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Waste lithium-ion battery projections

Lithium-ion forums: Recycling, transport and warehousing

In association with:

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RANDELL
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Waste lithium-ion battery projections

Client

Department of the Environment (DoE)

Client Contact

Paul Starr

Assistant Director Hazardous Waste Section Chemicals & Waste Branch Department of the Environment

02 6274 1909 / 0408 476 740

paul.starr@environment.gov.au

Authors

Paul Randell

Reviewers

Joe Pickin (Blue Environment)

Project Number: PREC060

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Randell Environmental Consulting Pty Ltd
ABN 17 153 387 501
Woodend Victoria 3442
Paul@randellenvironmental.com.au
Phone 0429 501 717

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1 Introduction

In February 2016 the Department of the Environment (DoE) engaged Randell Environmental Consulting (REC) in association with Blue Environment (providing peer review) to deliver:

- projections for waste lithium-ion (Li-ion) battery generation over the next 20 years
- a brief discussion of infrastructure gaps for waste Li-ion battery collection and processing
- a presentation of the content at the *Lithium-ion forums: Recycling, transport and warehousing.*

This report provides the projections for waste Li-ion batteries and a brief discussion regarding infrastructure gaps. A PowerPoint presentation has also been provided to DoE.

This report and the presentation content provides a complete revision of work completed in 2015 by REC, Blue Environment, and Ascend Waste and Environment in the report *Hazardous waste infrastructure needs and capacity assessment* (HWIN report) available at: https://www.environment.gov.au/protection/publications/hazardous-waste-infrastructure-needs-capacity-assessment

Following Lewis (2014), Li-ion batteries projections are considered in three categories as follows:

1. Handheld (< 5 kg) devices (i.e. mobile phones, laptop computers, hand tools)
2. Electric vehicle (EV) (i.e. batteries used to power electric cars)
3. Photovoltaic panel electricity storage (PVS) (i.e. batteries used to store power from solar photovoltaic cells (PVs)).

Analysis indicates that these three broad categories capture the bulk of current and future use of Li-ion batteries.

There are many Li-ion battery chemistries in use or under development. In this report Li-ion batteries refers to all Li-ion chemistries (both currently in use and those under development).

Lewis (2016) provides the following summary of Li-ion battery chemistries and the most common uses.

Table 1 Li-ion chemistries, status and common applications. *Source: Lewis (2016)*

Full name and common abbreviations	Status and common applications
Lithium nickel cobalt aluminium oxide (LiNiCoAlO2), also known as Lithium cobalt aluminium (NCA)	Gaining importance in electric vehicles (EV) and grid storage
Lithium nickel manganese cobalt oxide (LiNiMnCoO2), also known NMC	Power tools, e-bikes, EV, medical applications.
Lithium cobalt oxide (LiCoO2), also known as Li- cobalt or LCA	Smart phones, laptops, tablets cameras
Lithium iron phosphate (LiFePO4), also known as Lithium Ferrous or Lithium Ferro Phosphate (LFP) Lithium manganese oxide (Li-Mn2O4), also known as Li-manganese, LMO or spinel	Energy storage, power tools, e-bikes, EV, medical applications
Lithium titanate (Li4Ti5O12), also known as Li- titanate or LTO	Power tools, e-bikes, EV, medical devices, hobbies
Lithium nickel cobalt aluminium oxide (LiNiCoAlO2), also known as Lithium cobalt aluminium (NCA)	Grid storage, EV, buses and ferries
Lithium sulphur (Li-S)	Emerging technology
Lithium ion polymer – Term previously referred to batteries with a polymer electrolyte (still under development). More commonly refers to a Li-ion battery in a soft pouch instead of a rigid metal	Various including consumer electronics, EV

Full name and common abbreviations	Status and common applications
case	
Lithium manganese dioxide (primary battery)	Defence applications

Source: Lewis (2016)

1.1 Waste Li-ion batteries: a hazardous waste?

The response to this question provides important context.

For international exports Li-ion batteries **are** hazardous wastes and require an export permit to be issued by DoE (in accordance with the *Hazardous Waste (Regulation of Exports and Imports) Act 1989*).

Li-ion batteries **are** listed in the *Australian Code for the Transport of Dangerous Goods by Road & Rail* (DG code) as: Class 9 - miscellaneous dangerous substances and articles, including environmentally hazardous substances. The DG code listing applies to waste Li-ion batteries (in addition to new Li-ion batteries for sale individually or within another product).

The DG defines Class 9 as: substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes.

The DG code lists Li-ion batteries under:

- 3480 – lithium ion batteries (including lithium ion polymer batteries)
- 3481 – lithium ion batteries contained in equipment (including lithium ion polymer batteries) or
- 3481 lithium ion batteries packed with equipment (including lithium ion polymer batteries)

The DG code specifies a range of ‘special provisions’ (which outline labelling requirements, exemptions, etc.) and ‘packing instructions’ for Li-ion batteries

The International Air Transport Association (IATA) has established strict controls on the transport of Li-ion batteries by air. In April 2016, the International Civil Aviation Organization (ICAO) Council prohibited, on an interim basis, Li-ion batteries (UN 3480, packing instruction 965 only) as cargo on passenger aircraft, effective 1 April 2016. Source: http://www.iata.org/publications/tracker/feb-2016/Pages/lithium-batteries-update.aspx

Waste Li-ion batteries **are not** currently regulated as a hazardous waste by state governments and hence transport within the state is not required to be tracked (in hazardous waste tracking systems).

The *National Environment Protection (Movement of Controlled Waste between States and Territories) Measure 1998* (the NEPM) sets out the regulatory framework for transporting ‘controlled wastes’ between Australian states and territories.

The NEPM defines **controlled waste** as: “waste matter mentioned in List 1 of Schedule A that has one or more of the characteristics mentioned in List 2 of Schedule A. Waste matters mentioned in List 1 of Schedule A are considered to have one or more characteristics mentioned in List 2, unless the nominated agency in the jurisdiction of destination is satisfied otherwise” (page 2).

Waste Li-ion batteries **are not listed** in Schedule A (List 1) of the NEPM, **nor are lithium or lithium compounds**[1], which means that the NEPM does not currently cover Li-ion batteries and require a consignment authorisation to be completed to transport Li-ion batteries interstate.[2]

It is worth noting that waste Li-ion batteries can exhibit characteristics that are listed in Schedule A (List 2) which is why Li-ion batteries are regulated as a dangerous good for transport. Any future review of the NEMP should consider the addition of Li-ion batteries to Schedule A (List 1).

Lewis 2014 notes that waste Li-ion batteries disposal to landfill has caused landfill fires in the past.

If not appropriately managed, waste Li-ion batteries pose a fire and explosion risk to all resource recovery and landfill infrastructure.

Given the risks that poorly managed waste Li-ion batteries can pose, it is important to plan for the provision of the appropriate infrastructure to meet future projected needs.

2 Projections of waste Li-ion batteries generation

The projections of waste Li-ion batteries generation are provided under the following three scenarios:

- Best estimate = the scenario that analysis indicates is the most likely
- High estimate = the scenario that analysis indicates is the upper range for the projections
- Low estimate = the scenario that analysis indicates is the lower range for the projections.

In the sections that follow, the overall (combined) projections are provided first followed by projections for handheld, EV, and PVS Li-ion waste batteries. For the individual projections the analysis provides discussion of the projection method and assumptions.

Consideration of Li-ion battery life

Throughout this analysis it is assumed that all batteries projected as purchased in a particular year become waste after a nominated number of years that is equal to the estimated average battery lifespan. It is recognised that this is a simplification – in reality some batteries will reach end of life earlier and some later. However, the review did not identify any data to populate a lifespan distribution for Li-ion batteries. We believe our simplified approach is adequate in the context of the overall projection modelling uncertainties.

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[1] Lead acid batteries are covered and transported under the NEPM by the listing of “Lead; lead compounds”.

[2] Each state implements specific regulations to implement the NEPM within their jurisdiction. Some states may require Li-ion batteries to be transported under a consignment authorisation.

2.1 Overall projection for waste Li-ion batteries generation

Figure 1 and Table 2 show that waste lithium-ion battery generation is projected to increase strongly under all scenarios over the next 20 years. This table and chart include the sum of projections made for handheld, EV, and PVS batteries.

Figure 1 Overall projection for waste Li-ion batteries generation

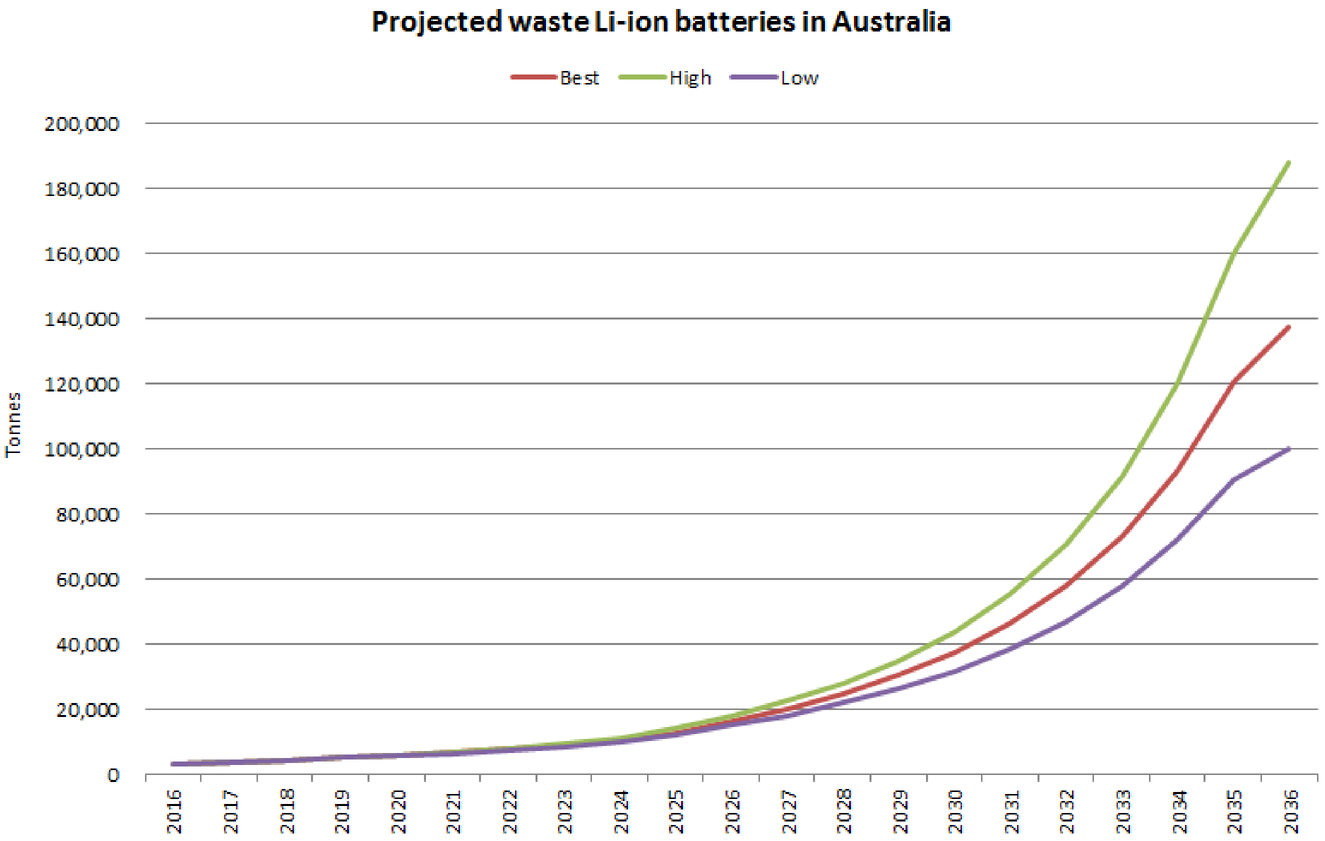

Table 2 Overall projection for waste Li-ion batteries and average annual growth rate

Projection	Year 2016	 2036	Average annual growth rate
	Tonnes		%
Best	3,340	137,618	20%
High	3,340	187,984	22%
Low	3,340	100,073	19%

2.1.1 Factors driving Li-ion battery waste generation

The following are the main factors driving the strong growth in Li-ion waste battery generation over the next 20 years.

1. Lithium is the lightest metal and is highly reactive making it very effective in batteries that require light weight application and/or high voltage applications. These characteristics mean that Li-ion batteries of various chemistries are likely to dominate battery chemistry for the next 20 years.
2. The cost of Li-ion batteries continues to decline which will in turn drive consumption and waste generation. Some analysts have suggested that the Tesla Motors Nevada-based 'Gigafactory' could drive down costs of its lithium-ion batteries by 50%.[3]
3. Australian per capita consumption and use of handheld devices is growing and this driver is compounded by projections for strong ongoing population growth.
4. Pressure to reduce reliance on fossil fuels for energy is driving the need for improved energy storage systems to:
    a. support renewable energy sources such as solar PVs
    b. provide improved driving distances (kms per charge) for EVs.
5. References identified in this report (AEMO 2015) predict strong growth in the consumption of Li-ion batteries for both EVs and PVS over the next 20 years. This report's projections assume batteries from EVs and PVS will begin to enter the Australian waste stream in significant tonnes around 2025. Figure 1 shows this significant increase beginning in 2025.

2.2 Handheld waste Li-ion batteries projections

Figure 2 shows the projections made for handheld waste Li-ion batteries. Under all scenarios strong growth is projected and the waste stream is already flowing through to waste infrastructure.

SRU (2014) estimated that in 2012-13 only 2% of Li-ion batteries were recovered, with the remainder going to landfill.

The handheld Li-ion battery waste stream represents an immediate issue and potential fire risk to landfill infrastructure in particular. It also presents an opportunity for recovery infrastructure investment supported by policy settings to drive Li-ion batteries out of landfill to recovery.

---

[3] Shallenberger K, 2015 *Updated: Tesla Gigafactory will cut battery costs 50%, analyst says,* available at http://www.utilitydive.com/news/updated-tesla-gigafactory-will-cut-battery-costs-50-analyst-says/405970/

Figure 2 Projections for handheld waste Li-ion batteries

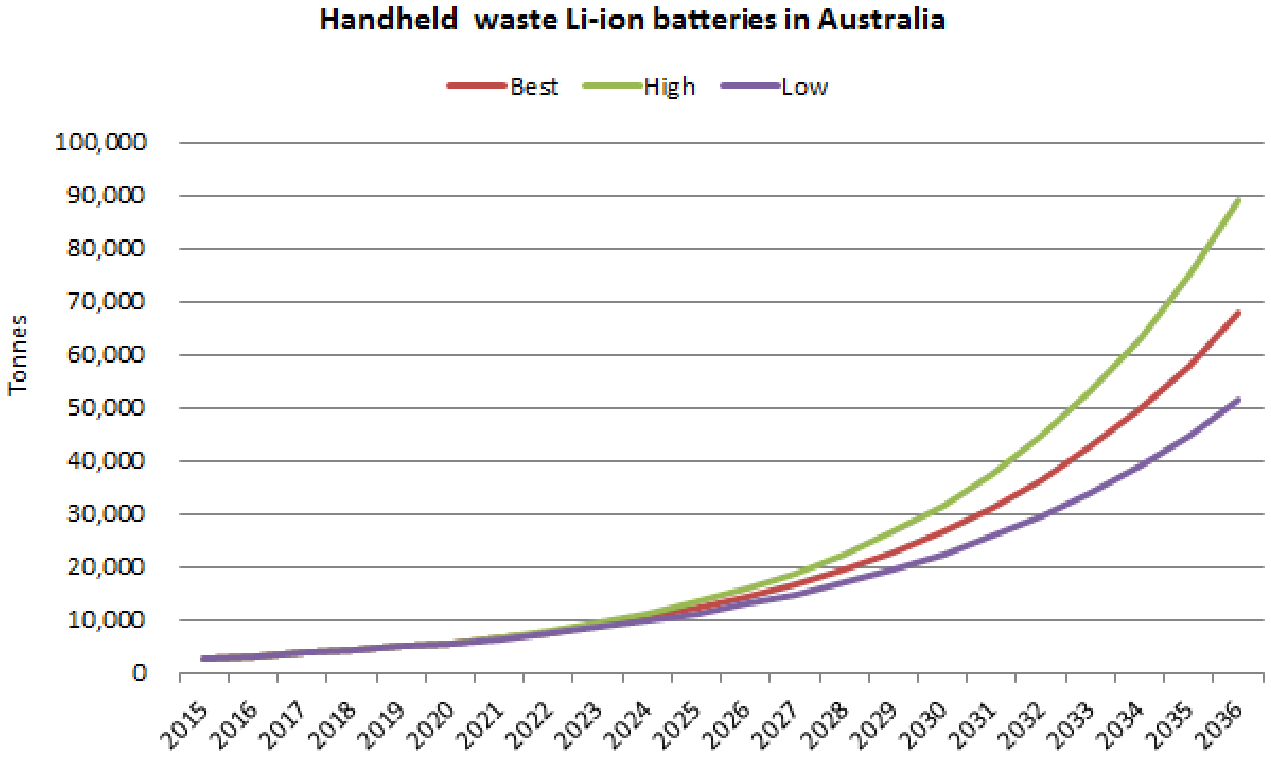

Table 3 Projection for waste Li-ion handheld batteries and average annual growth rate

Projection	Year		Av. annual growth rate
	2015	2036	
	Tonnes		%
Best	2,770	67,912	16%
High	2,770	89,115	18%
Low	2,770	51,512	15%

2.2.1 Projection method and assumptions

The projections for handheld waste Li-ion batteries are based on the existing credible projections for Australia provided in the SRU (2014) report.

Table 4 Projections approach for handheld waste Li-ion batteries

Projection	Approach
Best	Projections follow SRU (2014) projections until 2020. It is assumed that the SRU (2014) growth rate (16%) is maintained until 2036.
High	Projections follow SRU (2014) projections until 2020. It is assumed that the SRU (2014) growth rate plus 2% additional annual growth (total 18%) is maintained till 2036.
Low	Projections follow SRU (2014) projections until 2020. It is assumed that the SRU (2014) growth rate minus 2% annual growth (total 15%) is maintained till 2036.

This approach was taken based on the following:

1. Li-ion battery chemistries will likely remain dominant until at least 2030 in handheld batteries.
2. Australian per capita consumption and use of handheld devices is growing and this driver is compounded by strong ongoing population growth.

3. SRU (2014) provides a projected growth rate until 2020. It is assumed that this growth rate is maintained until 2036. Given the level of analysis included in SRU (2014) and the considerations above, a modest +/- 2% average annual growth rate variance from the best estimate was assumed.

2.3 Electric vehicle waste Li-ion batteries projections

Figure 3 shows the projections made for EV waste Li-ion batteries. Under all scenarios strong growth is projected over the next 20 years and the waste stream for EV batteries is projected to begin flowing through to waste infrastructure in significant amounts by around 2025.

Figure 3 Projections for EV waste Li-ion batteries

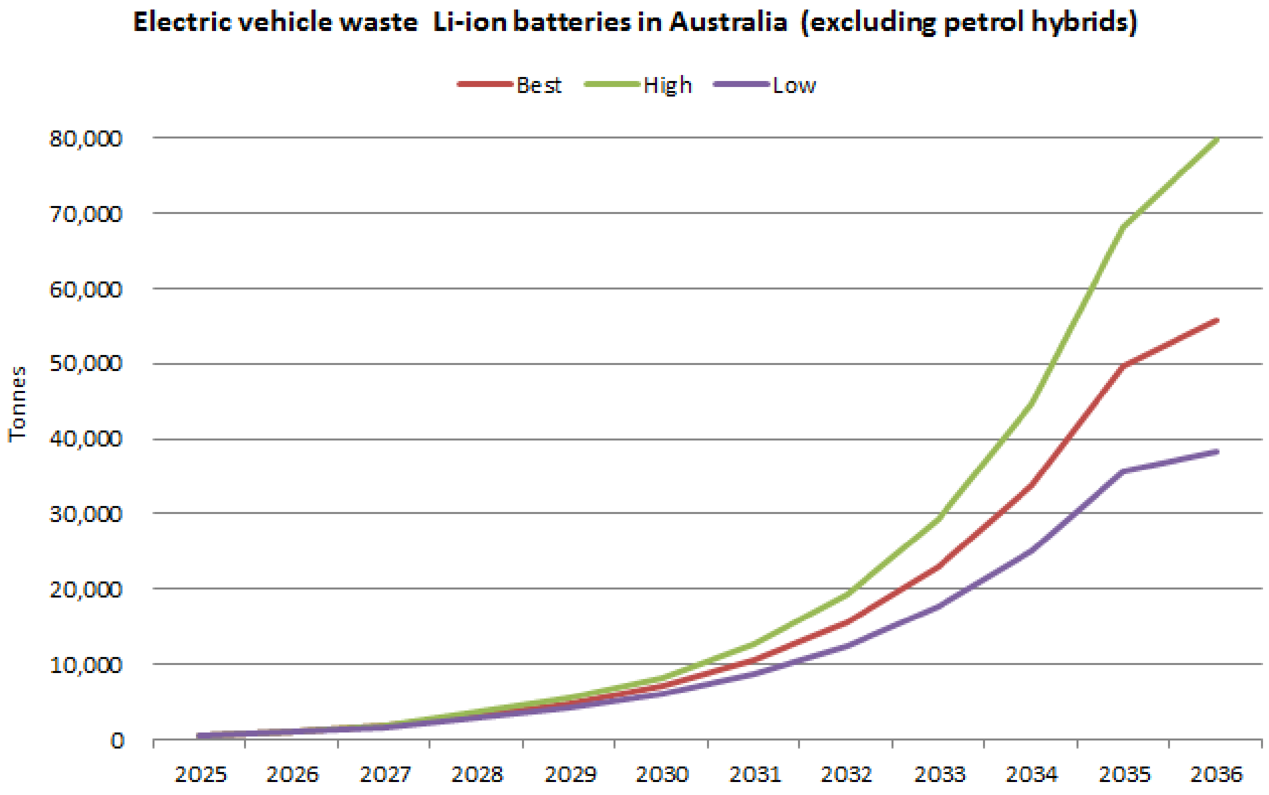

Table 5 Projection for waste Li-ion EV batteries and average annual growth rate (excludes petrol hybrids cars and commercial vehicles)

Projection	Year		Av. annual growth rate
	2026	2036	
	Tonnes		%
Best	571	55,655	52%
High	571	79,754	57%
Low	571	38,359	47%

2.3.1 Projection method and assumptions

Australian Energy Market Operator (AEMO) (2015) page 5 states the following:

> "Based on initial assumptions and current market conditions, AEMO anticipates there will be negligible impact on the daily load profiles in each NEM region in the 20-year outlook period based on the estimated uptake of electric vehicles[4].
>
> In the NEW only 1,909 electric vehicles were sold to 30 April 2015. In 2014, electric vehicles represented 0.1% of new vehicle sales[5]. Based on this current level of uptake and the absence of any policy incentives, AEMO assumes the uptake of electric vehicles to continue to be small, with a projected 165,734 electric vehicles across the NEM in 2024–25, increasing to 524,775 in 2034–35."

The projections of EV car sales provided by AEMO provide the basis for the EV waste Li-ion battery projections included above. Despite the expected slow uptake of EV cars in the Australian market, the waste EV Li-ion battery waste stream is still significant with a best estimate of around 55,000 tonnes in 2036, which represents an average growth rate of over 50%.

The AEMO projections do not include sales of petrol hybrid cars or commercial vehicles. Toyota state that they have sold over 40,000 Toyota hybrids in Australia since 2001.[6] Historically, the Toyota hybrid has used a nickel-metal hydride (NiMH) battery pack which is not relevant to the Figure 3 projections. However, the new generation Toyota hybrids (and presumable other manufactures hybrids) will be available in a Li-ion battery option.

The future sales of petrol hybrid cars in Australia that are powered by a Li-ion battery would (at the end of life) produce Li-ion batteries that are additional EV battery projections included in Figure 3.

Table 6 Projections approach for EV waste Li-ion batteries

Projections:	Approach
Best	Assumes the AEMO (2015) rate of growth in EV sales till 2036.
High	Assumes the AEMO (2015) rate of growth in EV plus an additional 5% annual growth rate to allow for faster EV uptake from 2015.
Low	Assumes the Australian Energy Market Operator (2015) rate of growth in EV minus 5% annual growth rate to allow for slower EV uptake from 2015.

In addition to the above the following method/assumptions are included in the waste EV Li-ion projections:

1. Li-ion batteries of various and potentially new chemistries will dominate EV batteries for the next 20 years at least.
2. Improvements in battery 'miniaturisation' or 'light weighting' will not result in significant weight reductions of EV battery packs installed. Higher driving range (kms/charge) will be the priority over reduced battery pack weight. The average EV battery pack weight is assumed to be just under 300kg. This is the average weight of several current EV battery pack weights; see Battery University (2016).

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[4] Electric vehicles in the AEMO paper are passenger vehicles propelled by one or more electric motors, powered by rechargeable battery packs. It does not include "hybrid" vehicles, or heavy transport.

[5] Source: Federal Chamber of Automotive Industries

[6] Source: http://www.toyota.com.au/hybrid-battery-recycling

3. 10 years is the average life of the EV according to AEMO (2015). It is assumed that the entire tonnage of EV batteries sold in a particular year become waste 10 years later. This explains why waste EV tonnages do not begin until 2025 (from sales made in 2015).
4. It is uncertain how quickly EV cars will be taken up in Australia. To allow for this and other uncertainties noted above, a range of +/- 5% has been applied to the best estimate projection.

2.4 Photovoltaic panel electricity storage waste Li-ion batteries projections

Figure 4 shows the projections made for waste PVS Li-ion batteries. Under all scenarios strong growth is projected over the next 20 years and the waste stream for PVS batteries is projected to begin flowing through to waste infrastructure by around 2025.

Historically, PVS batteries have been lead acid based, and this technology is still widely used. In the last few years Li-ion PVS batteries have become the dominant choice for new PVS installations. Lewis (2016) notes the following reasons for this shift to Li-ion:

- their greater energy density, which means that they are smaller and lighter
- they are expected to have longer life spans
- they are able to undergo deeper discharges, reducing the capacity required.

Li-ion batteries also are far less prone to discharging between uses than lead acid batteries.

Figure 4 Projections for PVS waste Li-ion batteries

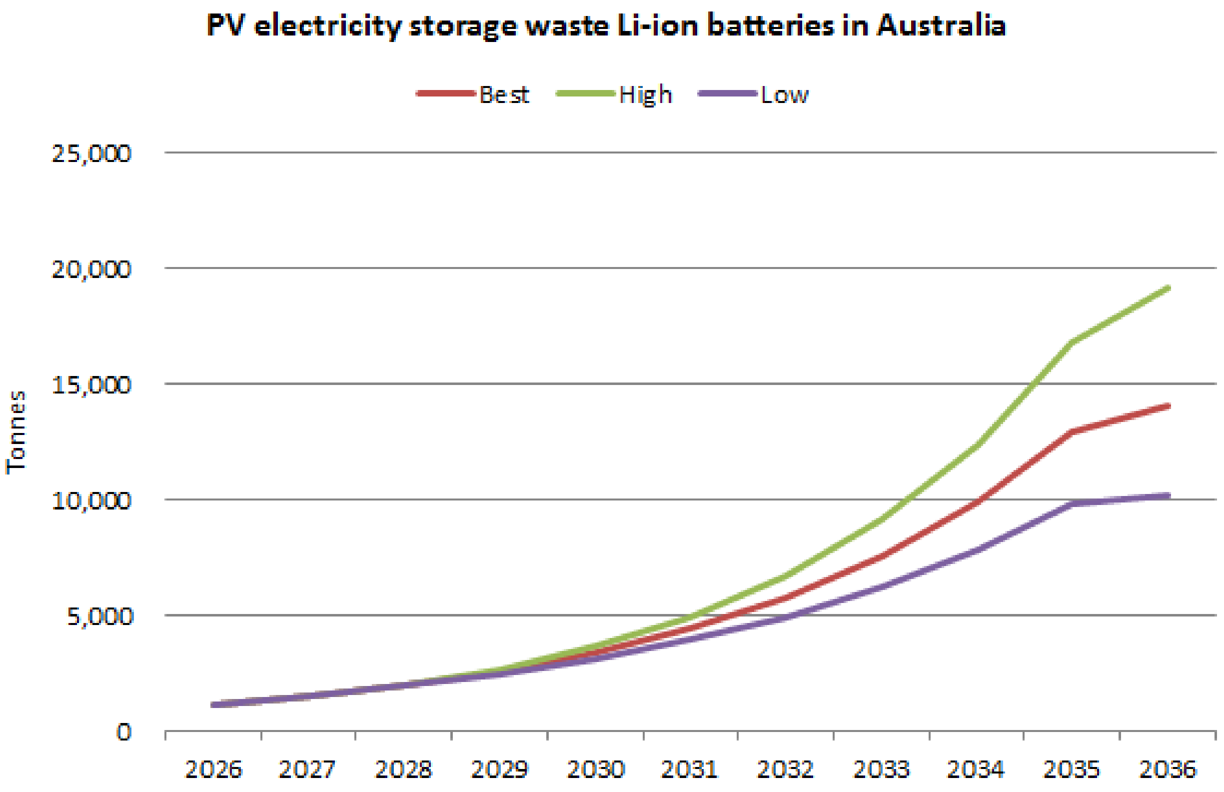

Table 7 Projection for waste Li-ion PVS batteries and average annual growth rate

Projection	Year		Av. annual growth rate
	2026	2036	
	Tonnes		%
Best	1,161	14,051	28%
High	1,161	19,115	32%
Low	1,161	10,202	24%

2.4.1 Projection method and assumptions

Australian Energy Market Operator (AEMO) (2015) page 4 includes the following table:

"Forecast installed capacity of battery storage (MWh)"

	Queensland	New South Wales	South Australia	Victoria	Tasmania	NEM
2017–18	129	201	2	188	9	**529**
2024–25	982	1,043	206	1,131	83	**3445**
2034–35	2,046	2,482	484	2,774	196	**7982**

The AEMO (2015) projected MWh of installed capacity of battery storage provides the basis for the waste Li-ion PVS batteries projections. It is important to note that AEMO (2015) projections for installed capacity includes only new installations of PV and battery systems. The retrofitting of batteries to existing rooftop PV systems was excluded from the AEMO (2015) analysis.

Table 8 Projections approach for PVS waste Li-ion batteries

Projections:	Approach
Best	Assumes the AEMO (2015) rate of growth in PVS battery storage till 2036.
High	Assumes the AEMO (2015) rate of growth in PVS battery storage plus an additional 5% annual growth rate to allow for faster PVS uptake from 2018.
Low	Assumes the AEMO (2015) rate of growth in PVS minus 5% annual growth rate to allow for slower PVS uptake from 2018.

In addition to the above the following method / assumptions are included in the waste PVS Li-ion projections:

1. Li-ion batteries of various and potentially new chemistries will dominate PVS batteries for the next 20 years at least. It is assumed that Li-ion batteries will provide 75% of AEMO (2015) projected PVS capacity.
2. 10 years is assumed to be the average life of the PVS batteries. The entire tonnage of PVS batteries sold in a particular year become waste 10 years later. This explains why waste PVS tonnages do not begin until 2026 (from sales made in 2016).[7]
3. The AEMO (2015) quantity of PVS (in MWh) is converted to tonnes of Li-ion batteries using a 'Ragone chart'. The power energy output of Li-ion battery is assumed to be 200 Wh/kg[8] (or 0.20 MWh/tonne).

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[7] Lewis 2016 noted that PVS batteries may have a longer life then 10 years (up to 20 years). If a longer average battery life is assumed, the same tonnages included in the projections above would enter the waste stream just in a later year than currently projected.

[8] Source:Battery University 2016, see http://batteryuniversity.com/learn/article/bu_1006_cost_of_mobile_power

4. It is uncertain how quickly PVS batteries will be taken up in Australia. To allow for this, and other areas of uncertainty noted above, a range of +/- 5% has been applied to the best estimate projection.

3 Discussion of waste Li-ion batteries recovery infrastructure in Australia

3.1 Collection systems and infrastructure

Australia has no specific Li-ion battery collection/transfer infrastructure. Li-ion batteries that are recovered are typically collected with other e-wastes. The collection of potentially flammable waste Li-ion batteries without appropriate infrastructure could create a fire hazard within the collection infrastructure for other batteries. The transport of waste Li-ion batteries in a skip bin of mixed e-wastes may also be in breach the DG code packaging requirements for Li-ion batteries.

The projections in Section 2 illustrate the lack of takeback/collection infrastructure for handheld Li-ion batteries <u>which is an immediate issue</u>.

For the larger EV and PVS Li-ion batteries, take-back/collection capacity is not likely to be needed in significant amounts until around 2025 (to manage the significant tonnages of batteries reaching end of life).

Lewis 2016 noted that most EV manufacturers already have standard operating procedures in place for waste batteries and contracts in place with recyclers. Such procedures and contracts will need to be able to handle the projected future generation of waste Li-ion batteries.

Where EV or PVS Li-ion batteries ‘leak’ from the intended takeback systems, there is a serious risk that requires consideration. For example, an EV that is involved in a car accident and taken to a scrap yard for shredding. Untrained workers in a steel yard could be at risk either during the removal of the battery or if the battery was sent into the shredder.

A faulty PVS Li-ion battery disposed of to a transfer station into a mixed e-waste bin also presents a risk of electric shock and/or fire.

‘Leakage’ of EV and PVS Li-ion batteries from a controlled takeback scheme into the ‘general’ waste stream needs careful consideration over the next few years.

3.2 Processing and recycling infrastructure

At the time of writing, Australia had only one facility providing partial processing of Li-ion batteries (PF Metals in Melbourne). In 2015 the Australian Battery Recycling Initiative published the following information regarding the PF Metals facility.

> ***“PF Metals to recycle batteries in Australia***
>
> *PF Metals was founded by Peter Freburg, who has worked in the scrap metal industry and the resource recovery business since 1964. In July 2015 the company adopted new sustainability targets to make sure all products that come into their yards leave as single material streams.*
>
> *To help achieve this outcome PF Metals has invested in equipment to process used lithium-ion (Li-ion), nickel metal hydride (NiMH) and silver oxide batteries. The metals (copper, aluminium and steel) are recycled locally and other products are sent to a third party in*

> *Asia to recover lithium, manganese, cobalt and nickel. This process achieves a high recovery rate of around 95%.*
>
> *The steps in the battery recovery process are:*
>
> 1. *Batteries are de-energized (which reduces the hazard of explosions and fire)*
> 2. *Disassembly (automotive units only)*
> 3. *Shredding and granulation (making material small enough to be sorted)*
> 4. *Dust recovery (over 60% of the battery mass)*
> 5. *Dust is then sent for processing overseas.*
>
> *PF Metals is currently offering this service free of charge for batteries delivered to their facility in Melbourne".*

Source: Australian Battery Recycling Initiative, see http://www.batteryrecycling.org.au/pf-metals-to-recycle-batteries-in-australia

The capacity of PF Metals to process Li-ion batteries is not known. The process is also new and yet to demonstrate reliable annual processing capacity.

Lewis 2016 noted that several other companies (including MRI (Aust) Pty Ltd, Powercell, Sims E-Recycling and TES-AMM) are collecting Li-ion batteries have exported them overseas for recycling.

The cross contamination of Li-ion batteries into existing battery collection and recycling systems, such as lead acid batteries, is also a significant issue and risk. Incidents of fires at lead acid battery recycling facilities, caused by accidental processing of Li-ion batteries, prompted Eurobat and the International Lead Association to release a safety notice to lead battery collectors, handlers, and sorters, see Appendix A. Source: http://www.eurobat.org/leaflet-warns-risks-lithium-ion-batteries-pose-safety-lead-battery-recycling-industry-14-december-20

The numerous and potentially changing Li-ion battery chemistries presents an ongoing challenge to the recycling industry. For example, Lewis (2016) noted that currently the most valuable materials that are recovered from Li-ion batteries include nickel, cobalt and copper. Battery manufacturers are trying to reduce the content of these metals to reduce their costs. This in turn will make Li-ion battery recycling less profitable.

The above discussion and the projections included in Section 2 illustrate that there is an immediate need to improve processing infrastructure capacity for handheld Li-ion batteries in Australia.

For the larger EV and PVS Li-ion batteries, some processing capacity will need to be in place in the early 2020's to manage batteries that begin to reach end of life.

Without the establishment of proven onshore processing and recycling infrastructure Australia will be mostly dependent on exporting waste Li-ion batteries for recycling. The exporting of Li-ion batteries introduces additional transport risks as illustrated by a recent ship fire carrying Li-ion batteries, see: http://maritimeinsrilanka.lk/view.php?cat=68.

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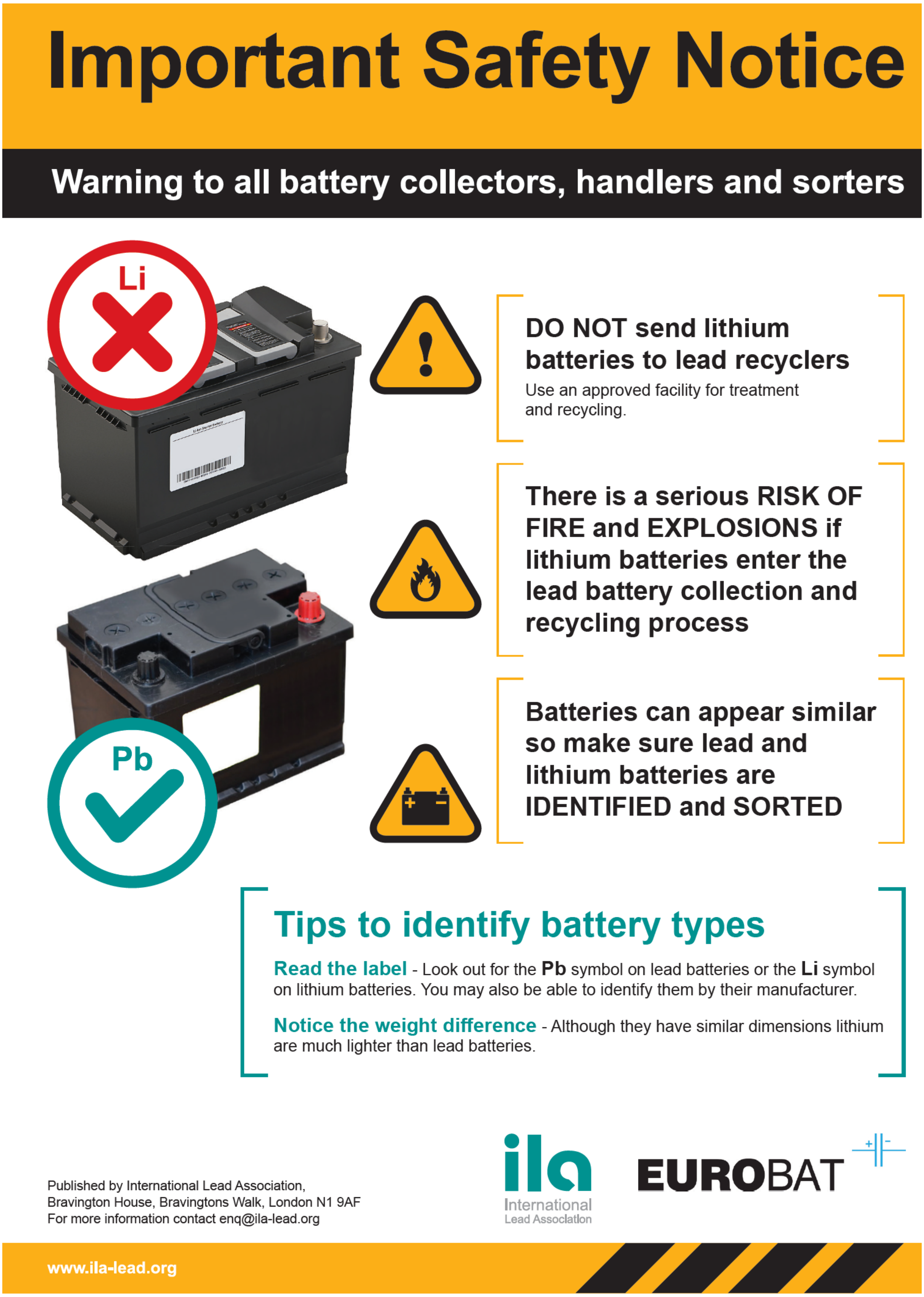
Appendix A – Eurobat safety notice for Li-ion batteries processing



Important Safety Notice

Warning to all battery collectors, handlers and sorters

DO NOT send lithium batteries to lead recyclers
Use an approved facility for treatment and recycling.

There is a serious RISK OF FIRE and EXPLOSIONS if lithium batteries enter the lead battery collection and recycling process

Batteries can appear similar so make sure lead and lithium batteries are IDENTIFIED and SORTED

Tips to identify battery types

Read the label - Look out for the **Pb** symbol on lead batteries or the **Li** symbol on lithium batteries. You may also be able to identify them by their manufacturer.

Notice the weight difference - Although they have similar dimensions lithium are much lighter than lead batteries.

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Bravington House, Bravingtons Walk, London N1 9AF
For more information contact enq@ila-lead.org

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Appendix B Best, high and low projected waste Li-ion battery generation 2016 to 2036

	Year																				
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**
Total tonnes/year																					
Best	3,340	3,910	4,490	5,080	5,680	6,633	7,745	9,045	10,562	12,905	16,591	20,183	24,943	30,412	37,358	46,280	57,873	73,115	93,391	120,671	137,618
High	3,340	3,910	4,490	5,080	5,680	6,746	8,013	9,518	11,304	13,998	18,165	22,410	28,086	34,898	43,736	55,350	70,818	91,699	120,269	159,871	187,984
Low	3,340	3,910	4,490	5,080	5,680	6,519	7,482	8,588	9,857	11,884	15,145	18,166	22,139	26,462	31,830	38,563	47,090	57,997	72,093	90,490	100,073
Handheld tonnes/year																					
Best	3,340	3,910	4,490	5,080	5,680	6,633	7,745	9,045	10,562	12,334	14,403	16,819	19,640	22,935	26,782	31,275	36,522	42,648	49,802	58,157	67,912
High	3,340	3,910	4,490	5,080	5,680	6,746	8,013	9,518	11,304	13,427	15,948	18,942	22,498	26,722	31,740	37,699	44,777	53,183	63,169	75,029	89,115
Low	3,340	3,910	4,490	5,080	5,680	6,519	7,482	8,588	9,857	11,313	12,985	14,903	17,105	19,633	22,533	25,863	29,684	34,069	39,103	44,881	51,512
EV tonnes/year																					
Best										571	1,027	1,846	3,319	4,884	7,188	10,577	15,564	22,904	33,703	49,596	55,655
High										571	1,056	1,950	3,604	5,484	8,344	12,695	19,316	29,390	44,718	68,040	79,754
Low										571	998	1,745	3,050	4,336	6,163	8,761	12,455	17,705	25,168	35,777	38,359
PVS tonnes/year																					
Best											1,161	1,518	1,984	2,593	3,388	4,428	5,787	7,564	9,885	12,919	14,051
High											1,161	1,518	1,984	2,692	3,653	4,956	6,725	9,125	12,382	16,802	19,115
Low											1,161	1,518	1,984	2,493	3,134	3,939	4,951	6,223	7,822	9,832	10,202