50, by application area



Due to the large differences in the scales of battery stocks in different application areas, some application areas are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery stocks at the application area level.

Table 22 – Battery stocks to 2049–50, by application area

Year	Consumer electronics (tonnes)	Torches /lanterns (tonnes)	Power tools (tonnes)	Toys (tonnes)	Personal mobility (tonnes)	SES[1] (tonnes)	Vehicles (tonnes)	Other / unknown (tonnes)	Total (tonnes
2014–15	10 140	360	6 930	1 490	2 740	120 310	239 060	6 900	**387 920**
2019–20	17 270	370	14 990	2 160	3 580	165 680	267 170	7 780	**478 990**
2024–25	20 800	370	16 560	2 370	3 940	367 770	403 080	7 840	**822 720**
2029–30	22 280	370	18 170	2 470	4 280	937 360	798 050	7 860	**1 790 820**
2034–35	23 730	370	19 770	2 570	4 530	1 795 020	1 631 100	7 870	**3 484 950**
2039–40	25 300	370	21 450	2 690	4 690	2 631 910	2 678 440	7 890	**5 372 750**
2044–45	27 010	370	23 290	2 810	4 860	3 191 950	3 680 080	7 910	**6 938 270**
2049–50	28 930	370	25 320	2 950	5 040	3 493 370	4 310 680	7 950	**7 874 620**

1. Storage, emergency & standby

4.2.3 Stocks by chemistry group

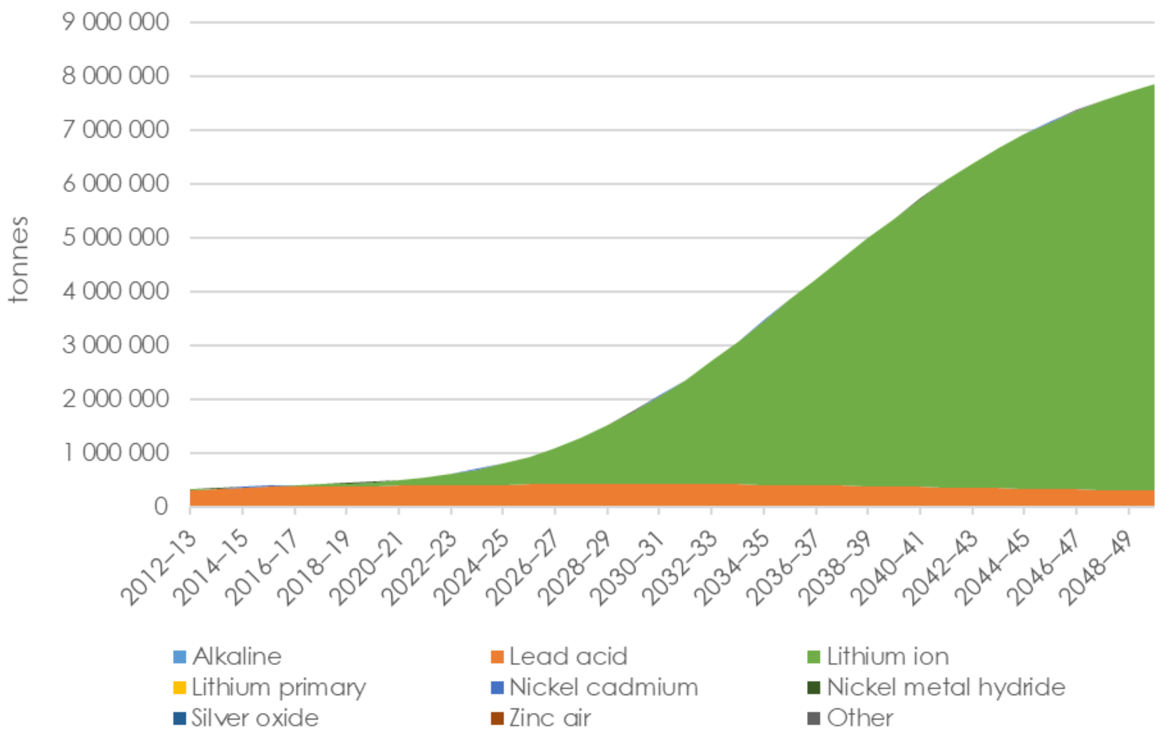
In Figure 21 and Table 23 are presented projected battery stocks (***all*** batteries in use or in storage prior to disposal) by chemistry group across the period of 2012–13 to 2049–50.

At the end of 2019–20 it is estimated that there will be around 390 000 tonnes of lead acid and 66 000 tonnes of lithium chemistry batteries in use across all applications, which is 82% and 14% of all batteries in use respectively.

By the end of the 2029–30 financial year stocks of lithium ion batteries are projected to be 1.3 million tonnes, compared with lead acid battery stocks of 0.4 million tonnes. These stocks will be primarily be in BESS & EV related applications.

By 2050 lithium ion battery stocks are projected to be well over 7 million tonnes, and lead acid battery stocks are forecast to have fallen to 0.3 million tonnes.

Figure 21 – Battery stocks to 2049–50, by chemistry group



Due to the large differences in the scales of battery stocks in different chemistry groups, some chemistry groups are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery stocks at the chemistry group level.

Table 23 – Battery stocks to 2049–50, by chemistry group

Year	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
2014–15	5 970	357 700	13 120	80	5 720	5 130	200	**387 920**
2019–20	6 150	394 390	66 130	70	5 070	6 950	230	**478 990**
2024–25	6 150	415 610	387 620	80	3 900	9 120	250	**822 720**
2029–30	6 150	434 730	1 337 220	80	3 200	9 170	260	**1 790 820**
2034–35	6 150	416 880	3 050 510	90	2 990	8 030	290	**3 484 950**
2039–40	6 150	382 810	4 974 100	100	2 970	6 310	310	**5 372 750**
2044–45	6 150	342 130	6 581 770	100	2 970	4 820	330	**6 938 270**
2049–50	6 210	301 210	7 559 850	110	2 970	3 890	370	**7 874 620**

4.3 BATTERY END-OF-LIFE ARISINGS

4.3.1 EoL arisings by market segment

End-of-life (EoL) arisings are batteries that are entering waste streams and are potentially available for recovery. Modelling of EoL arisings suggests that significant changes will be seen in the market out to 2050.

Figure 22 – Battery end-of-life arisings to 2049–50, by market segment

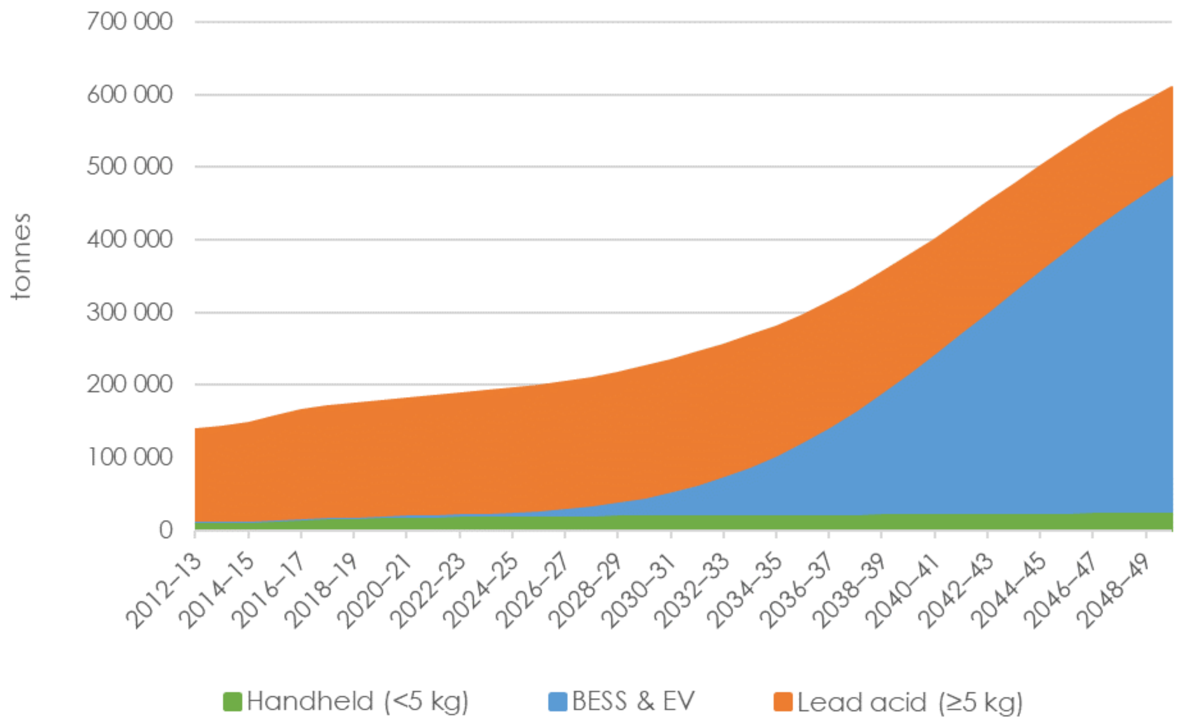


Table 24 – Battery end-of-life arisings to 2049–50, by market segment

Year	Handheld (<5 kg) (tonnes)	BESS & EV (tonnes)	Lead acid (≥5 kg) (tonnes)	Total (tonnes
2014–15	13 970	1 620	130 040	**145 630**
2019–20	20 240	2 430	153 380	**176 050**
2024–25	22 710	5 240	165 510	**193 450**
2029–30	23 700	23 820	175 920	**223 440**
2034–35	24 610	81 630	172 690	**278 930**
2039–40	25 550	192 900	156 670	**375 120**
2044–45	26 570	335 300	137 060	**498 940**
2049–50	27 560	464 440	116 020	**608 020**

At the end of 2019–20 it is estimated that there will be 176,000 tonnes of batteries reaching end-of-life. By weight this consists of:

- 159 000 tonnes of lead acid batteries (90% of total EoL arisings).
- 7 600 tonnes of lithium chemistry batteries (4% of total EoL arisings).
- 8 000 tonnes of alkaline batteries (5% of total EoL arisings).

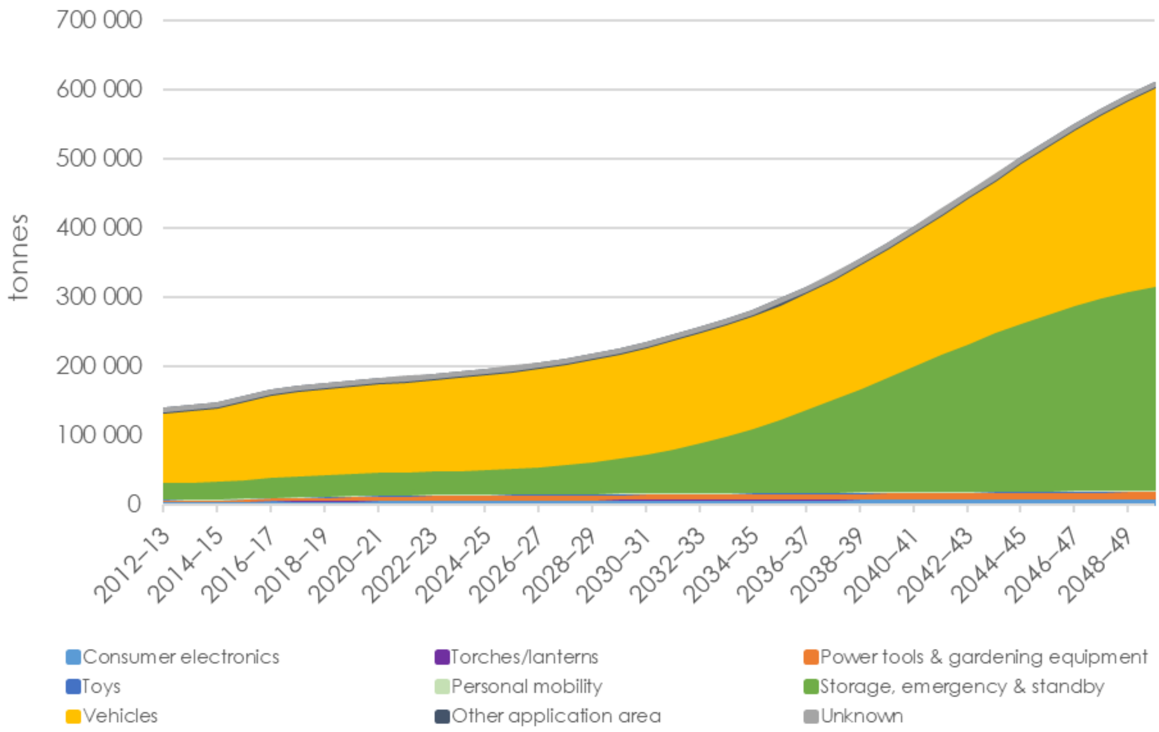
It is projected that lithium ion batteries EoL arisings will exceed lead acid battery by 2040. This is due to the anticipated long average lifespans of lithium chemistry batteries in BESS and EV applications, which are 12 and 16 years respectively.

4.3.2 EoL arisings by application area

In Figure 23 and Table 25 are presented projected battery end-of-life (EoL) arisings by application area across the period of 2012–13 to 2049–50.

At the end of 2019–20 it is estimated that there will be around 176 000 tonnes of batteries reaching end-of-life. This consists of 125 000 tonnes of vehicle related lead acid batteries (71% of total EoL arisings), 32 000 tonnes of storage, emergency and standby related batteries (18% of total EoL arisings), 8 500 tonnes of consumer electronics related batteries (5% of total EoL arisings), and 5 700 tonnes of power tool related batteries (3% of total EoL arisings).

Figure 23 – Battery end-of-life arisings to 2049–50, by application area



Due to the large differences in the scales of battery EoL arisings in different application areas, some application areas are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery EoL arisings at the application area level.

Table 25 – Battery end-of-life arisings to 2049–50, by application area

Year	Consumer electronics (tonnes)	Torches /lanterns (tonnes)	Power tools (tonnes)	Toys (tonnes)	Personal mobility (tonnes)	SES[1] (tonnes)	Vehicles (tonnes)	Other / unknown (tonnes)	Total (tonnes
2014–15	7 120	450	1 940	710	580	26 290	106 760	1 780	**145 630**
2019–20	8 530	480	5 680	890	780	32 160	125 400	2 130	**176 050**
2024–25	9 690	480	6 730	980	900	35 120	137 350	2 200	**193 450**
2029–30	10 080	480	7 370	1 000	970	49 940	151 380	2 220	**223 440**
2034–35	10 350	480	8 040	1 020	1 030	92 770	162 970	2 250	**278 930**
2039–40	10 640	480	8 730	1 050	1 070	165 840	185 030	2 270	**375 120**
2044–45	10 950	480	9 480	1 070	1 110	242 700	230 850	2 300	**498 940**
2049–50	11 230	480	10 240	1 090	1 140	295 590	285 930	2 320	**608 020**

1. Storage, emergency & standby

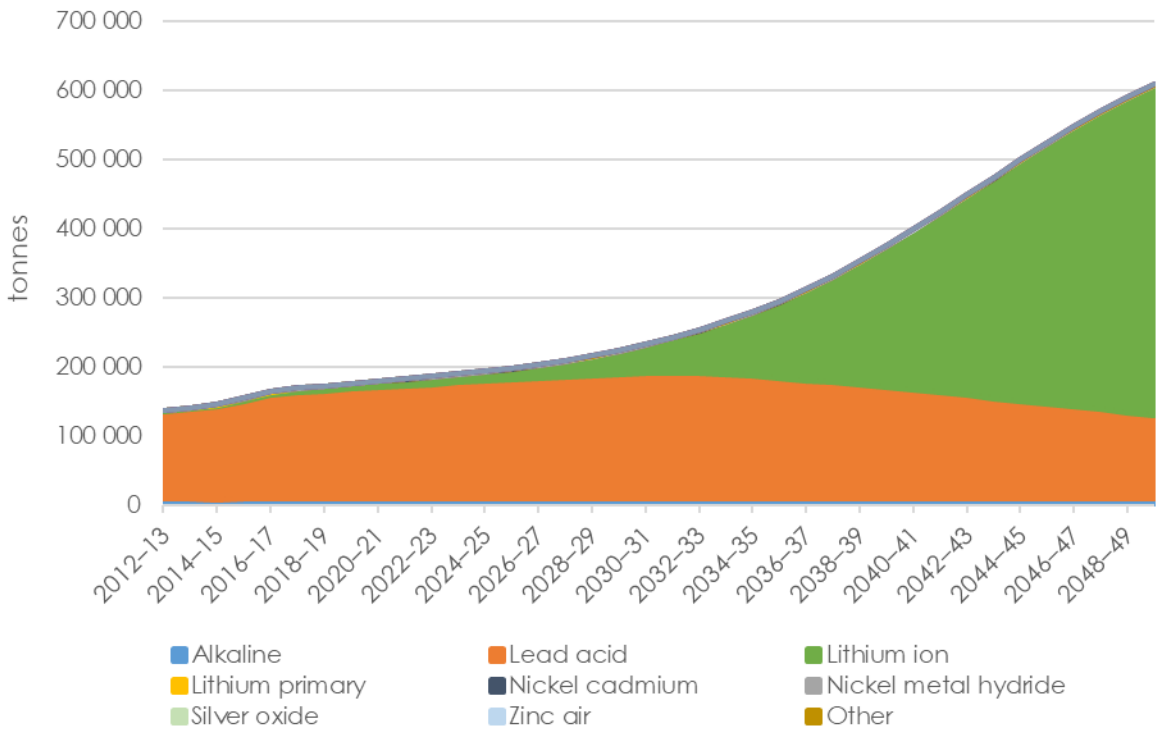
4.3.3 EoL arisings by chemistry group

In Figure 24 and Table 26 are presented projected battery end-of-life (EoL) arisings by chemistry group across the period of 2012–13 to 2049–50. EoL arisings are batteries that are entering waste streams and are potentially available for recovery.

At the end of 2019–20 it is estimated that there will be around 176 000 tonnes of batteries reaching end-of-life. This consists of 159 000 tonnes of lead acid batteries (90% of total EoL arisings), 7 600 tonnes of lithium chemistry batteries (4% of total EoL arisings), and 8 000 tonnes of alkaline batteries (5% of total EoL arisings).

It is not until 2038–39 that lithium ion batteries EoL arisings of 178 000 tonnes are projected to exceed lead acid battery EoL of 165 000 tonnes. This reflects the fairly long anticipated lifespans of lithium chemistries batteries in vehicle and BESS applications of 16 years and 12 years respectively.

Figure 24 – Battery end-of-life arisings to 2049–50, by chemistry group



Due to the large differences in the scales of battery EoL arisings in different chemistry groups, some chemistry groups are not visible in the figure above. Please refer to the following table of 5-year interval data for further detail on battery EoL arisings at the chemistry group level.

Table 26 – Battery end-of-life arisings to 2049–50, by chemistry group

Year	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
2014–15	7 430	134 910	2 430	120	230	230	270	**145 630**
2019–20	8 040	159 220	7 600	90	440	350	300	**176 050**
2024–25	8 040	170 760	13 260	100	440	540	320	**193 450**
2029–30	8 040	180 940	33 020	110	310	670	350	**223 440**
2034–35	8 040	177 690	91 700	110	240	770	370	**278 930**
2039–40	8 040	161 590	203 960	120	230	770	400	**375 120**
2044–45	8 040	141 900	347 540	140	220	660	440	**498 940**
2049–50	7 980	120 760	477 890	150	220	550	470	**608 020**

5 BATTERY COLLECTION IN 2017–18

Presented in this section of the report are the findings of the national survey of end-of-life battery collection service operators, e-waste disassemblers and sorters, and batteries reprocessors.

There were eight batteries reprocessors identified as operating nationally, of which six responded directly to the information request for this project. Reprocessing activity for the other two (both lead acid battery recyclers) was estimated based on discussions with others in the sector.

Battery reprocessors are defined as those organisations actually disassembling, breaking up or shredding batteries and then sorting the resultant materials into discrete product streams for subsequent further downstream processing.

In addition, there were 19 companies and government agencies identified as operating a battery collection service in some form, excluding local governments. All these organisations were also surveyed as part of the project. See Section 7 for the review of local government activity in the end-of-life battery collection space.

In this section of the report battery 'collection' relates to the quantity of batteries collected and sent to a reprocessing facility.

5.1 COLLECTION BY CHEMISTRY AND WEIGHT RANGE

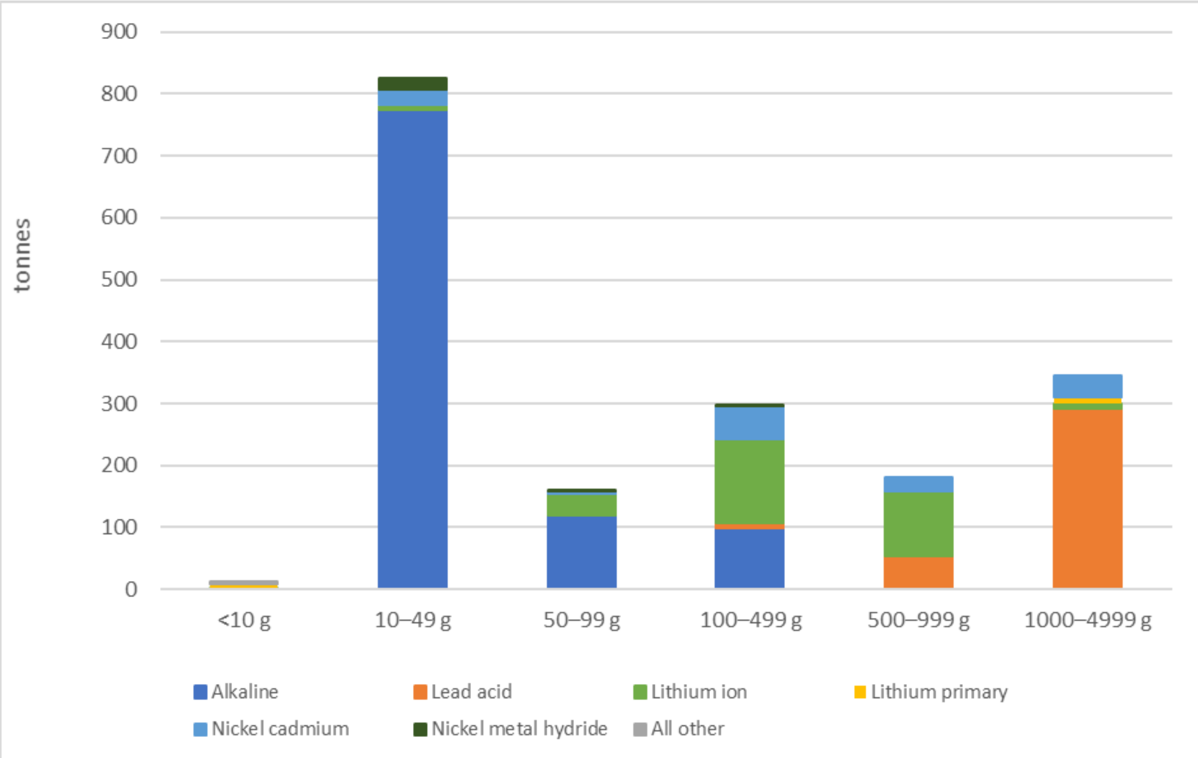
Presented in Table 27 and Figure 25 are 2017–18 battery collection by chemistry group and weight range. Note that Figure 25 only presents battery collection for which the battery weight is <5 kg.

In the weight ranges that are less than 5 kg, there were 990 tonnes of alkaline battery collection (54% of <5 kg collection), 350 tonnes of lead acid battery collection (19% of <5 kg collection), and 290 tonnes of lithium ion battery collection (16% of <5 kg collection).

Table 27 – Battery collections in 2017–18, by chemistry group and weight range

Weight range	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
<10 g	0	0	3	6	0	0	3	**12**
10–49 g	770	0	6	3	20	20	0	**830**
50–99 g	120	0	30	0	6	2	0	**160**
100–499 g	100	9	140	0	50	2	0	**300**
500–999 g	0	50	110	0	20	0	0	**180**
1000–4999 g	0	290	9	9	30	0	0	**350**
Total <5 kg	**990**	**350**	**290**	**19**	**140**	**20**	**3**	**1 820**
5–10 kg	0	30	6	0	18	0	0	**60**
>10–50 kg	0	142 790	0	0	130	0	0	**142 920**
>50–100 kg	0	5 730	13	0	0	150	0	**5 900**
>100 kg	0	0	10	0	0	0	0	**10**
Total ≥5 kg	**0**	**148 560**	**30**	**0**	**150**	**150**	**0**	**148 890**
Total	**990**	**148 910**	**320**	**19**	**290**	**180**	**3**	**150 710**

Figure 25 – Battery collection in 2017–18, by chemistry group and weight range (<5 kg only)



5.2 COLLECTION BY CHEMISTRY AND APPLICATION AREA

Presented in Table 28 and Figure 26 is 2017–18 battery collection by chemistry group and application area. Note that Figure 26 only presents battery collections to local reprocessing and excludes lead acid batteries.

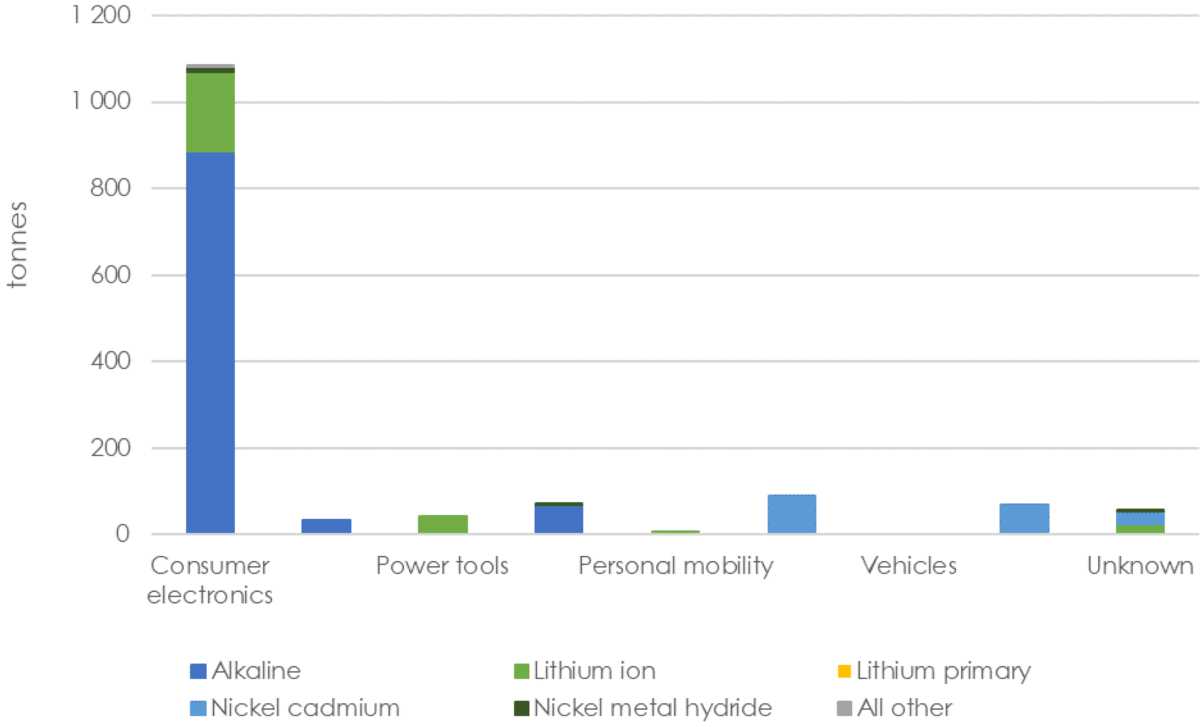
Table 28 – Battery collection in 2017–18, by chemistry group and application area

	Application area	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
Local reprocessing	Consumer electronics	890	3	180	3	0	11	3	**1 090**
	Torches/lanterns	40	0	0	0	0	0	0	**40**
	Power tools	0	0	40	0	0	0	0	**40**
	Toys	70	0	0	0	0	2	0	**70**
	Personal mobility	0	5	9	0	0	0	0	**14**
	SES[1]	0	2 520	2	0	90	0	0	**2 610**
	Vehicles	0	131 100	0	0	0	0	0	**131 100**
	Other applications	0	3 290	0	0	70	0	0	**3 360**
	Unknown	0	0	30	0	30	3	0	**60**
	Total <5 kg	***990***	***136 910***	***260***	***3***	***190***	***16***	***3***	***138 370***
Overseas reprocessing	Consumer electronics	0	0	30	6	3	0	0	**40**
	Torches/lanterns	0	0	0	0	0	0	0	**0**
	Power tools	0	0	6	0	30	0	0	**30**
	Toys	0	0	0	0	0	0	0	**0**
	Personal mobility	0	0	0	0	0	0	0	**0**
	SES[1]	0	0	12	0	70	0	0	**80**
	Vehicles	0	12 000	15	0	0	150	0	**12 170**
	Other applications	0	0	0	9	4	0	0	**13**
	Unknown	0	0	0	0	1	8	0	**9**
	Total ≥5 kg	***0***	***12 000***	***60***	***16***	***100***	***160***	***0***	***12 340***
	Total	**990**	**148 910**	**320**	**19**	**290**	**180**	**3**	**150 710**

1. SES – Storage, emergency & standby.

Locally reprocessed battery (excluding lead acid) collections were primarily through 890 tonnes of alkaline batteries and 180 tonnes of lithium ion batteries from consumer electronics applications.

Figure 26 – Battery collection in 2017–18, by chemistry group and application area (<5 kg only)



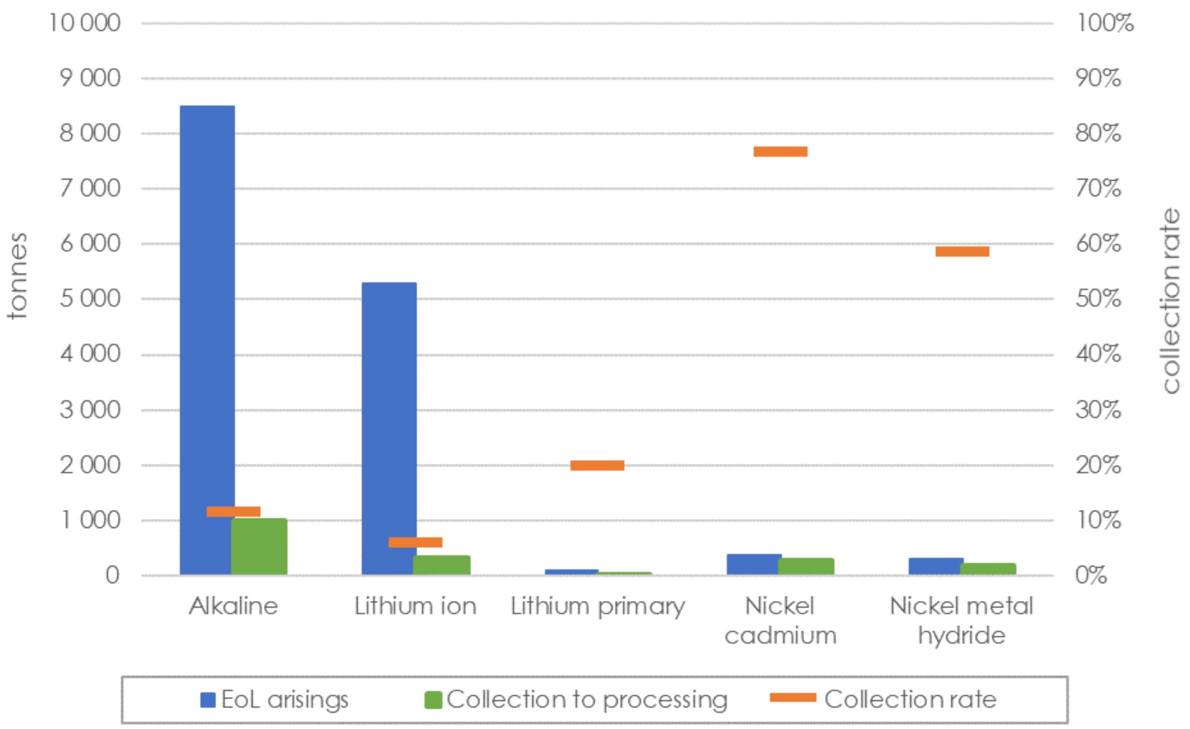
5.3 COLLECTION RATES BY CHEMISTRY GROUP

Presented in Table 29 and Figure 27 are 2017–18 battery collection rates (to processing) by chemistry group for all batteries.

Table 29 – Battery collection rates in 2017–18, by chemistry group

Chemistry group	EoL arisings (tonnes)	Collection to processing (tonnes)	Collection rate (tonnes)
Alkaline	8 490	990	**12%**
Lead acid	154 490	148 910	**96%**
Lithium ion	5 290	320	**6%**
Lithium primary	90	20	**20%**
Nickel cadmium	370	290	**77%**
Nickel metal hydride	300	180	**59%**
All other	280	0	**1%**
Total	**169 320**	**150 710**	**89%**

Figure 27 – Battery collection rates in 2017–18, by chemistry group (excluding lead acid)



Lead acid batteries have the highest collection rate of 96%. This is followed by nickel cadmium batteries at 77%, reflecting the concentrated use of this chemistry in emergency lighting backup and the activity of the Exitcycle product stewardship scheme in supporting the collection of batteries used in this application.

Nickel metal hydride batteries have a relatively high collection rate of 59%. However, this good performance is largely due to the collection of nickel metal hydride batteries from Toyota hybrid vehicles, which have very high collection rates when replaced.

The collection rate of alkaline batteries is estimated at 12% in 2017–18. This is a significant increase on the estimated 2% in 2012–13 (SRU, 2014), but still very low in absolute terms.

Provided in Table 30 are the handheld (<5 kg) battery EoL arisings, collection, and collection rate estimates for 2012–13 (SRU, 2014, p. 38). In 2012–13 the collection rate for alkaline batteries was only 2%, and the overall collection rate for <5 kg batteries was only 3%. These collection rates have increased to 12% and 11% respectively in 2017–18.

Table 30 – Battery collection rate in 2012–13, by chemistry group (<5 kg)

Chemistry group	EoL arisings (tonnes)	Collection (tonnes)	Collection rate (tonnes)
Alkaline	8 710	140	**2%**
Lead acid	2 700	130	**5%**
Lithium ion	1 750	30	**2%**
Lithium primary	150	10	**5%**
Nickel cadmium	670	40	**5%**
Nickel metal hydride	720	30	**4%**
All other / unknown	40	30	**N/A**
Total	**14 730**	**400**	**3%**

Source: SRU (2014)

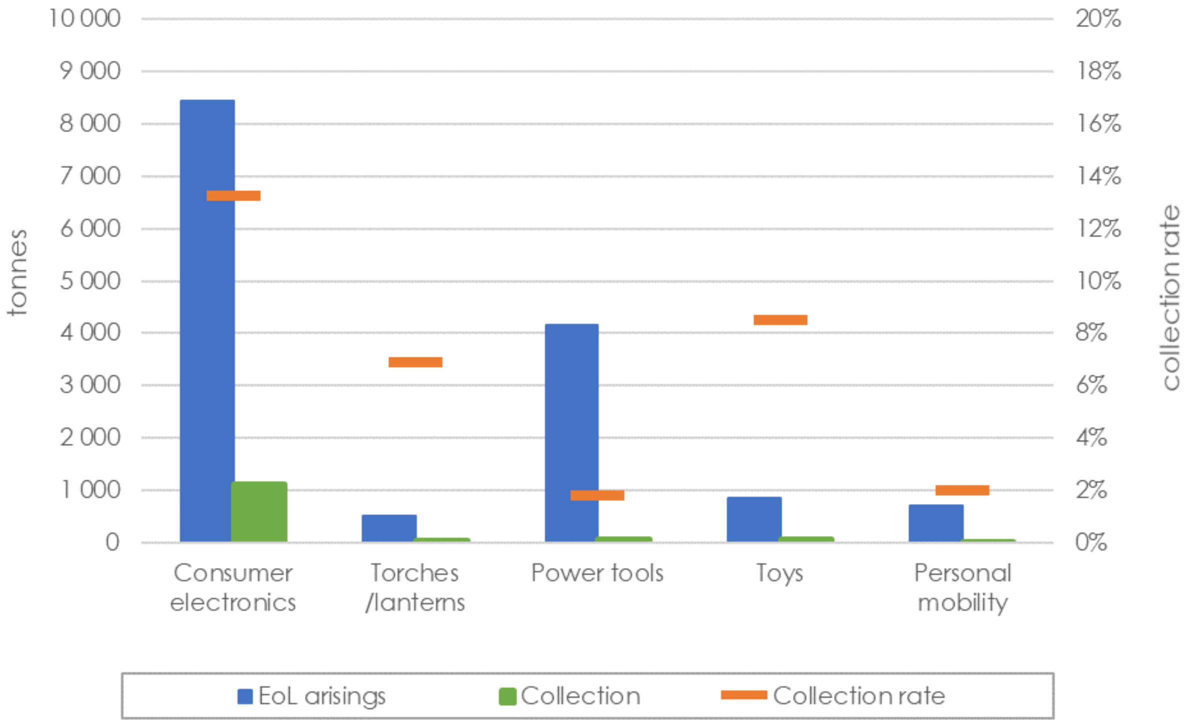
5.4 COLLECTION RATES BY APPLICATION AREA

Presented in Table 31 and Figure 28 are 2017–18 battery collection rates (to processing) by application area. Note that the storage, emergency & standby (SES) and vehicles application areas are combined as they are dominated by lead acid batteries and it is not possible to adequately separate collection to processing between these two application areas for the purposes of determining collection rates.

Table 31 – Battery collection rates in 2017–18, by application area

Application area	EoL arisings (tonnes)	Collection to processing (tonnes)	Collection rate (tonnes)
Consumer electronics	8 450	1 120	**13%**
Torches /lanterns	510	40	**7%**
Power tools	4 170	70	**2%**
Toys	850	70	**9%**
Personal mobility	700	10	**2%**
SES & vehicles	152 660	145 960	**96%**
Total	**167 340**	**147 280**	**88%**

Figure 28 – Battery collection rates in 2017–18, by application area (excluding lead acid dominated application areas)



Excluding lead acid dominated application areas, consumer electronics batteries have the highest collection rate of 13%. This is followed by toys at 9% and torches/lanterns at 7%. The higher collection rate of consumer electronics batteries is underpinned by the collection of laptop, tablet and mobile phone batteries through the National TV and Computer Recycling Scheme (NTCRS) and MobileMuster.

5.5 COLLECTION BY CHEMISTRY AND COLLECTION ROUTE

Provided in Table 32 is an overview of the potential collection routes for waste batteries. Collection service operators and battery reprocessors were surveyed for information on batteries collected through each collection route.

Data on batteries to landfill was not directly surveyed, but is determined as the difference between end-of-life arisings estimates (as determined in Section 4.3) and reported battery collection to recovery processing.

Table 32 – Collection and disposal routes description

Collection/disposal route	Description	Fate
Retail store drop-off	In-store recycling drop-off service, for example programs offered by ALDI, Battery World and Officeworks.	Recovered for recycling
Hazardous household chemical collection (HHCC)	Typically operated by state agencies or local government for paint, batteries and gas bottles etc. – both permanent and temporary sites.	Recovered for recycling
E-waste collection programs	Includes the TVs/computers scheme (NTCRS), MobileMuster and Exitcycle.	Recovered for recycling
Commercial collection services	Recycling companies that offer a service to collect batteries from individual businesses and organisations.	Recovered for recycling
Institutional collection programs	Collections through schools, universities, government, hospitals.	Recovered for recycling
Other collection routes	Any other collections routes that might be identified.	Recovered for recycling
Municipal or commercial & industrial (C&I) garbage collections	Kerbside collection of garbage.	To landfill
Municipal or C&I recycling collections	Kerbside collection of packaging and paper. These are recycled but batteries are a contaminant and disposed to landfill.	To landfill
Other disposal to landfill	All other disposal of handheld batteries to landfill from household and commercial sources, e.g. drop-off of waste at transfer stations or landfills by householders.	To landfill

Battery collection in 2017–18 by chemistry group and collection route is presented in Table 33, Figure 29 and Figure 30.

Table 33 – Battery collection in 2017–18, by chemistry group and collection route (all batteries)

Collection route	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
Retail store drop-off	300	7 170	50	0	30	10	0	**7 560**
HHCC drop-off	130	10	10	0	40	10	0	**180**
E-waste collection	70	20	200	0	10	0	0	**300**
Commercial collection	420	88 620	40	0	160	10	0	**89 260**
Institutional collection	70	10	0	10	10	0	0	**110**
Other routes[1]	0	53 100	10	0	40	150	0	**53 300**
Total collection	**990**	**148 910**	**320**	**20**	**290**	**180**	**0**	**150 710**
Landfill	**7 500**	**5 580**	**4 970**	**70**	**90**	**130**	**280**	**18 610**
Total	**8 490**	**154 490**	**5 290**	**90**	**370**	**300**	**280**	**169 320**
% collection rate	**12%**	**96%**	**6%**	**20%**	**77%**	**59%**	**1%**	**89%**

1. Other routes include corporate take-back programs and third party collections.

Figure 29 – Battery collection in 2017–18, by chemistry and collection route

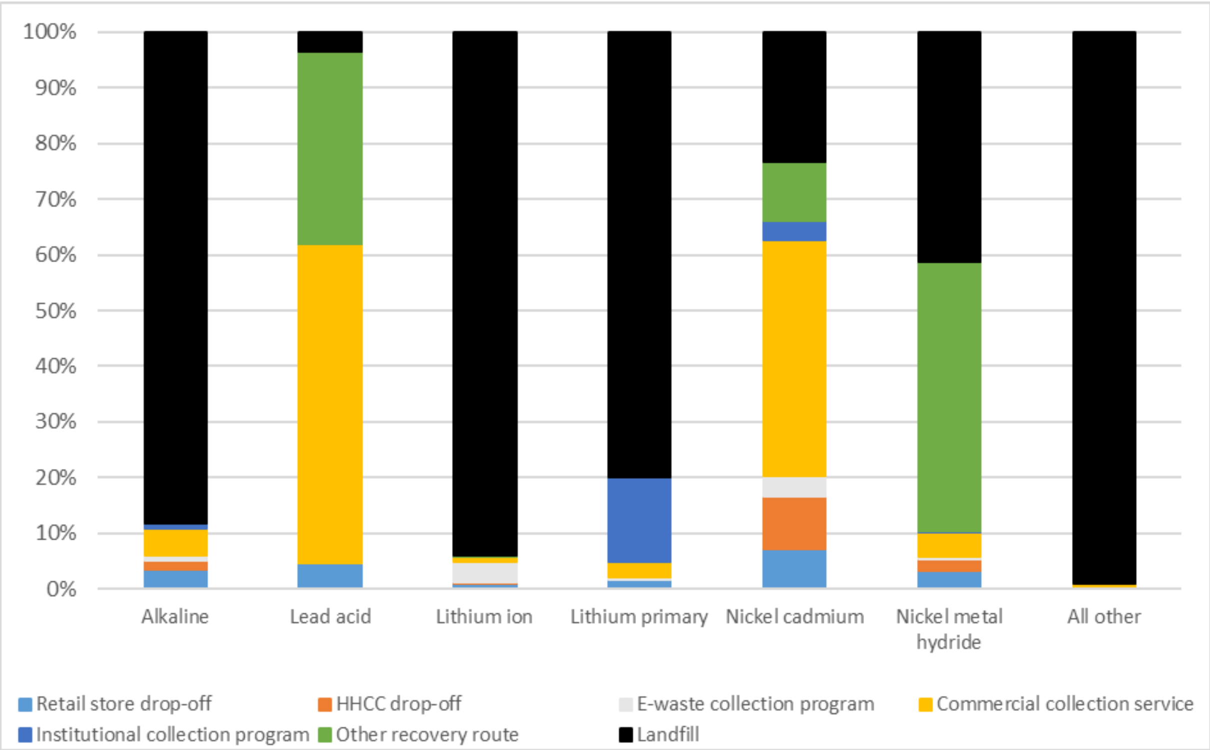
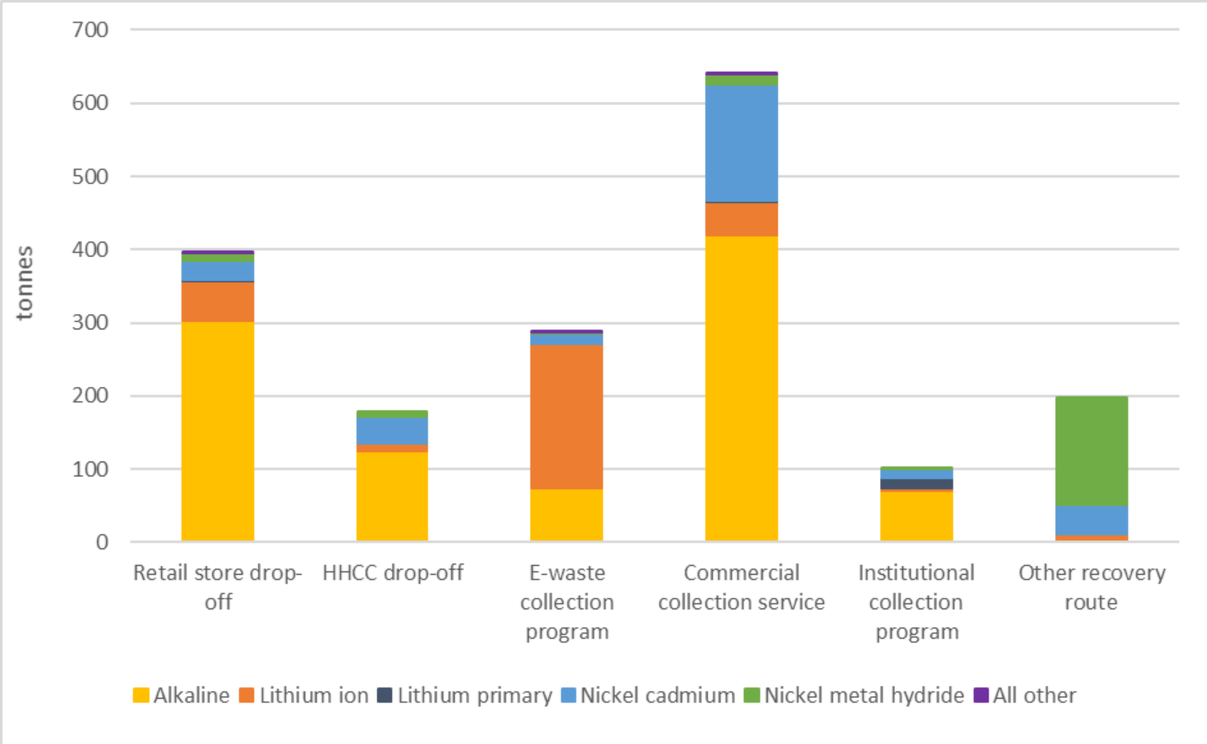


Figure 30 – Battery collection in 2017–18, by chemistry and collection route (excluding lead acid)

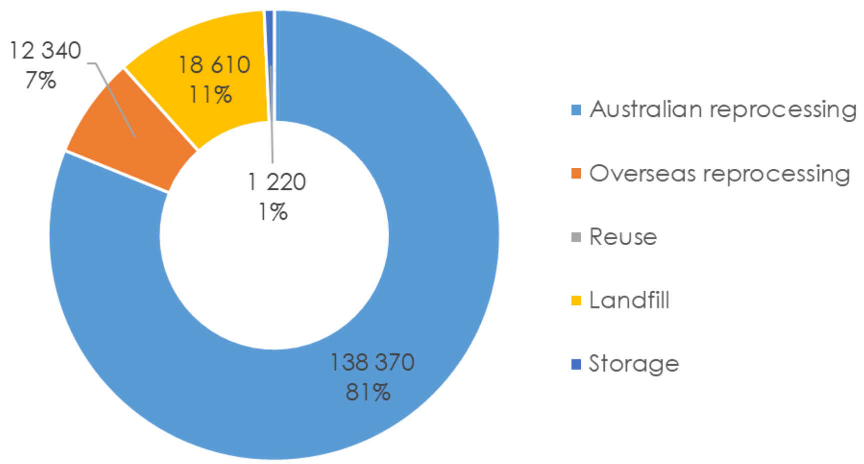


5.6 BATTERY FATES

Provided in Figure 31 is a summary of battery fates in 2017–18. The Australian reprocessing of lead acid batteries dominates the fates of the 169 000 tonnes of batteries reaching end-of-life in Australia in 2017–18.

For this study reprocessing is defined as putting the used batteries through a process or processes to recover materials leading to the use in the manufacture of new products. It does not include the sorting of batteries for subsequent downstream processing.

Figure 31 – Battery fates in 2017–18



Provided in Table 34 is a summary of battery fates in 2017–18 by chemistry. In 2017–18 all alkaline batteries that were collected for reprocessing were identified as reprocessed in Australia, as were most lithium ion and nickel cadmium batteries. Nickel metal hydride batteries were largely exported for reprocessing.

The 12 000 tonnes of exported lead acid batteries is an estimate of illegal exports, as there were no permitted lead acid exports in 2017–18.

Table 34 – Battery fates in 2017–18, by chemistry

Fate	Alkaline (tonnes)	Lead acid (tonnes)	Lithium ion (tonnes)	Lithium primary (tonnes)	Nickel cadmium (tonnes)	Nickel metal hydride (tonnes)	All other (tonnes)	Total (tonnes)
Local reproc	990	136 910	260	0	190	20	0	**138 370**
Export reproc.	0	12 000[b]	60	20	100	160	0	**12 340**
Reuse	0	0	0	0	0	0	0	**<50[c]**
Landfill	7 500	5 580	4 970	70	90	130	280	**18 610**
Total EoL	**8 490**	**154 490**	**5 290**	**90**	**390**	**300**	**280**	**169 340**
Storage[d]	*260*	*430*	*200*	*10*	*280*	*50*	*0*	***1 220***

a. Reprocessing quantities are 'in-the-gate' estimates and include any processing losses to landfill.
b. Estimated illegal exports during the 2017–18 period.
c. Some battery reuse reported. Chemistry not reported due to confidentiality constraints.
d. Reported storage by collectors, disassemblers and reprocessors in mid-2019. Mostly stored for less than 6 months but includes a relatively small quantity of batteries stored for more than 12 months.

Reprocessors and electrical and electronic equipment (EEE) disassemblers were also surveyed for estimates on battery processing material yield rates from scrap batteries by chemistry. A summary of this data is provided in Table 35. Note that these estimates do not include any subsequent downstream material losses, e.g. during smelting operations, and are the estimated yield rates out the gate of battery reprocessing facilities.

Table 35 – Scrap battery processing material yield rates

Chemistry	Material yield
Alkaline	90%
Lead acid	95%–97%
Lithium ion	90%
Lithium primary	NR
Nickel cadmium	95%
Nickel metal hydride	90%

It is important to note that downstream recovery rates of cathode, anode and electrolyte material are dependent on battery chemistry and processing technology. The actual utilisation rates in new products, of materials recovered from scrap batteries, other than lead acid, may be significantly lower than the 'out-the-gate' yield rate estimates provided in the table above.

Lead acid batteries are the only chemistry for which a significant proportion of end-of life arisings are collected, disassembled and processed into secondary (recovered) materials suitable for use in the manufacture of new products in significant quantities.

Provided in Table 36 is a summary of the available information on scrap battery reprocessing products and identified fates of locally collected batteries. A number of EoL battery aggregators and reprocessors did not provide information on the fates of the related scrap battery reprocessing products.

Table 36 – Australian reprocessor scrap battery reprocessing products and fates

Chemistry group	Products	Identified fates
Alkaline	Anode and cathode	Fertiliser additive.
	Electrolyte	Fertiliser additive.
	Plastics and paper	Landfill.
	Steel	Steel recycling.
	Other	Other non-ferrous metal components to fertiliser additive or non-ferrous metal recycling.
Lead acid	Anode and cathode	Lead metal and compounds to downstream metal recovery.
	Electrolyte	Neutralised and converted into sodium sulfate; or Neutralised and disposed to trade-waste or landfill.
	Plastics (mainly polypropylene)	Plastics recycling (washed and granulated).
	Steel	None reported.
	Other	No other products reported.
Lithium ion	Anode and cathode	Material sent to downstream recovery.
	Electrolyte	Unknown.
	Plastics	Unknown.
	Steel	Unknown.
	Other	No other products reported.
Lithium primary	Anode and cathode	Unknown.
	Electrolyte	Unknown.
	Plastics	Unknown.
	Steel	Unknown.
	Other	No other products reported.
Nickel cadmium	Anode and cathode	Nickel & cadmium compounds (only) to metal recovery.
	Electrolyte	Neutralised and disposed to trade-waste or landfill.
	Plastics	Unknown.
	Steel	Unknown.
	Other	No other products reported.
Nickel metal hydride	Anode and cathode	Nickel compounds (only) to metal recovery.
	Electrolyte	Neutralised and disposed to trade-waste or landfill.
	Plastics	Unknown.
	Steel	Unknown.
	Other	No other products reported.
Silver oxide	Anode and cathode	Silver compounds (only) to metal recovery.
	Electrolyte	Neutralised and disposed to trade-waste or landfill.
	Plastics	Unknown.
	Steel	Unknown.
	Other	No other products reported.

6 BATTERY RECOVERY MARKET ECONOMIC ASSESSMENT

6.1 MARKET ASSESSMENT OVERVIEW

Undertaken in this section of the report is a market assessment of the Australian end-of-life battery collection, sorting and processing sector. The purpose of this assessment is to explore the market characteristics and cost structures within which the battery recovery sector currently operates, and consider the implications for the recovery of increasing flows of end-of-life batteries in the future.

The assessment is broken into two main parts, which are:

1. Recovery market characteristics
2. Recovery market financial assessment

This assessment of the market characteristics of battery recovery and recycling in Australia has been framed across two dimensions: battery chemistry groups; and the type of recovery activity. The chemistry groupings that have been adopted for the analysis are:

Single-use batteries:

- **Alkaline chemistries** – Includes alkaline and zinc carbon batteries and cells.
- **All other single-use battery chemistries** – Lithium metal, silver oxide and zinc air batteries or cells.

Rechargeable batteries:

- **Lead acid** – This chemistry comprises the bulk of recycling that recovers component materials. It has been able to establish an internal sustaining market without supplementary gate fees, albeit in tough competition with overseas processors.
- **All other rechargeable battery chemistries** – Lithium ion, nickel cadmium and nickel metal hydride batteries.

In addition, there are a range of activities in the recovery chain. For the purposes of the assessment these have been combined into three broad categories, which are:

- Collection service operator – Organisations providing a collection service only, some disassembly of battery-containing devices, and sorting into battery types. The sorted batteries are then sent to another local processor to extract recoverable materials.
- EEE disassembler – Organisations undertaking some degree of disassembly of battery-containing devices, and sorting into battery types. These organisations may also operate a collection service. The sorted batteries are then sent to a local or overseas reprocessor to extract recoverable materials.
- Reprocessor – Organisations undertaking the disassembly or shredding of batteries or cells to facilitate the subsequent recovery of materials from batteries. These organisations may also operate as collection service operator and or disassemblers.

6.2 SUMMARY STATISTICS ON THE SECTOR

As found in earlier studies in on recycling generally (Access Economics, 2009; Net Balance, 2012) there is fairly limited data available on the financial characteristics of the recycling sector in Australia. Data is typically derived from broader categories and allocated to the recycling sector.

For the purposes of this market assessment, we have sought to estimate a range of financial, economic and other characteristics from the industry survey. In reporting these data, there is a natural conflict between breaking down the data into specific battery types and processes, and the need to protect commercial-in-confidence information. Unless explicitly authorised, we have erred on the side of confidentiality. As a rule of thumb, at least three (non trivial) estimates from separate entities were required to report financial information.

6.2.1 Quantity of batteries collected for reprocessing

Information was obtained from both collection service providers and reprocessors. It is estimated that around 150 710 tonnes of batteries were collected and send to reprocessing. The overwhelming majority of these volumes were from lead acid batteries of ≥5 kg per battery in weight.

Table 37 – Quantity of batteries collected

Chemistry	Collection in 2017–18 (tonnes)
Alkaline	990
Lead acid	148 910
Lithium ion	320
Lithium primary	20
Nickel cadmium	290
Nickel metal hydride	180
All other	0
Total	**150 710**

6.2.2 Employment and turnover

A number of respondents provided ranges of both employment and turnover for the reprocessing. These have been scaled up using the quantities reported Table 37.

Table 38 – Indicative employment and turnover

Activity	Employment (FTE)	Turnover ($m)
Reprocessing	400	$71.3m

The estimate for employment suggests a ratio of 26.4 (equivalent) full time employees (FTEs) per 10,000 tonnes of reprocessed batteries. This compares with the Access Economics (2009) estimate of 9.2 FTEs per 10 000 tonnes of recycled waste.

Figure 32 highlights the two elements of reprocessing firms. Over half of the firms undertaking processing employ fewer than 20 employees in those processes. The remainder have at least 20 employees undertaking reprocessing activities.

This split is more evident when looking at turnover (Figure 33). The smaller firms have significantly lower revenues from reprocessing compared with that earned by those employing 20 or more in reprocessing.

Figure 32 – Size of reprocessing firms by number of employees

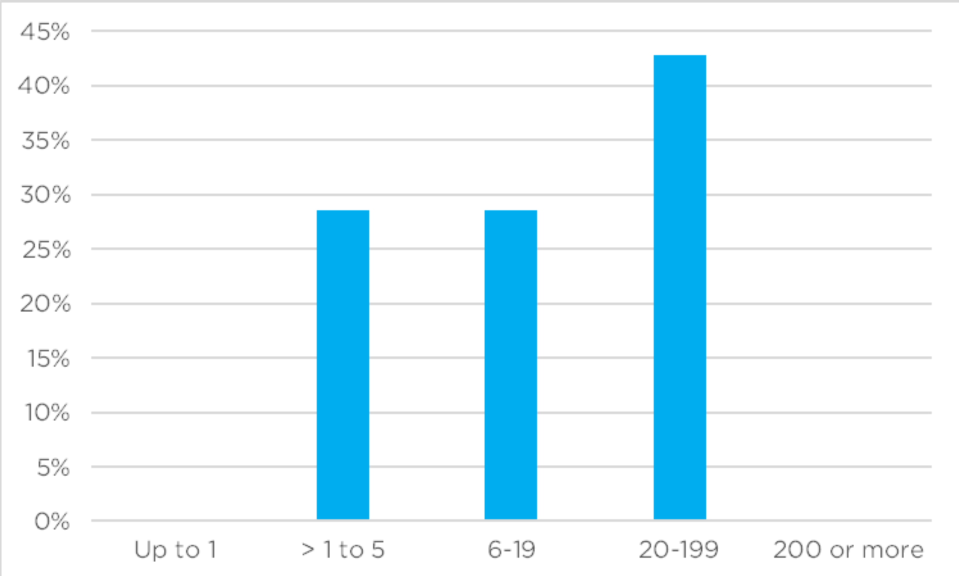
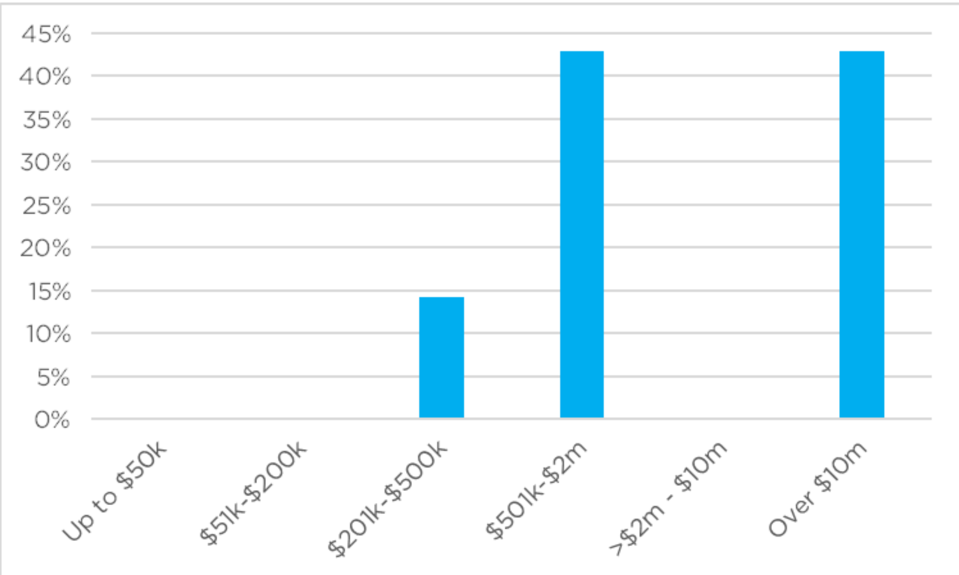


Figure 33 – Turnover of reprocessing firms



6.2.3 Economic impact

Separate estimates of the contribution of battery recycling and recycling more generally to Australian GDP are not available. We have therefore applied the factors used for waste industries in general.

The estimate is based on the (battery related) turnover of the sector and estimates of the total value of waste activity of $15.5b in Australia, of which $6.9b contributed to Australia's GDP (The CIE, 2017, p. 33).

The indicative estimated contribution of battery recycling to Australian GDP is $31m.

6.3 RECOVERY MARKET CHARACTERISTICS

6.3.1 Battery recycling supply chain participants

As outlined in Section 4.3.3, of all battery chemistries, lead acid is the only one collected for which a significant proportion of end-of life arising are collected, disassembled and processed into secondary (recovered) materials suitable for use in the manufacture of new products in significant quantities.

The collection and recovery of alkaline batteries is low (12%). The downstream beneficial recovery of materials in these batteries is also probably fairly low. There is no virgin material (into battery manufacture) competing recovery of the cathode, anode or electrolyte components of these batteries in Australia, and no confirmed recovery of these materials in overseas facilities.

Major participants in the Australian battery recovery chain are summarised across the following three tables. Note that these lists are not comprehensive to all organisation handling end-of-life e-waste in Australia.

Table 39 – Collection service operators

Organisation	Comment on activity
ACT NOWaste	Hazardous household chemical collection (HHCC) program operator.
ALDI	Retail store drop-off.
Australia and New Zealand Recycling Platform (ANZRP) / TechCollect	National TV and Computer Scheme (NTCRS) collection operator.
Australian Mobile Telecommunications Association	MobileMuster scheme operator (mobile phones).
BAT REC Battery Recycling	Commercial collection service.
Cleanaway	Commercial collection service.
Dodd & Dodd Group	Commercial collection service.
Green Industries SA	Hazardous household chemical collection (HHCC) program operator.
IKEA	Retail store drop-off.
Infoactiv Australia	Commercial collection service.
Lighting Council of Australia	Exitcycle scheme operator (exit lighting batteries).
NSW EPA	Hazardous household chemical collection (HHCC) program operator.
Sustainability Victoria	Hazardous household chemical collection (HHCC) program operator.
Total Green Recycling	Commercial collection service.
WA Local Government Association	Hazardous household chemical collection (HHCC) program operator.

Table 40 – EEE disassemblers

Organisation	Comment on activity
Certified Destruction Services (CDS Recycling)	NTCRS e-waste disassembler.
Close The Loop	-
Electronic Recycling Australia	NTCRS e-waste disassembler.
Endeavour Foundation	NTCRS e-waste disassembler.
Sims E-Recycling Pty Ltd	NTCRS e-waste disassembler.
TES-AMM Australia Pty Ltd	NTCRS e-waste disassembler.

Table 41 – Reprocessors

Organisation	Comment on activity
Ecocycle Pty Ltd	Shredding of alkaline cells and distillation/refining of silver oxide cells.
Enirgi Metal Group	Lead acid battery breaking and lead smelting.
Envirostream Australia Pty Ltd	Shredding and separation processes on alkaline, lithium ion and nickel metal hydride batteries.
Hydromet Corporation Pty Limited	Lead acid battery breaking.
Lex Enviro	Lead acid battery breaking.
MRI	Large format nickel cadmium battery breaking. Major e-waste disassembler.
ReSource	Shredding and separation processes on alkaline batteries.
V Resource	Lead acid battery breaking.

6.3.2 Drivers and barriers to battery recycling

6.3.2.1 Materials recovery and material values

The critical financial factors driving battery recycling at present and likely to drive future recovery is:

- recoverability of materials in batteries
- yield of materials in batteries
- the medium to long term values of the recovered materials.

Economic recovery of low value materials, such as plastics and electrolytes, is restricted in all battery types.

In small and mid-sized batteries, such as alkaline batteries and button batteries, even moderate to high value materials such as iron, aluminium, copper, lead, lithium, nickel and zinc have limited recoverability due to the small quantities of these materials in the batteries.

Economic recovery of materials in these batteries generally requires significant quantities of high and very high value materials such as cobalt, rare earth elements (REE) or precious metals such as silver.

Even in larger batteries, which can contain significant quantities of moderate to high value materials, economic recovery can be restricted by the prices that recyclers receive for these materials. These prices are, in turn, determined by international commodity prices which, in turn, are influenced by factors that are largely outside of Australian recyclers' control including:

- primary commodity supply
- demand linked to the status of the global economy and political factors.

6.3.2.2 Nickel, lithium and cobalt

As outlined in Table 42, alkaline, nickel cadmium, nickel metal hydride and lithium ion batteries all contain small to significant quantities of recoverable metals including base metals and lithium. As previously noted however, economic recovery of materials is limited to high to very high value materials in small and mid-size batteries.

Table 42 – Material compositions of selected battery types by weight

Substance	Battery type					
	Alkaline	Pb	NiCd	NiMH (cylindrical)	NiMH (Prius II)	Li-ion ($LiCoO_2$)
Carbon (graphite)				<1%		16%
Cadmium			16–18%			
Cobalt				3–4%	4%	27.5%[1]
Copper						14.5%
Iron	5–30%		40–45%	22–25%	36%	24.5%
Lead components		25–30%				
Lead paste		35–50%				
Lithium					<0.5%	1%
Manganese	10–25%					
Nickel			18–22%	36–42%	23%	
Plastics		9–15%		3–4%	18%	14%
Rare earth elements				8–10%	7%	
Zinc	15–30%					
Electrolyte		10–20%			9%	3.5%

1. Present as lithium cobalt dioxide ($LiCoO_2$).
Source: Worrell & Reuter (2014)

Larger batteries, such as the nickel metal hydride batteries used in hybrid vehicles and some lithium-ion chemistries (e.g. lithium nickel manganese cobalt oxide cells used in Tesla EVs) can contain enough quantities of nickel and cobalt to potentially support economic recovery.

As detailed in Figure 34, nickel prices have been increasing in recent years, driven in part by booming demand for batteries. Prices spiked in 2019, caused mainly by problems experienced by a major Indonesian supplier. This spike is likely to be short-lived, but in the longer-term nickel prices are expected to remain strong, underpinned by the growing demand for electric vehicles, and continued growth in China's production of stainless steel (the major use of nickel).

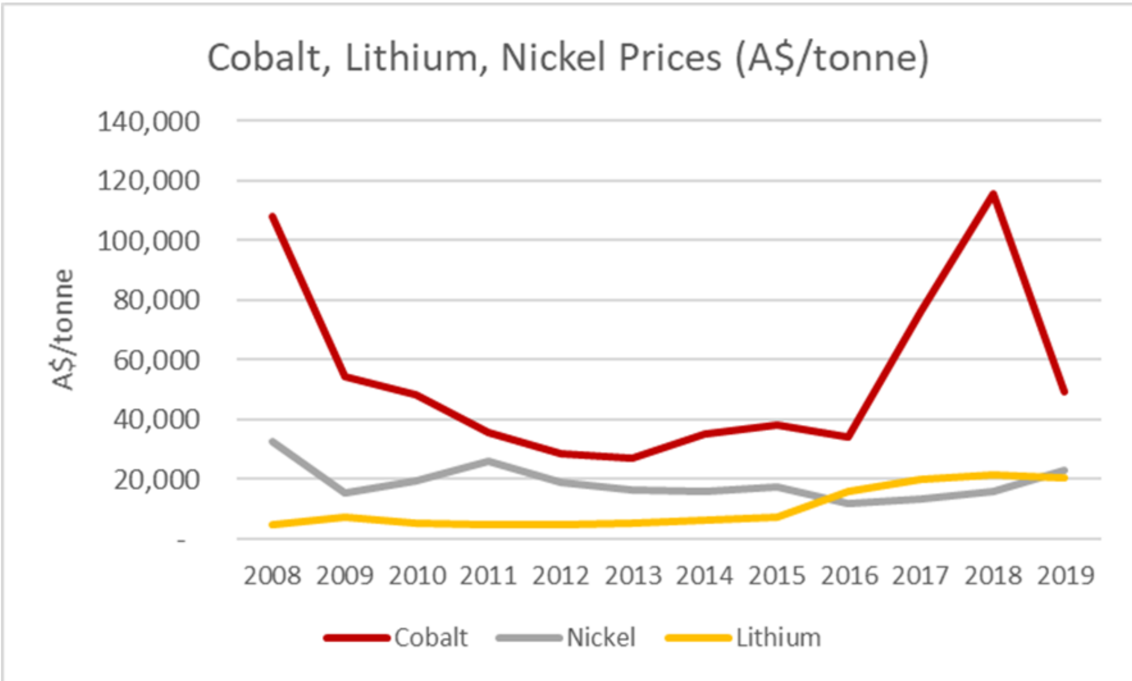
This trend should ensure increasing viability of recycling of batteries containing significant quantities of nickel. The key to that processing occurring in Australia will probably be an adequate supply of used batteries to justify the capital expenditure on recycling operations here.

At present, lithium-ion batteries often contain insufficient quantities of lithium to ensure economic viability of its recovery, even as a co-product. That situation could change if lithium prices continue to increase in line with the trend of recent years (Figure 34), although it is unclear whether this will be the case.

A number of analysts suggest that the increasing demand and prices for lithium, driven by forecasts of the future dominance of electric cars in the auto industry and by the use of lithium in mobile phones, will be outweighed by a massive increase in primary supply expected to arrive on the market in coming years.

Morgan Stanley forecasts that new primary supplies from Argentina, Australia, and Chile, could add 500,000 tonnes of lithium to the market per year by 2025. This is more than twice as much as the current annual supply of lithium. This massive new supply of primary (virgin) lithium may keep prices low, which will undermine the economic viability of lithium recovery for the foreseeable future.

Figure 34 – International prices for cobalt, lithium and nickel, 2008–2019



Source: Marsden Jacob Associates

The cobalt content of batteries is important in influencing the economic viability of recycling small and medium sized batteries and larger electric vehicle batteries.

However, few of the commodities found in batteries have experienced greater volatility over the last few years than cobalt. Cobalt prices are now closely linked to its use in lithium-ion batteries and the rapidly growing use of these batteries in electric-vehicles.

There is an expectation that the numbers of EVs globally will triple to 13 million by 2020 and increase 30-fold to 130 million vehicles by 2030. This expectation fuelled massive price increases between 2016 and 2018. In the past year however, prices have fallen substantially again, with the metal losing around 70 percent of its value. This loss in value has been attributed to several factors including:

- statements by Tesla that the cobalt content in Tesla batteries could be reduced to "almost nothing" in the future
- stockpiling of cobalt by China, the world's largest cobalt consumer.

Nonetheless, many analysts still believe that cobalt prices will increase significantly in the long term, with demand growth expected to outmatch supply in the coming years.

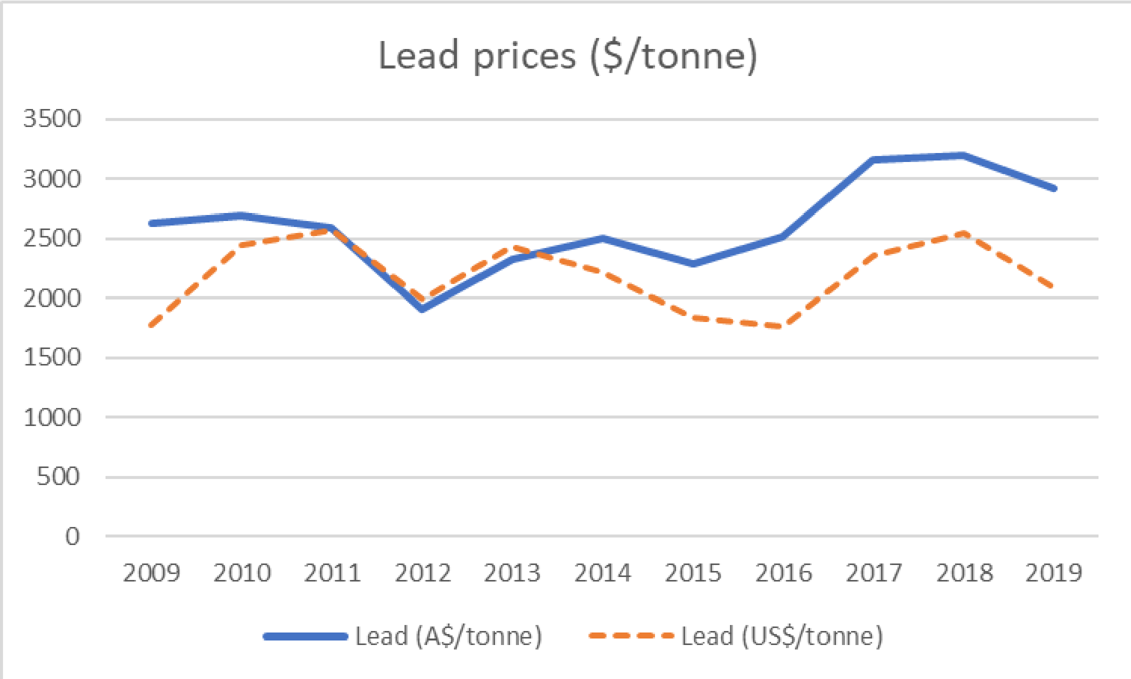
The viability of recycling lithium ion batteries in Australia in the future may well hinge on whether the batteries continue to contain significant quantities of cobalt, and the associated demand and prices for that cobalt. Significant unknowns that hamper the development of any business case for battery reprocessing infrastructure capital expenditure.

6.3.2.3 Lead

Lead acid batteries typically comprise around 60–65% lead by weight. This lead is readily recoverable and as indicated in Figure 35 below, lead prices have been reasonably steady over the past 10 years. Although prices have ranged from about AUD1900 /tonne to AUD3200 /tonne over this period, significant fluctuations have been relatively short-lived.

Prices overall have been trending upwards, particularly since 2012, reflecting reasonably strong demand, assisted by a decline in the value of the Australian dollar. Notwithstanding the impacts of the US/China trade war, the medium-term outlook from most analysts is for continued strong demand for lead in China, driven especially by growth in the automobile sector.

Figure 35 – International prices for lead, 2009–2019



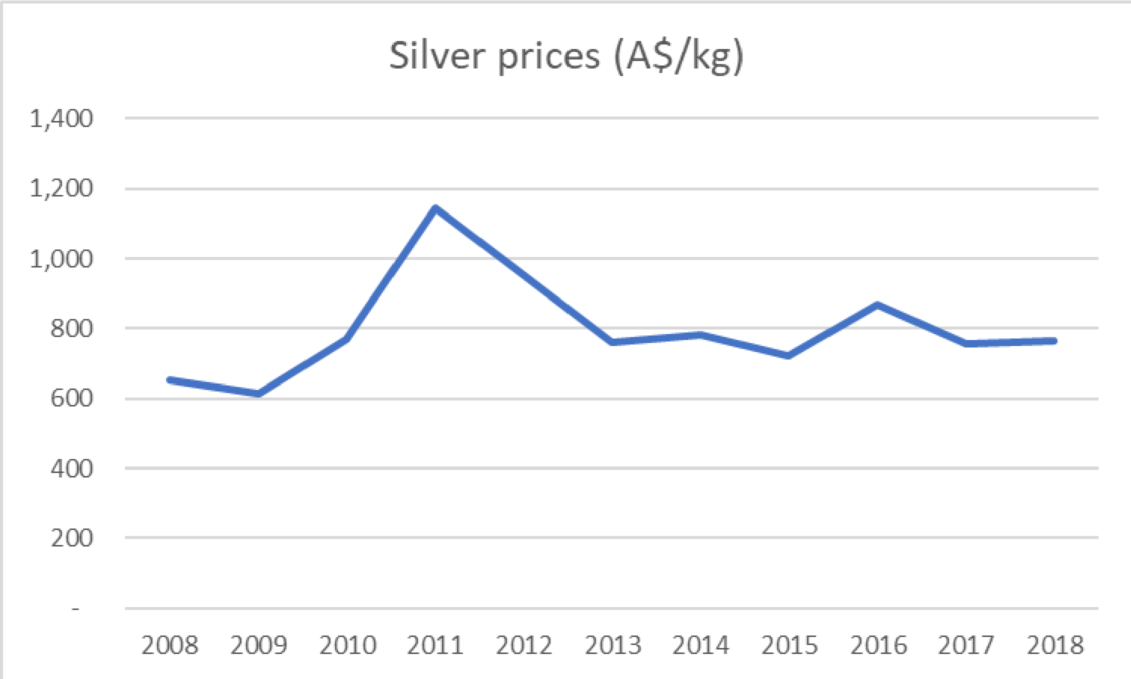
Source: Marsden Jacob Associates

6.3.2.4 Silver

Silver oxide batteries can contain up to 35% silver by weight. However, because these batteries are typically very small in size (e.g. button cells) the total amount of silver used is small and is not therefore a significant contributor to the cost of initial production.

It follows that the value of recovered silver in a button cell is low; at current prices (Figure 36) typically around 30 cents/cell. Nevertheless, it should be economically viable to recycle these batteries provided an adequate supply of the batteries can be readily obtained.

Figure 36 – International prices for silver, 2008–2019



Source: Marsden Jacob Associates

6.3.2.5 Other barriers to battery recycling

Several other market barriers and failures are likely to hinder recycling of batteries in Australia. Previous market analysis of e-waste indicates that the main barriers with respect to batteries are likely to include:

- high collection and transport costs;
- high processing costs; and/or
- information failures.

Analysis of the financial aspects of recycling batteries presented in the following section indicates that for some battery types, battery recycling is unlikely to be financially viable simply because the costs of collecting, sorting and processing the batteries often substantially outweigh the value of materials that can be recovered from the batteries. Lead-acid batteries are an obvious exception to this situation.

For other battery types high collection and transport costs are often associated with insufficient scale. This is particularly evident in regional and rural areas where lack of consumer access to collection facilities is likely to exacerbate costs that are already high due to insufficient scale.

In regional and rural areas of NSW, for example, collection and sorting costs can be between 25% and 200% higher than in metropolitan Sydney. Similarly, transport costs from regional and rural areas to processing facilities – almost all of which are located in Greater Sydney – are typically 100–400% higher than transport costs within Sydney.

Insufficient consumer information is another key barrier to recycling of batteries. A recent CSIRO report on lithium battery recycling (CSIRO, 2018) in Australia concludes that lack of consumer awareness of recycling options is the number one issue that must be addressed in order to increase Australia's lithium ion battery collection rate.

This lack of consumer awareness is underpinning the low collection rates, which in turn is limiting confidence and investment by industry into recycling infrastructure. This conclusion is consistent with prior e-waste market analyses (Marsden Jacob, 2017), which has found that a lack of consumer knowledge around:

- the existence of recycling programs and schemes (e.g. the NTCRS)
- products that can be recycled through these schemes
- where and when consumers can take batteries to be recycled through these schemes
- how confident they can be that e-waste returned for recycling will actually be recycled.

6.3.3 Environmental and health risks of batteries and battery recycling

6.3.3.1 Environmental and health risks associated with disposal of hazardous materials

Batteries can contain hazardous materials including cadmium, lead, mercury and nickel. When landfilled, stored inappropriately or illegally dumped, batteries can leach these metals and other chemical compounds. If not managed properly, this leaching can be hazardous to human populations and the environment. When disposed correctly to well-managed landfills, leaching is likely to be minimal.

A full assessment of hazardous materials contained in batteries was not undertaken for this analysis. Previous analyses of e-waste indicate that hazardous materials represent only about 0.2% of the total quantity of the waste. Proportionately, the percentage of hazardous materials will be higher in batteries due to their chemical composition. Nevertheless, only a small percentage (<1%) is likely to be at risk of leaching into the environment, with leachate rates being especially low in well-managed landfills (Marsden Jacob, 2017; Blue Environment, 2015).

6.3.3.2 Risks associated with collection, storage and recycling of e-waste

Because of the hazardous materials contained in batteries, in the absence of appropriate environmental and OH&S standards at all points in the recycling chain, workers could be exposed to significant risks and the environment could face threats from uncontrolled discharges.

OH&S and environmental regulations are in place to prevent these outcomes in all jurisdictions. In NSW, for example, large recycling facilities are licensed by the EPA under *The Protection of the Environment Operations Act 1997*. However, minimum thresholds for the quantities of batteries or hazardous materials processed mean that at least some reprocessors and many collection points and transporters of waste batteries are unlicensed.

The Australian Standard for the *Collection, storage, transport and treatment of end-of-life electrical and electronic equipment* (AS5377) provides guidance and specifies requirements for the safe and environmentally sound collection, storage, transport and treatment of end-of-life electrical and electronic equipment.

The Standard includes specific requirements for the management of batteries recovered with e-waste. Batteries need to be removed as an 'identifiable stream' before the equipment is processed and processes must be in place to 'prevent the combustion, explosion or leaking of batteries.

Again, while many facilities and operators in the e-waste and battery waste supply chains, notably larger recyclers, are certified to this standard it is likely that many smaller facilities, including collection points and logistics providers are not certified. This this could amount to 'free riding'. From a regulatory economics perspective, there is a strong case for ensuring that regulatory consistency is applied to equivalent all participants at different points in the e-waste and battery waste supply chains.

6.4 RECYCLING INDUSTRY FINANCIAL ASSESSMENT

6.4.1 Overview

The financial assessment undertaken for this project has been structured across four battery groups, which are:

Single-use batteries:

1. Alkaline chemistries – Includes alkaline and zinc carbon batteries and cells.
2. All other single-use battery chemistries – Lithium metal, silver oxide and zinc air batteries or cells.

Rechargeable batteries:

3. Lead acid.
4. All other rechargeable battery chemistries – Lithium ion, nickel cadmium and nickel metal hydride batteries.

The battery groups have been selected in part to meet agreed confidentiality arrangements, due to the small number of battery reprocessors operating in Australia.

During the data collection phase of this project end-of-life battery collectors, EEE disassemblers and reprocessors were surveyed to identify the costs and revenues through the recovery chain. In summary, these costs and revenues are:

Costs

- Collection costs incurred through providing infrastructure and staff to collect batteries or battery-operated devices, or to engage third parties to do the same.
- Any separate transport costs not included in collection costs incurred by the processor.
- Disassembling any devices to recover an embedded battery.
- Sorting batteries in types to facilitate recovery of component materials.
- Costs associated with extraction of component materials.
- Costs associated with disposal of remaining waste material (transport, landfill costs and any landfill levy).
- Costs of on selling component materials.

- Where the processor does not extract the component materials, it may be charged a gate fee by a downstream processor to which it provides batteries materials.

Revenues

- Gate fees from original suppliers of batteries or battery-operated devices.
- Revenue from materials extracted from batteries where extraction occurs.
- Potentially, gate fees charged to upstream processors for sorted batteries.

These do not include common costs such as return on capital, managerial costs or other overheads. These will vary across businesses reflecting scale and diversity of operations.

It is obvious that businesses won't undertake an activity unless it is profitable to do so (with some obvious exceptions, such as loss leading or strategic positioning). In general, for recycling, processors will charge suppliers a gate fee where it cannot recover its own costs from its final product.

For intermediate processors, batteries can represent a small element of the overall waste that was collected. These intermediate processors can generate value from other components; conversely any residual waste that can't be recovered will then need to be sent to landfill. In the case of mobile phones and computers there may be significant value in the circuit boards.

There are therefore three general cost/revenue elements for processors:

- The direct costs of processing for each type of processor.
- The (net) value derived from extracting materials. This could be represented by the gate fee obtained by exporters.
- The net cost not funded from extraction.

Note that other gate fees that are underpinned by a regulated or quasi-regulated funding mechanism are not considered here.

6.4.2 Single-use battery recycling

6.4.2.1 Alkaline batteries

Table 43 provides details of the net financial position for EoL alkaline batteries collection and recycling. After lead acid batteries, alkaline batteries represent the second most significant weight of batteries collected for reprocessing in Australia.

Where these batteries are collected for reprocessing, the revenue generated through the sale of the recovered materials is significantly outweighed by the costs of collection and reprocessing.

Table 43 – Indicative financial assessment – Alkaline batteries

Parameter	Collection and EEE disassembling	Reprocessing	Overall assessment for local processing	Local processing for export
Quantity (t)	990	990	990	0
Direct costs ($'000)	$200	$670	$870	n/a
Material value / exporter gate fee ($'000)	–	–$180	–$180	n/a
Net costs to be recovered ($'000)	$200	$490	$690	n/a
Net costs / tonne ($)	$200	$490	$690	n/a

Source: Marsden Jacob Associates

6.4.2.2 Other (non-alkaline) single-use batteries

Other single-use batteries include lithium primary, silver oxide and zinc air button cells. There are currently only small amounts of these batteries collected, with most collected for local processing being silver oxide and all for export from lithium primary cells.

Table 44 – Indicative financial assessment – Other (non-alkaline) single-use batteries

Parameter	Collection and EEE disassembling	Reprocessing	Overall assessment for local processing	Local processing for export
Quantity (t)	22	22	3	19
Direct costs ($'000)	CIC	CIC	CIC	CIC
Material value / exporter gate fee ($'000)	CIC	CIC	CIC	CIC
Net costs to be recovered ($'000)	CIC	CIC	CIC	CIC
Net costs / tonne ($)	CIC	CIC	CIC	CIC

CIC – Commercial in confidence.

Source: Marsden Jacob Associates

The reporting of data in the table above on the collection and reprocessing costs of other (non-alkaline) single-use batteries was not possible due to confidentiality constraints and a lack of information on processing costs, noting that only very small volumes of silver oxide batteries are currently processed.

There is likely to be significant net value from the extraction of silver from silver oxide batteries. This is offset by significant average collection/sorting costs for small battery sizes and volumes.

The recovered material value of reprocessing lithium primary and zinc air button cells will be relatively low, and the available quantities are low. It is highly likely that these markets will not be self-financing, even when integrated into existing collection networks.

6.4.3 Rechargeable battery recycling

6.4.3.1 Lead acid batteries

Table 45 provides details of the net position for lead acid batteries. Lead acid batteries represent the most significant weight of batteries recycled in Australia. The sector is clearly able to fund its own operations.

It is not clear if the direct costs reflect intermediate collection costs. In addition, there are likely to be higher disposal costs from the process.

Table 45 – Indicative financial assessment – Lead acid batteries

Parameter	Collection and EEE disassembling	Reprocessing	Overall assessment for local processing	Local processing for export
Quantity (t)	148,910	148,910	148,910	0
Direct costs ($'000)	$28,167	$29,465	$57,633	0
Material value / exporter gate fee ($'000)	–	$101,042	$101,042	0
Net costs to be recovered ($'000)	$28,167	–$71,577	$43,410	0
Net costs / tonne ($)	$189	–$481	–$292	0

Source: Marsden Jacob Associates

6.4.3.2 All other (non-lead acid) rechargeable batteries

The final grouping includes lithium ion, nickel cadmium and nickel metal hydride batteries.

Table 46 – Indicative financial assessment – Lithium ion, nickel cadmium and nickel metal hydride batteries

Parameter	Collection and EEE disassembling	Reprocessing	Overall assessment for local processing	Local processing for export
Quantity (t)	787	787	787	466
Direct costs ($'000)	$677	$78	$754	$710
Material value / exporter gate fee ($'000)	–	$1,107	–$1,107	–$88
Net costs to be recovered ($'000)	$677	$1,030	–$353	$622
Net costs / tonne ($)	$860	–$1,308	–$448	$1,336

Source: Marsden Jacob Associates

Nickel cadmium and nickel metal hydride chemistries are likely to have viable local reprocessing markets. However, the viability of lithium-ion batteries is likely marginal or not viable on average across all lithium-ion chemistries. Export for reprocessing is less financially viable due to lost revenue from the materials recovery from nickel cadmium and nickel metal hydride batteries.

It is important to note that for lithium-ion batteries the material values are dependent on the specific lithium-ion chemistries, and chemistries with higher compositions of some metals, in particular cobalt and nickel, can be processed to produce anode and cathode materials that are significantly more valuable than other lithium-ion chemistries that are cobalt and nickel poor (e.g. lithium iron phosphate). Sufficient data was not available to undertake financial assessments at the specific lithium-ion battery chemistry level. There is significant competitive economic pressure driving reduced usage of cobalt and nickel in lithium-ion batteries, so it can be expected that the average value of the recoverable materials used in lithium-ion batteries will reduce over time.

It is important to note that minimal processing cost information was available for processors in Australia for these battery types, and the estimated costs may be understated.

6.5 MARKET ASSESSMENT CONCLUSIONS

6.5.1 Financial viability of battery collection and reprocessing

Based on the analysis, detailed in the previous section, the financial viability of the collection and intermediate (disassembling) stages of non-lead acid battery recovery is very uncertain. Preliminary analysis suggests that the collection and disassembling stages are not viable financially if battery collection and disassembly are considered in isolation.

However, given that recovered batteries are typically housed in larger products that contain other recoverable materials (e.g. computers, which contain circuit boards as well as the batteries), the overall financial viability of the collection and disassembling stages depends on the value that the intermediate processors receive for these other materials.

Based on analysis undertaken for previous studies (e.g. Marsden Jacob (2017), which was extensively used in the Victorian e-waste review in 2017), the financial viability of e-waste recovery at the collection and disassembly stages is only marginal at best.

Furthermore, analysis of the financial position of the battery processing stage of recovery indicates that reprocessing of the major battery types of alkaline and lithium ion to recover material is generally not financially viable. The value of recovered materials are significantly exceeded by reprocessing and other associated costs (e.g. disposal of residual waste).

In coming to this conclusion, it is also important to note that there is no allowance for any costs associated with purchasing recovered batteries from intermediate battery processors.

Another key factor holding back recycling is ensuring an adequate supply of sorted batteries provided through the intermediate processing stage. In addition, reprocessing operations may need to contribute towards overheads and common costs incurred at the intermediate stage.

6.5.2 Potential interventions

Discussion in the proceeding sections indicates that low recovery rates of most battery types, lead acid batteries excepted, is being contributed to by the marginal financial viability of battery recycling, especially at the collection and disassembling stages of recycling. A key pathway forward is ensuring an adequate supply of sorted batteries through the intermediate processing stage. This, in turn, is likely require active intervention in the form of a range of policies and programs.

6.5.2.1 Product stewardship

The development of a separate product stewardship scheme specifically focused on batteries, such as that proposed by the Battery Stewardship Council (BSC), offers perhaps the most straightforward pathway for significantly increasing the supply of sorted batteries for recovery. This is particularly the case given the diverse range of chemistries and applications that batteries consist of or are used in.

Product stewardship schemes do work, and the National TV and Computer Recycling Scheme (NTCRS) is a successful example of such a scheme. The NTCRS is the key driver of recycling of televisions, computers and computer peripherals in Australia. Commencing in 2012, the NTCRS was established as a co-regulatory product stewardship under the *Product Stewardship Act 2011*. Four 'Co-regulatory Arrangements' are responsible for operating the Scheme on behalf of liable manufacturers and importers of TVs and computers. These are:

- Australia and New Zealand Recycling Platform Limited (ANZRP), operating as Techcollect;
- MRI PSO Pty Ltd;
- Ecocycle Solutions Pty Ltd; and
- Electronic Product Stewardship Australasia (EPSA).

Under the NTCRS recycling of televisions and computers has increased to over 60%, from only about 20% before scheme commencement. Although batteries contained in computers are not specifically required to be recycled under the NTCRS, it is notable that 3 of the 4 scheme Co-regulatory Arrangements are involved in battery recycling including through collection, disassembly or reprocessing.

Although there have been some criticisms of aspects of the NTCRS, stakeholder consultation, undertaken as part of an NSW e-waste market analysis, indicates very strong support for continuing and extending the NTCRS to include other products (Marsden Jacob, 2018).

A key advantage of a product stewardship scheme for batteries, as with the NTCRS, is that the costs of battery recycling, including collection and disassembly costs, will paid for consumers, passed on by battery suppliers who bear the initial cost.

6.5.2.2 Targeted infrastructure investment

With or without a product stewardship scheme in place, targeted investment recycling infrastructure is likely to be required, especially to enhance the network of collection infrastructure.

The costs to consumers of accessing collection or drop-off services – often referred to as 'participation costs', can be a major barrier to recycling. Those costs, which include travel cost as well the opportunity cost of time, can be significant, even where there is reasonable access (as defined in Box 1 below).

Overcoming this barrier requires significant investment in collection infrastructure, especially if a good level of access is to be achieved (see Box 1).

Table 47 – 'Reasonable access' and 'good access' definitions

Region	Access definition and key criteria	
	Good access	**Reasonable access**
Metropolitan	At least one permanent drop-off point in every municipality plus 1-2 mobile collection events in alternative locations in every municipality.	One permanent drop-off point for every 250,000 people plus mobile collection events in municipalities that don't have a permanent drop-off point.
Regional, rural and remote	One permanent drop-off point for every municipality plus a permanent drop-off point or event for every town of 2,000 people or greater.	One permanent drop-off point for every municipality plus a permanent drop-off point or event for every town of 4,000 people or greater.

Box 1: Reasonable level of access for battery collection

'Reasonable access' is a concept promoted in relation to a range of government services. There is no hard and fast definition of reasonable access. With waste management services, for example, different definitions of reasonable access are applied to the design of collection systems for the National Television and Computer Recycling Scheme (NTCRS) compared with, for example, container deposit schemes that are in place in different jurisdictions. Previous analysis by Marsden Jacob (2017) has used the following definition of access in the context of e-waste collection:

> *A travel distance of less than 10 kilometres each way in metropolitan areas, which requires less than 20 minutes of driving time each way in non-peak hour traffic. In regional areas the estimated level of access is based on the proportion of the population living within 25 kilometres of towns providing an e-waste service, which also requires less than 20 minutes of driving time each way*.

Drawing on this definition of access, good access is defined as access for at least 98% of households in metropolitan areas and at least 90% of households in regional and remote areas. Reasonable access is defined as access for >90% of households in metropolitan areas and at least 80% of households in regional and remote areas. The criteria required to achieve these outcomes are presented in Table 47. Based on these definitions and criteria, reasonable access for battery recycling probably requires collection points and events in at least 150 different localities across metropolitan areas in Australia and at least 250 in regional and rural areas. Good access probably requires collection points and events in at least 250 different localities across metropolitan areas, as a minimum, and more than 350 in regional and rural areas.

6.5.2.3 Enhanced community information and educations programs

Investment in improved community information and education is likely to be an important complement to a battery stewardship scheme and infrastructure investment. A program should be designed and implemented by marketing specialists and focus on improving understanding by households and businesses about what types of batteries can be recycled and where they can take the batteries to ensure that they are recycled.

6.5.2.4 Improved data collection

Improved information on how much battery waste is being generated and how much is being recovered will also be an important complement to other market interventions. Data reporting on collection and recovery rates can be integral component of a battery stewardship scheme.

7 LOCAL GOVERNMENT ACTIVITY REVIEW

7.1 OVERVIEW OF SURVEY PROCESS AND RESPONDING COUNCILS

7.1.1 Method

Local governments throughout Australia were asked to contribute to the study by answering a short (5 minute) online survey about their council's battery recycling programs.

Councils were asked to provide information and feedback on:

- Whether or not council provides any battery collection services.
- Who is the service offered to.
- What sort of drop-off points are offered.
- What are the batteries chemistries accepted.
- What quantity of batteries are recovered.
- Why does council offer the service.
- Could additional collection services be implemented or current services expanded, and if so what would be required for this to occur.

Representatives were invited to complete the survey via direct email from the project team and communications through local government associations.

7.1.2 Response

The target for this phase of the study was feedback from 60–80 local governments. In total the survey received 121 usable local government responses. The sample represents approximately:

- 23% of the 537 Australian councils[1]
- more than 4 million households; or around 40% of all Australian households.

Some responses were from Regional Councils, representing the waste management functions of multiple individual local governments.

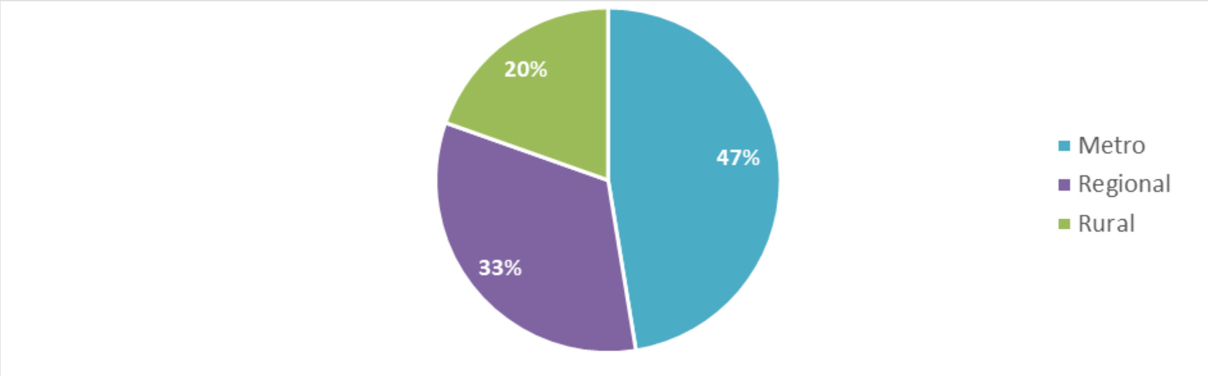
By state, responding councils were split as follows:

- 26% New South Wales
- 22% Victoria
- 21% Western Australia
- 19% Queensland
- 13% South Australia

The local government sample included a mix of metropolitan, regional and rural councils as seen below.

[1] https://alga.asn.au/facts-and-figures/

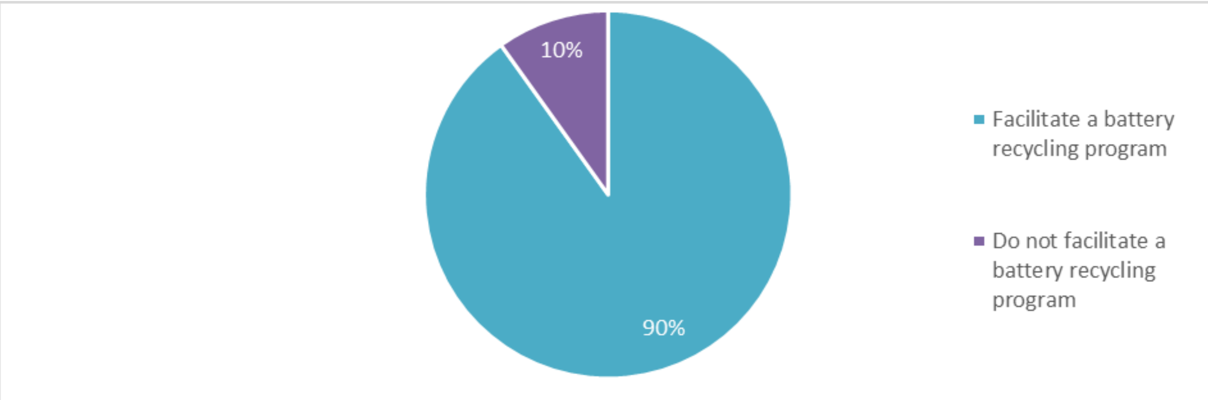
Figure 37 – Type of local government area



7.2 OVERVIEW OF LOCAL GOVERNMENT BATTERY RECYCLING

Most of the local governments responding to the survey indicated that their council operates a battery collection or recycling program (90%). Although councils were asked to participate in the study *whether or not they provide a battery recycling program*, it is likely that this finding over-represents the incidence of battery recycling in Australian councils due to non-response bias, as local governments not offering any kind of battery program may have been less likely to voluntarily participate in the study.

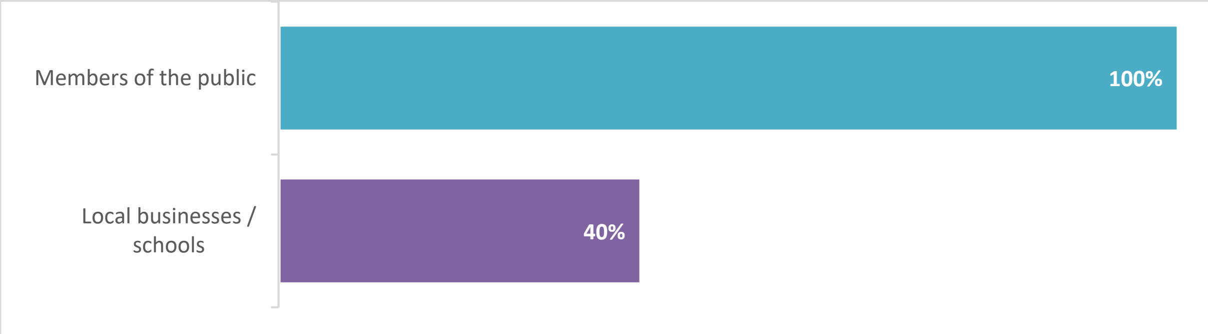
Figure 38 – Proportion of surveyed councils offering battery collection or recycling programs



7.2.1 Availability

Members of the public, namely residents, are the focus of council battery recycling initiatives. All responding councils with battery programs indicated that the service is available to members of the public. Many (40%) also indicated the service is available to local businesses and/or schools.

Figure 39 – Target users of local government battery recycling programs



7.2.2 Collection methods

Local government battery recycling initiatives typically rely on proactive drop-off by members of the public. Accessibility of drop off points varies greatly. For some there is a single drop off point, often either the main administration building (particularly for household batteries), or a transfer station or waste facility (particularly for ULABs).

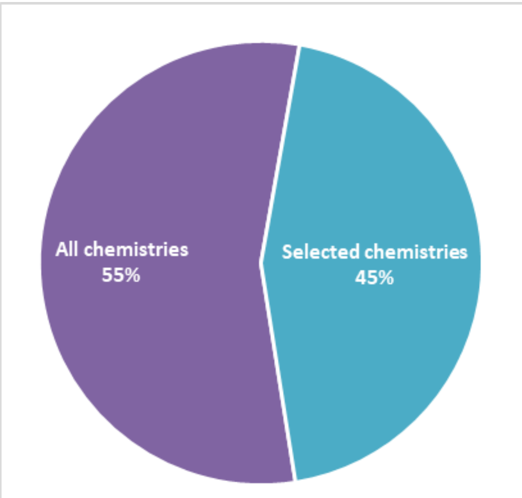
In contrast, some local councils provide many drop off sites which may include; libraries and other public council buildings, schools, shopping centres, community recycling centres, and local businesses.

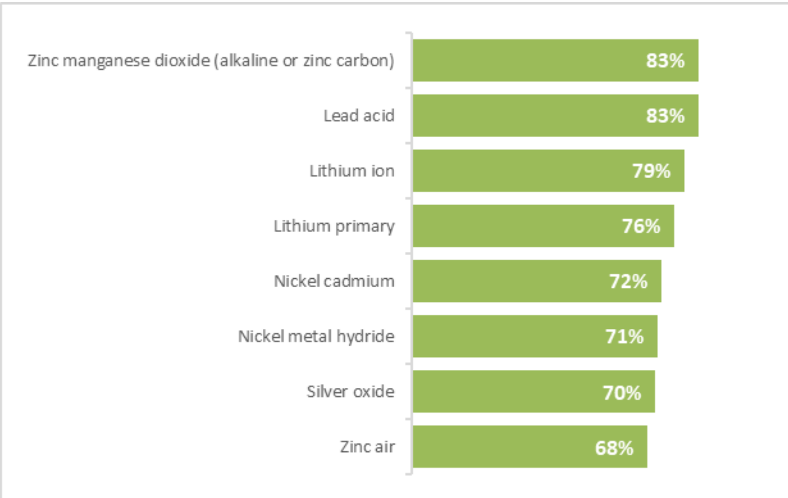
7.2.3 Battery chemistries

More than half of surveyed councils with battery collection programs collect all battery chemistries, while the remainder only collect some chemistry types. In some cases, it is unclear whether the council only *accepts* certain chemistries, or whether they only *receive* some chemistry types.

More than three quarters of surveyed councils who provided information on collected battery chemistries indicated that they collect alkaline (83%), lead acid (83%), lithium ion (79%) and/or lithium primary batteries (76%).

Figure 40 – Battery chemistries included in local government recycling programs (% of responding councils with battery programs)





7.2.4 Volume of collected batteries

Many surveyed councils do not have accessible data on the volume of batteries collected. In some instances, this data is maintained elsewhere; examples include Sustainability Victoria in Victoria, the WA Local Government Association (WALGA) in WA, collective regional councils, and recycling contractors. For other councils, battery collection programs are relatively new, so data is not yet available.

In total, 57 surveyed councils provided an estimate for the volume of batteries collected in the 2017–18 financial year. Findings from the provided data include:

- 1,222 tonnes total combined weight from these 57 councils.
- Lead acid batteries account for more than 40% of reported volume.
- 21 tonnes per council on average, however reported volume ranged from less than 50 kg to more than 250 tonnes.
- Just under 1 kg per household on average. However, the average weight of batteries per drop-off was not determined.

7.3 FACTORS UNDERPINNING LOCAL GOVERNMENT BATTERY RECYCLING INITIATIVES

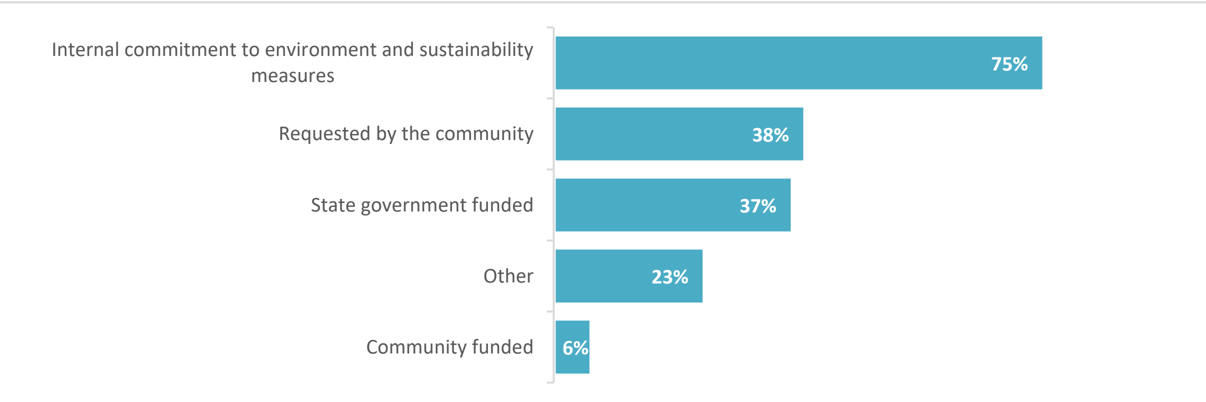
7.3.1 Battery recycling drivers

Most of the local governments responding to the survey indicated that the drive for their council to provide a recycling program was due to an internal commitment to good environmental management and sustainability (75% of local governments with battery collection programs). Community pressure (38%), and state government funding (37%) also play a role in encouraging battery recycling within local governments (see Figure 41).

Significantly more metropolitan councils indicated that they engage in battery recycling programs because of community requests (59%), compared to regional (27%) or rural (19%) councils.

“Other” reasons that councils provide battery recycling programs include revenue generation from lead acid batteries, and keeping batteries out of landfill due to environmental, toxicity, and fire hazard concerns.

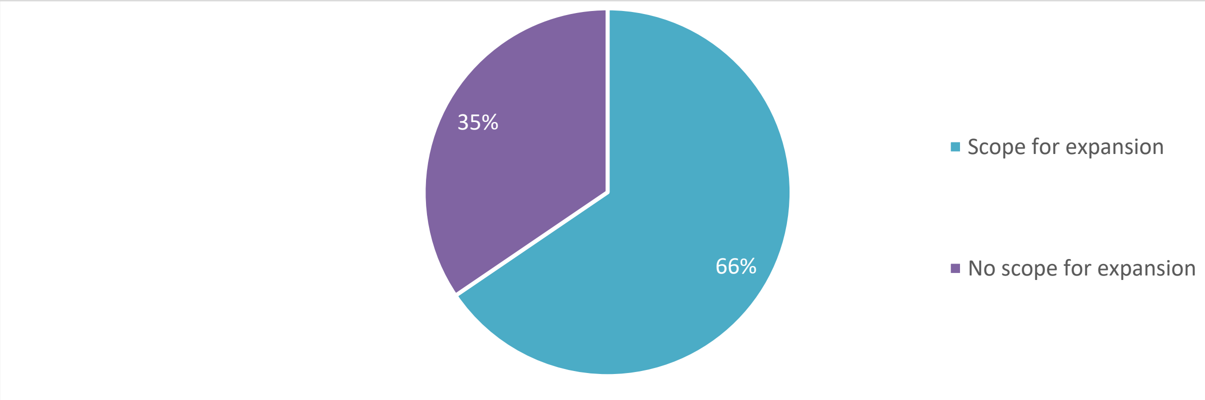
Figure 41 – Local government battery recycling program drivers



7.3.2 Scope for expansion

As shown in Figure 41 two thirds of local governments with existing battery recycling programs have potential scope for expansion.

Figure 42 – Potential for expansion of existing local government battery recycling programs



Justification from those suggesting no scope for expansion include:

- Current program is adequate to meet demand.
- Current program is under-utilised by public.
- Already collecting from all viable sites.
- Costs / lack of funding.
- Challenges of transport to, or collection by, recyclers in remote areas.
- No product stewardship scheme (which should aim to make recovery cost neutral for councils).

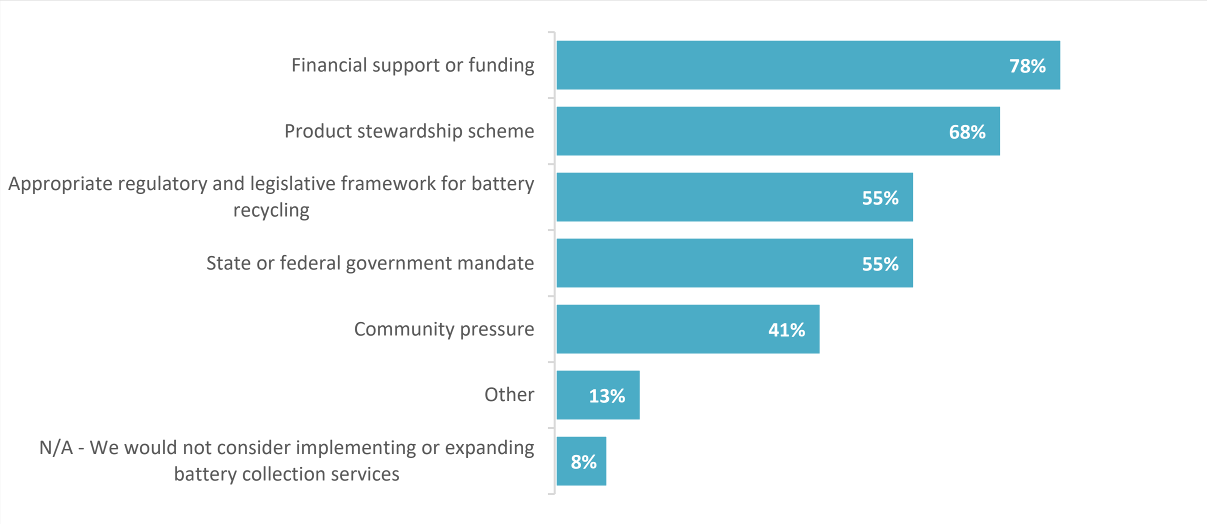
7.3.3 Conditions for considering implementing or expanding battery recycling

As shown in Figure 43 funding (78%) and a product stewardship scheme (68%) are the conditions most likely to prompt local governments to implement or expand battery collection or recycling initiatives.

Financial support / funding (87%) and product stewardship (81%) are particularly important for councils in regional areas in considering expanding or implementing battery programs.

A small number of local government representatives indicated that their council would not consider expanding battery collection services (8%). This subset of responses all refer to the expansion of existing services, not implementation of new services.

Figure 43 – Conditions for considering implementing or expanding battery recycling services (Councils with and without current programs)



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APPENDIX A – STAKEHOLDER CONSULTATION

The organisations contacted during the stakeholder consultation phase of the project are outlined in the following table.

Organisation name	Organisation type
Adeal (Vitec)	Brand-owner
Bosch	Brand-owner
BYD	Brand-owner
Canon (Australia)	Brand-owner
Century Yuasa Batteries	Brand-owner
Cisco	Brand-owner
Duracell Company (Berkshire Hathaway Group)	Brand-owner
Dyson	Brand-owner
Energizer	Brand-owner
Enphase	Brand-owner
GNB (Exide Technologies US)	Brand-owner
Hitachi	Brand-owner
LG Chem	Brand-owner
LG Electronics	Brand-owner
Makita	Brand-owner
Marshall Batteries (Exide)	Brand-owner
NBN Co	Brand-owner
Panasonic Australia	Brand-owner
Positec (Rockwell, Worx)	Brand-owner
Ramcar Batteries (Enirgi Metal Group)	Brand-owner
Remington Products (Varta)	Brand-owner
RF Industries	Brand-owner
Samsung Australia	Brand-owner
Stanley Black & Decker	Brand-owner
Techtronic Industries	Brand-owner
Tesla	Brand-owner
Tooltechnic Systems (Australia) Pty Ltd	Brand-owner
Toshiba	Brand-owner
Toyota Motor Corporation Australia	Brand-owner
TradeTools	Brand-owner
Zen Energy	Brand-owner
ALDI	Brand-owner / retailer
Amazon	Brand-owner / retailer
Apple (Australia)	Brand-owner / retailer
Battery World	Brand-owner / retailer
Bunnings	Brand-owner / retailer

Organisation name	Organisation type
Coles Supermarkets	Brand-owner / retailer
IKEA	Brand-owner / retailer
Metcash / IGA	Brand-owner / retailer
Officeworks	Brand-owner / retailer
R&J Batteries	Brand-owner / retailer
Super Retail Group	Brand-owner / retailer
Wesfarmers	Brand-owner / retailer
Woolworths	Brand-owner / retailer
Cleanaway	Collector
Ecycle Solutions	Collector
Electronic Recycling Australia	Collector
Endeavour Foundation	Collector
Infoactiv Australia	Collector
ACT NOWaste | ACT Government	Government
Department of the Environment and Energy	Government
Green Industries SA	Government
Local Government Association of Queensland	Government
Local Government Association of South Australia	Government
Local Government Association Tasmania	Government
Local Government NSW	Government
Municipal Association of Victoria (MAV)	Government
NSW Environment Protection Authority	Government
Queensland Department of Environment and Science	Government
Sustainability Victoria	Government
WA Department of Environment and Water Regulation	Government
WA Local Government Association (WALGA)	Government
Australian Industry Group (Ai Group)	Industry group
Australian Information Industry Association (AIIA)	Industry group
Australian Mobile Telecommunications Association (AMTA)	Industry group
Australian Toy Association	Industry group
Clean Energy Council	Industry group
Consumer Electronics Suppliers Association (CESA)	Industry group
Lighting Council of Australia	Industry group
Sunwiz Solar Consultants	Industry specialist
Australia and New Zealand Recycling Platform (ANZRP) / TechCollect	Reprocessor
BAT REC Battery Recycling	Reprocessor
Certified Destruction Services (CDS Recycling)	Reprocessor
Close the Loop	Reprocessor
Dodd & Dodd Group	Reprocessor
Ecocycle Australia Pty Ltd	Reprocessor
Enirgi Metal Group (Ramcar Batteries)	Reprocessor

Organisation name	Organisation type
Envirostream Australia	Reprocessor
Global Renewables	Reprocessor
Hydromet Corporation Pty Ltd	Reprocessor
Lex Enviro	Reprocessor
Lithium Australia	Reprocessor
MRI PSO Pty Ltd	Reprocessor
ReSource Pty Ltd	Reprocessor
Sims E-Recycling Pty Ltd	Reprocessor
TES-AMM Australia Pty Ltd	Reprocessor
Total Green Recycling	Reprocessor
Tricycle	Reprocessor
V-Resource	Reprocessor

APPENDIX B – BATTERY CHEMISTRIES, SIZES AND APPLICATIONS

B-1 BATTERY CHEMISTRIES

Chemistry	Chemistry group	Comments
Zinc manganese dioxide – alkaline	Alkaline	Zinc metal anode, manganese dioxide and carbon cathode, and electrolyte of potassium hydroxide.
Zinc manganese dioxide – zinc carbon	Alkaline	Zinc metal anode, manganese dioxide and carbon cathode, and electrolyte of zinc chloride and ammonium chloride.
Zinc manganese dioxide – zinc chloride	Alkaline	Zinc metal anode, manganese dioxide and carbon cathode, and electrolyte of zinc chloride.
Lead acid – flooded	Lead acid	Unsealed lead acid battery types.
Lead acid – sealed	Lead acid	Sealed lead acid battery types include gel batteries and absorbed glass mat (AGM) batteries.
Lithium ion (unknown specific chemistry)	Lithium ion	Listing for lithium ion batteries where the specific chemistry is unknown.
Lithium cobalt oxide ($LiCoO_2$)	Lithium ion	Also known as Li- cobalt or LCA. Applications include: mobile phones, laptops, tablets cameras.
Lithium iron phosphate ($LiFePO_4$)	Lithium ion	Also known as lithium ferrous or lithium ferro phosphate (LFP). Applications include: BESSs (e.g. BYD, CALB and Sony), power tools, e-bikes, EVs, medical applications.
Lithium manganese oxide ($LiMn_2O_4$)	Lithium ion	Also known as Li-manganese, LMO or lithium manganese-spinel. Applications include: power tools, e-bikes, EVs, medical devices, hobbies.
Lithium nickel cobalt aluminium oxide ($LiNiCoAlO_2$)	Lithium ion	Also known as (lithium) nickel cobalt aluminium (NCA). Applications include: electric vehicles (EVs) and grid storage.
Lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$)	Lithium ion	Also known as (lithium) nickel manganese cobalt (NMC). Applications include: BESSs (e.g. LG Chem, Samsung and Tesla), power tools, e-bikes, EVs (e.g. Tesla), medical applications.
Lithium ion polymer	Lithium ion	Lithium ion battery chemistries with a polymer electrolyte. Various applications including consumer electronics, EVs.
Lithium titanate ($Li4Ti_5O_{12}$)	Lithium ion	Also known as Li- titanate or LTO. Applications include: grid storage, EV, buses and ferries.
Lithium iron disulfide $LiFeS_2$)	Lithium primary	Primary cell or battery. Applications include: AA and AAA cells for consumer products.
Lithium manganese dioxide	Lithium primary	Primary cell or battery. Applications include: button cells for consumer products, defence applications.
Lithium sulfur (Li-S)	Lithium primary	Emerging technology with rechargeable lithium metal anode.
Nickel cadmium	Nickel cadmium	

Nickel metal hydride	Nickel metal hydride	
Silver oxide	Silver oxide	
Zinc air	Zinc air	Zinc metal anode, oxygen cathode, and electrolyte of zinc chloride and ammonium chloride.

B-2 BATTERIES SIZES OR WEIGHT RANGES

Size or weight range
AA
AAA
Button cell
C
D
Lantern (6 V)
9 V
Laptop
Mobile phone
Tablet
Power tool
<10 g
10–49 g
50–99 g
100–499 g
500–999 g
1000–4999 g
5–10 kg
>10–50 kg
>50–100 kg
>100 kg

B-3 BATTERY APPLICATIONS

Application	Application area	Primary market segment
Standard single-use applications	Consumer electronics	Handheld (<5 kg)
Cameras	Consumer electronics	Handheld (<5 kg)
Cordless phones and answering machines	Consumer electronics	Handheld (<5 kg)
Health / hygiene and wearable devices	Consumer electronics	Handheld (<5 kg)
Laptops	Consumer electronics	Handheld (<5 kg)
Mobile phones	Consumer electronics	Handheld (<5 kg)
Remote controls	Consumer electronics	Handheld (<5 kg)
Tablets	Consumer electronics	Handheld (<5 kg)
Watches and calculators	Consumer electronics	Handheld (<5 kg)
Other consumer electronic devices	Consumer electronics	Handheld (<5 kg)
Torches/lanterns	Torches/lanterns	Handheld (<5 kg)
Blowers, vacuums, trimmers, garden edgers and similar	Power tools & gardening equipment	Handheld (<5 kg)
Drills, circular saws, sanders, routers and similar	Power tools & gardening equipment	Handheld (<5 kg)
Lawn mowers (electric)	Power tools & gardening equipment	Handheld (<5 kg)
Other handheld tools	Power tools & gardening equipment	Handheld (<5 kg)
Toys	Toys	Handheld (<5 kg)
Video game consoles and related	Toys	Handheld (<5 kg)
Other toys	Toys	Handheld (<5 kg)
e-bicycles	Personal mobility	BESS & EV
Power wheelchairs	Personal mobility	BESS & EV
Other personal mobility (e.g. golf buggies, boating)	Personal mobility	BESS & EV
BESSs – residential	Storage, emergency & standby	BESS & EV
BESSs – commercial & utility	Storage, emergency & standby	BESS & EV
Emergency lighting	Storage, emergency & standby	Handheld (<5 kg)
Fire and burglar alarms	Storage, emergency & standby	Handheld (<5 kg)
Street and garden lights	Storage, emergency & standby	Handheld (<5 kg)
Uninterruptible power supply (UPS)	Storage, emergency & standby	Lead acid (≥5 kg)

Other storage, emergency and standby	Storage, emergency & standby	Lead acid (≥5 kg)
Engine starting	Vehicles	Lead acid (≥5 kg)
EVs – passenger	Vehicles	BESS & EV
EVs – commercial	Vehicles	BESS & EV
Other traction applications	Vehicles	Lead acid (≥5 kg)
Outdoor public works	Other application area	Lead acid (≥5 kg)
Farming applications	Other application area	Lead acid (≥5 kg)
Industrial applications	Other application area	Lead acid (≥5 kg)
Mining applications	Other application area	Lead acid (≥5 kg)
All other applications	Other application area	Handheld (<5 kg)

APPENDIX C – AVERAGE BATTERY WEIGHTS

This table is the summary of default battery weights (per battery) by battery size and chemistry, adopted throughout the study as required. It is a synthesis of battery weights obtained through the consumption surveys and audited battery weights.

Size or weight range	Average battery weights (g/battery)								
	Alkaline	Lead acid	Lithium ion	Lithium primary	Nickel cadmium	Nickel metal hydride	Silver oxide	Zinc air	Other
AA	20.5	0.0	15.0	15.0	16.7	25.8	0.0	0.0	18.6
AAA	10.6	0.0	0.0	7.5	9.5	10.0	0.0	0.0	9.4
Button cell	2.1	0.0	0.0	2.7	0.0	0.0	0.9	0.5	1.6
C	59.1	0.0	0.0	42.0	71.0	66.0	0.0	0.0	59.5
D	125.7	0.0	0.0	83.9	101.0	73.0	0.0	0.0	95.9
Lantern (6 V)	683.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	683.0
9 V	44.8	0.0	0.0	35.4	0.0	31.0	0.0	0.0	37.1
Laptop	0.0	0.0	299.4	0.0	0.0	0.0	0.0	0.0	299.4
Mobile phone	0.0	0.0	49.5	0.0	110.0	92.0	0.0	0.0	83.8
Tablet	0.0	0.0	125.0	0.0	0.0	0.0	0.0	0.0	125.0
Power tool	0.0	0.0	605.3	0.0	577.0	150.0	0.0	0.0	444.1
<10 g	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4
10–49 g	30.0	0.0	43.3	13.8	0.0	29.5	0.0	0.0	29.1
50–99 g	0.0	0.0	62.0	0.0	75.0	74.5	0.0	0.0	70.5
100–499 g	201.0	325.0	167.9	0.0	300.0	263.0	0.0	0.0	251.4
500–999 g	0.0	712.0	531.6	0.0	577.0	0.0	0.0	0.0	606.9
1000–4999 g	0.0	2,710.6	3,000.0	2,999.5	2,560.7	0.0	0.0	0.0	2,817.7

Size or weight range	Average battery weights (g/battery)								
	Alkaline	Lead acid	Lithium ion	Lithium primary	Nickel cadmium	Nickel metal hydride	Silver oxide	Zinc air	Other
5–10 kg	0.0	8,055.0	7,500.0	0.0	7,522.2	0.0	0.0	0.0	7,692.4
>10–50 kg	0.0	20,006.8	44,000.0	0.0	29,463.3	50,000.0	0.0	0.0	35,867.5
>50–100 kg	0.0	63,125.0	90,912.9	0.0	63,875.0	75,000.0	0.0	0.0	73,228.2
>100 kg	0.0	0.0	350,584.8	0.0	0.0	0.0	0.0	0.0	350,584.8

APPENDIX D – DATA SOURCES AND ASSUMPTIONS FOR ANNUAL BATTERY SALES BY CHEMISTRY

Provided in this appendix is a summary of the main data sources and underlying assumptions applied in the modelling to determine annual changes in sales of batteries by chemistry group across the period of 2003–04 to 2049–50.

D-1 ALKALINE BATTERIES

2003–04 to 2012–13 period

- Total alkaline battery sales estimates for 2003–04 to 2012–13 based on SRU (2014) estimated alkaline battery sales.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total alkaline battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) estimated alkaline battery sales.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2017–18 period

- Total alkaline battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Market growth assumed flat from 2018–19 to 2049–50, based on average annual change of imports across 2009–10 to 2018–19 of less than 1%, and assumed ongoing competition by rechargeable chemistries.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

D-2 LEAD ACID BATTERIES

2003–04 to 2012–13 period

- Battery sales estimates for 2003–04 to 2012–13 based on compound annual growth rate (CAGR) derived from DFAT (2019a) import data totals across the period of 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) import data totals.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2017–18 period

- Total lead acid battery sales based on imported and locally manufactured lead acid battery estimates for 2017–18.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Toys; Power wheelchairs; Other storage, emergency and standby; Other traction applications; Industrial applications – Market growth assumed flat from 2018–19 to 2049–50 due to competition by other rechargeable chemistries.
- BESSs – residential, BESSs – commercial & utility – Market growth assumed sharp fall annually from 2018–19 to 2049–50 due to ongoing loss of market share to other rechargeable chemistries.
- Engine starting – Market growth assumed proportional to estimated all vehicle registrations, minus uptake of EVs. Cumulative EV sales is adopted as a proxy for EV registrations from 2018–19 to 2049–50.

D-3 LITHIUM ION BATTERIES

2003–04 to 2012–13 period

- Total lithium ion battery sales estimates for 2003–04 to 2012–13 based on SRU (2014) estimated lithium ion battery sales.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total lithium ion battery sales estimates for 2013–14 to 2016–17 based on interpolated lithium ion battery sales between 2012–13 and 2017–18.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total lithium ion battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Cameras; Laptops; Mobile phones; Tablets; Blowers, vacuums, trimmers, garden edgers and similar; Drills, circular saws, sanders, routers and similar; Other handheld tools; Toys – Assumed per capita growth 2018–19 to 2049–50.
- Lawn mowers (electric) – Assumed 10% annual growth rate to 2029–30 (high default rate), and per capita growth from 2030–31 to 2049–50.
- e-bicycles – Assumed 5% annual growth rate to 2029–30 (medium default rate), and per capita growth from 2030–31 to 2049–50.
- BESSs – residential, BESSs – commercial & utility – Growth out to 2049–50 based on Energeia (2019) BESS market projections. Residential and commercial/utility sales allocated based 2018 sales data (SunWiz, 2019).

- EVs – passenger, EVs – commercial – Growth out to 2049–50 based on Energeia (2019) EV market projections (but with flat sales of EVs from 2042–43, instead of decreasing sales). Passenger and commercial vehicle sales allocated based CSIRO (2019) estimates. Passenger vehicle battery size projections based on BITRE (2019). No data available on commercial vehicle battery size so conservatively assumed to be the same as passenger BEVs. Battery gravimetric energy density based on lithium nickel manganese cobalt (NMC) chemistry, and density improvement projections to 2030 based on Elbanhawi, et. al. (2017).

D-4 LITHIUM PRIMARY BATTERIES

2003–04 to 2012–13 period

- Total lithium primary battery sales estimates for 2003–04 to 2012–13 based on SRU (2014) estimated lithium primary battery sales.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total lithium primary battery sales estimates for 2013–14 to 2016–17 based on interpolated lithium primary battery sales between 2012–13 and 2017–18.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total lithium primary battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Assumed per capita growth 2018–19 to 2049–50.

D-5 NICKEL CADMIUM BATTERIES

2003–04 to 2012–13 period

- Total nickel cadmium battery sales estimates for 2003–04 to 2012–13 based on SRU (2014) estimated nickel cadmium battery sales.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total nickel cadmium battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) estimated nickel cadmium battery sales.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total nickel cadmium battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Market growth assumed flat from 2018–19 to 2049–50 based on assumed ongoing competition by other rechargeable chemistries.
- Pro-rated to applications based on 2017–18 estimated application splits.

D-6 NICKEL METAL HYDRIDE BATTERIES

2003–04 to 2012–13 period

- Total nickel metal hydride battery sales estimates for 2003–04 to 2012–13 based on SRU (2014) estimated nickel metal hydride battery sales.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total nickel metal hydride battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) estimated nickel metal hydride battery sales.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total nickel metal hydride battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Cordless phones and answering machines; Other consumer electronic devices – Assumed per capita growth 2019–20 to 2049–50. Pro-rated to applications based on 2017–18 estimated application splits.
- EVs – passenger – No data available, but known that Toyota is bringing in PHEVs with lithium ion batteries starting in 2019–20. Assumed -10% market growth from 2019–20 to 2049–50 as assumed that the large format NiMH batteries will be phased out of the market.

D-7 SILVER OXIDE BATTERIES

2003–04 to 2012–13 period

- Total silver oxide battery sales estimates for 2003–04 to 2012–13 based on the 5 year CAGR silver oxide battery sales from 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total silver oxide battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) estimated silver oxide battery sales.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total silver oxide battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.

- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Total silver oxide battery sales estimates for 2019–20 to 2049–50 based on the 5 year CAGR silver oxide battery sales from 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 estimated application splits.

D-8 ZINC AIR BATTERIES

2003–04 to 2012–13 period

- Total zinc air battery sales estimates for 2003–04 to 2012–13 based on the 5 year CAGR zinc air battery sales from 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total zinc air battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) estimated zinc air battery sales.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total zinc air battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.
- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses

2018–19 to 2049–50 period

- Total zinc air battery sales estimates for 2019–20 to 2049–50 based on the 5 year CAGR zinc air battery sales from 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 estimated application splits.

D-9 ALL OTHER BATTERIES

2003–04 to 2012–13 period

- Total other chemistries battery sales estimates for 2003–04 to 2012–13 based on the 5 year CAGR other chemistries battery sales from 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 target year sales survey responses.

2013–14 to 2016–17 period

- Total other chemistries battery sales estimates for 2013–14 to 2016–17 based on DFAT (2019a) estimated other chemistries battery sales.
- Pro-rated to applications based on 2017–18 estimated application splits.

2017–18 period

- Total other chemistries battery sales estimates for 2017–18 primarily based on DFAT (2019a) import data.

- Allocated to applications based on analysis of DFAT (2019a) import data and sales survey responses.

2018–19 to 2049–50 period

- Total other chemistries battery sales estimates for 2019–20 to 2049–50 based on the 5 year CAGR other chemistries battery sales from 2013–14 to 2018–19.
- Pro-rated to applications based on 2017–18 estimated application splits.

APPENDIX E – BATTERY LIFESPANS BY APPLICATION AREA AND CHEMISTRY

Application area	Chemistry	Age at disposal (yrs)	Reference	Comments
Consumer electronics	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Torches/lanterns	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Power tools & gardening equipment	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Toys	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Personal mobility	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Storage, emergency & standby	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Vehicles	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Other application area	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Unknown	Alkaline	1.75	Warnken ISE (2010, p. 69)	
Consumer electronics	Lead acid	5.0	Warnken ISE (2010, p. 79)	Average lifespan adopted of golf carts, mobility assisted travel and electric fork lift equipment.
Torches/lanterns	Lead acid	5.0	Warnken ISE (2010, p. 79)	Average lifespan adopted of golf carts, mobility assisted travel and electric fork lift equipment.
Power tools & gardening equipment	Lead acid	5.0	Warnken ISE (2010, p. 79)	Average lifespan adopted of golf carts, mobility assisted travel and electric fork lift equipment.
Toys	Lead acid	5.0	Warnken ISE (2010, p. 79)	Average lifespan adopted of golf carts, mobility assisted travel and electric fork lift equipment.
Personal mobility	Lead acid	5.0	Warnken ISE (2010, p. 79)	Average lifespan adopted of golf carts, mobility assisted travel and electric fork lift equipment.
Storage, emergency & standby	Lead acid	5.0	Envisage (2019c)	
Vehicles	Lead acid	3.0	Envisage (2019c)	
Other application area	Lead acid	5.0	Envisage (2019c)	
Unknown	Lead acid	5.0	Envisage (2019c)	
Consumer electronics	Lithium ion	6.4	Panasonic (2013, p. 22)	Laptop is 7.8 years and mobile is 4.9 years. Average of these two values adopted. Also see Huisman, et. al. (2016, p. 28) for some other estimates.
Torches/lanterns	Lithium ion	5.8	Panasonic (2013, p. 21)	Assumed the same as the electric bicycle retention period for lithium ion.
Power tools & gardening equipment	Lithium ion	3.4	Panasonic (2013, p. 18)	
Toys	Lithium ion	5.8	Panasonic (2013, p. 21)	Assumed the same as the electric bicycle retention period for lithium ion.
Personal mobility	Lithium ion	5.8	Panasonic (2013, p. 21)	Assumed the same as the electric bicycle retention period for lithium ion.
Storage, emergency & standby	Lithium ion	12.5	LG Chem (2017)	LG RESU warranty is 10 years. Assumed lifespan is 25% more than this on average.
Vehicles	Lithium ion	16.2	Energeia (2016, p. 39)	Value from page 39. This value may be conservative, as the most recent Energeia (2019, p. 27) report adopts a lifetime value of 18 years in Australia (same as an ICV).

Application area	Chemistry	Age at disposal (yrs)	Reference	Comments
Other application area	Lithium ion	7.8	Panasonic (2013, p. 22)	Assumed the same as the retention period for laptop computer lithium ion.
Unknown	Lithium ion	7.8	Panasonic (2013, p. 22)	Assumed the same as the retention period for laptop computer lithium ion.
Consumer electronics	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Torches/lanterns	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Power tools & gardening equipment	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Toys	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Personal mobility	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Storage, emergency & standby	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Vehicles	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Other application area	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Unknown	Lithium primary	1.75	Warnken ISE (2010, p. 69)	
Consumer electronics	Nickel cadmium	10.0	Panasonic (2013, p. 17)	
Torches/lanterns	Nickel cadmium	12.1	Panasonic (2013, p. 20)	
Power tools & gardening equipment	Nickel cadmium	9.4	Panasonic (2013, p. 18)	
Toys	Nickel cadmium	10.0	Panasonic (2013, p. 17)	
Personal mobility	Nickel cadmium	9.6	Panasonic (2013, p. 21)	
Storage, emergency & standby	Nickel cadmium	14.2	Panasonic (2013, p. 23)	
Vehicles	Nickel cadmium	9.6	Panasonic (2013, p. 21)	
Other application area	Nickel cadmium	10.0	Panasonic (2013, p. 17)	
Unknown	Nickel cadmium	10.0	Panasonic (2013, p. 17)	
Consumer electronics	Nickel metal hydride	7.5	Panasonic (2013, p. 20)	
Torches/lanterns	Nickel metal hydride	7.5	Panasonic (2013, p. 20)	
Power tools & gardening equipment	Nickel metal hydride	6.4	Panasonic (2013, p. 18)	
Toys	Nickel metal hydride	7.5	Panasonic (2013, p. 20)	
Personal mobility	Nickel metal hydride	8.6	Panasonic (2013, p. 21)	
Storage, emergency & standby	Nickel metal hydride	7.5	Panasonic (2013, p. 20)	
Vehicles	Nickel metal hydride	16.2	Energeia (2016, p. 39)	Assumed same as lithium ion in EVs. Reported to typically last the lifespan of the vehicle and warranty is 10 years by Toyota.
Other application area	Nickel metal hydride	7.5	Panasonic (2013, p. 20)	
Unknown	Nickel metal hydride	7.5	Panasonic (2013, p. 20)	
Consumer electronics	Silver oxide	1.75	Warnken ISE (2010, p. 69)	

Application area	Chemistry	Age at disposal (yrs)	Reference	Comments
Torches/lanterns	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Power tools & gardening equipment	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Toys	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Personal mobility	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Storage, emergency & standby	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Vehicles	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Other application area	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Unknown	Silver oxide	1.75	Warnken ISE (2010, p. 69)	
Consumer electronics	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Torches/lanterns	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Power tools & gardening equipment	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Toys	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Personal mobility	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Storage, emergency & standby	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Vehicles	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Other application area	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Unknown	Zinc air	1.75	Warnken ISE (2010, p. 69)	
Consumer electronics	Other	1.75	Warnken ISE (2010, p. 69)	
Torches/lanterns	Other	1.75	Warnken ISE (2010, p. 69)	
Power tools & gardening equipment	Other	1.75	Warnken ISE (2010, p. 69)	
Toys	Other	1.75	Warnken ISE (2010, p. 69)	
Personal mobility	Other	1.75	Warnken ISE (2010, p. 69)	
Storage, emergency & standby	Other	1.75	Warnken ISE (2010, p. 69)	
Vehicles	Other	16.2	Energeia (2016, p. 39)	Assumed same as lithium ion in EVs.
Other application area	Other	1.75	Warnken ISE (2010, p. 69)	
Unknown	Other	1.75	Warnken ISE (2010, p. 69)	