Sustainability Evaluation of Energy Storage Technologies

Report prepared by the Institute for Sustainable Futures for the Australian Council of Learned Academies

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About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures. We utilise a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity.

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Executive Summary

Key findings

This study of key energy storage technologies - battery technologies, hydrogen, compressed air, pumped hydro and concentrated solar power with thermal energy storage - identified and evaluated a range of social and environmental impacts along the supply chain.

Lithium-ion batteries in particular are anticipated to have a high rate of deployment and have significant associated adverse impacts, including human rights and pollution impacts during mining, fire risk, and are a future waste management challenge owing to the lack of established recycling systems.

Current planning and decision-making influencing the deployment of energy storage technologies needs to acknowledge and manage these short and longer-term impacts as they pose a significant risk to the viability of the industry and could hinder the transition to a renewable energy system.

Considering the major research, development and investment in energy storage technologies, it is likely that those that will dominate the market in the coming decades are unlikely to be the same technologies that dominate the market currently. Our evaluation demonstrates the importance of assessing environmental and social impacts across the whole supply chain to mitigate potential adverse impacts ahead of the implementation of new technologies.

Sustainable supply chains

KEY CHALLENGE: The mining of raw materials for battery production (such as lithium, cobalt and graphite) has significant environmental and social impacts, such as poor working conditions and health impacts from the pollution of local environments. There is a paucity of data and a lack of stakeholder awareness around these environmental and social impacts at the front-end of the supply chain, exacerbated by the complexity of the supply chains.

OPPORTUNITY: As an early market for batteries, Australia has an opportunity to champion storage sustainable storage supply chains. Australia's expertise in mining can support international standards development and engaged consumers can demand that the major brands, that can influence brand action globally and act responsibly.

Best practice for battery safety

KEY CHALLENGE: There are safety risks during transport, installation, use and handling and processing at end-of-life for energy storage batteries. Current safety initiatives are happening in the right direction but at the wrong pace. Safety risks are being addressed through industry-led voluntary initiatives, including the development of installation guides, training, accreditation pathways, the establishment of a national energy storage register, as well as standards development. However, the level of industry and consumer awareness and engagement may be out of step with the rapid rate of deployment and technology development.

OPPORTUNITY: There is an opportunity to promote the development of a vibrant and world-leading industry that models a culture of safety and best practice in installation, maintenance, use and end-of-life management. Fostering stakeholder awareness and incentivising the industry to engage with safety guidelines, without creating barriers for the emerging market necessitates consistent government intervention.

Responsible end-of-life management

KEY CHALLENGE: Energy storage batteries present a future waste management challenge, but if managed strategically, are a resource recovery opportunity. In the absence of an economic driver or clear policy directives there is currently no certainty for industry to invest in local end-of-life solutions for recycling and reusing storage batteries.

OPPORTUNITY: Australia has an opportunity to develop a stewardship approach to ensure the sustainable management of batteries across the whole product lifecycle. There is a strong rationale to act now to engage all stakeholders in developing a viable approach and to drive timely investment in recycling infrastructure and technology. A further impetus to act now is to coordinate with the current safety initiatives that are targeting retailers and installers – these stakeholders are critical for supporting a sustainable product stewardship scheme.

Our evaluation demonstrates the importance of assessing environmental and social impacts across the whole supply chain to mitigate potential adverse impacts ahead of the implementation of new technologies.

Introduction

Energy storage technologies are considered important for future energy systems with large amounts of variable renewable generation to ensure energy system adequacy and security. However they often have high resource requirements with consequent environmental and social impacts that need to be appropriately managed to support the transition to a sustainable energy system.

This report presents findings from an evaluation of the possible environmental and social impacts associated with the anticipated rapid uptake of energy storage in Australia; it also provides an appraisal of the important mitigation and management strategies.

This research contributes to a broader study examining the range of opportunities and challenges presented by the uptake of energy storage in Australia's energy supply and use systems out to 2030 delivered to the Australian Council of Learned Academies (ACOLA).

Five key stationary energy storage technologies are reviewed: Battery technologies – i.e., the dominant lithium-ion chemistries, lead-acid, sodium-based chemistries and flow batteries; pumped hydro energy storage (PHES); compressed air energy storage (CAES); hydrogen energy storage; and, concentrated solar power with thermal energy storage (CSP TES).

A 'streamlined' life cycle approach was developed, providing a consistent impact assessment framework to evaluate the technologies. The framework defined six environmental impact criteria: lifecycle energy efficiency, lifecycle greenhouse gas emissions, supply-chain criticality, material intensity, recyclability and environmental health; and, two social impact criteria: human rights and health and safety. This was applied to identify and characterise the impacts along the supply chain and mitigation strategies for the targeted storage technologies. A high-level comparison is presented in the following Table A with important impact factors discussed below.

Table A: Overall impact assessment showing the order of impacts from high low.

This coding was adjusted to account for the maturity of the mitigation strategies (reproduced from Chapter 8)

High Medium Low

		Li-ion NMC	Li-ion LFP	Lead-based	Flow batteries	Sodium-ion	PHES	CAES	Hydrogen	CSP with TES
Environmental Impact	Lifetime energy efficiency	Low	Low	Medium	Medium	Medium	Low	Medium	Medium	Low
	Lifecycle GHG emissions	Low	Low	Medium	Medium	Medium	Low	High	Medium	Low
	Supply chain criticality	High	Medium	Low	Medium	Low	Low	Low	Medium	Medium
	Material intensity	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low
	Recyclability	Medium	Medium	Low	Medium	Medium	Low	Low	Low	Low
	Environmental health	Medium	Medium	Medium	Low	Low	Medium	Low	Low	Low
Social Impact	Human rights	High	Medium	Low	Low	Low	Low	Low	Low	Low
	Health & safety	High	Medium	Medium	Low	Low	Low	Low	Medium	Low
	Overall	High	Medium	Medium	Low	Low	Low	Medium	Medium	Low

Key lifecycle impacts

Lifetime energy efficiency

Lifecycle energy efficiency is important because a high efficiency maintained over a long expected lifetime minimises technology uptake requirements and the associated impacts.

Lithium-ion batteries perform well with a high average round-trip-efficiency (~ 90 %) compared to for example lead-acid (~ 80 %) and flow batteries (~ 75 %). The expected lifetimes for lithium batteries are also slightly longer, but still short in comparison to bulk storage technologies.

PHES has the highest round-trip-efficiency (75–80 %) of high-volume bulk energy storage technologies, compered to CAES (40-55 %), and also has the longest lifetime of all technologies between 50 and 150 years. Hydrogen-to-power is not competitive (20 %).

Lifecycle greenhouse gas emissions

Supply chain criticality not only considers geological availability of key resources but also potential supply chain vulnerabilities and risks associated with economic, technological, social or geopolitical factors; it provides vital insight for understanding technology development trends and enabling new opportunities for industry and research. Lithium-ion batteries have the highest level of criticality owing to the use of cobalt, natural graphite, fluorspar, phosphate rock and lithium. Considering the different lithium-ion battery chemistries, the nickel manganese cobalt oxide (NMC) chemistry is considered to have a higher level of criticality owing to the supply risk of cobalt; 50% of world cobalt production is from the Democratic Republic of Congo (DRC) and the vast majority of the world's resources in the DRC and Zambia. The security of supply of antimony used in certain lead-acid batteries and vanadium for Vanadium Redox Flow batteries (VRB) are also potentially of concern. Polymer Exchange Membrane (PEM) electrolysis technology for hydrogen production uses platinum catalysts that are identified as critical on the basis of supply chain constraints. For CSP TES plants, there are no issues in terms of material criticality of the TES materials (nitrate salts) although there are potential constraints on supply of silver and cerium for CSP. None of the materials used for PHES or CAES are considered critical.

Supply chain criticality

While the carbon intensity of the energy mix in the use phase has the biggest impact on lifecycle greenhouse gas emissions, as the system transitions to a renewable energy system the contribution to emissions of material extraction and manufacturing become more significant.

Considering the current high carbon-intensity of Australia's energy grid, in general the technologies with a high round-trip-efficiency, such as lithium-ion perform relatively well. For bulk energy storage, PHES likely performs the best whilst CAES is not competitive as it is typically integrated with natural gas combustion resulting in CO_2 emissions. Hydrogen-to-power is not competitive however the flexibility of hydrogen in terms of end-use could support the decarbonisation of heat, power, transport and industrial processes; there is also potential for large-scale long-distance renewable energy export. It is difficult to directly compare CSP with TES in terms lifecycle emissions because these systems generate electricity as well as provide energy storage, but within the system the thermal storage component contributes a very small amount to the overall emissions.

Material intensity

Owing to the high use of non-renewable resources in key energy storage technologies the material intensity is an important metric. In general, battery storage technologies have a higher material intensity compared to the other technologies. Lithium-ion batteries have a relatively high energy density that makes them less material intense than the alternative battery technologies (whilst noting there are significant differences between the lithium-ion chemistries). The material intensity of CSP is relatively high compared to other renewable generation technologies, however the molten nitrate salts used for thermal storage are abundant.

Recyclability

The recyclability of energy storage technologies has the potential to alleviate high material intensity through recycling, reuse, or remanufacturing.

Low recyclability highlights a need to develop new infrastructure and technology and stewardship approaches. Lead-acid batteries are the only battery technology to have a high level of recycling in Australia of 90% as recycling offers a return to recyclers and new batteries are typically manufactured with 60–80 % recycled content. Whilst most lithium-ion batteries are technically recyclable, at present, there is neither the economic driver nor a policy incentive for recycling in Australia. There are other niche resource efficiency pathways for batteries under development, for example the potential for 'rebirthing' batteries from electric vehicles at the end-of-first-life for use in stationary energy storage.

For hydrogen storage, there are established pathways (although not located in Australia) for platinum catalyst recycling capable of achieving high recovery efficiencies (greater than 95 %). Recycling is well established for the major materials used for PHES, CAES and CSP with TES; furthermore, the long lifetimes for these bulk storage technologies make the recyclability less vital.

Environmental health

Environmental health is important as adverse impacts to ecosystems or human health along the supply chain can undermine the benefits of moving to a renewable energy system. As batteries are material intense technology they have the most significant impacts. The impact varies depending on the location of mining, processing, and end-of-life, owing to differences in technology, production pathways and local environmental and social standards. The most significant impacts from mining in China include contamination of air, water and soil from lead, graphite and phosphate mining, all of which have serious health impacts.

Pumped Hydro
has up to
80%
round-trip-efficiency
and long lifetimes

50%
of world's cobalt
produced in Democratic
Republic of Congo

The cobalt mining area of the DRC is one of the top ten most polluted places in the world due to heavy metal contamination of air, water and soil, leading to severe health impacts for miners and surrounding communities.

Considering bulk storage technologies, whilst PHES has a relatively large land and infrastructure footprint the impacts can be minimised by locating in areas that have already been modified such as existing reservoirs, away from conservation areas and with closed loop systems that reuse water. CAES has a lower visible impact on landscape however the process of forming salt caverns for compressed air storage involves the removal and processing of large volumes of salt water. Hydrogen storage has a relatively low land-footprint (for electrolysis technology) and there is good potential to use existing infrastructure. Because water is a feedstock this is an important consideration in dry areas.

Human rights

There are significant human rights impacts associated with the material demand for lithium-ion batteries, particularly lithium and cobalt. The mining of cobalt in the DRC is often done by artisanal and small-scale miners who work in dangerous conditions in hand-dug mines without proper safety equipment and there is extensive child labour.

Whilst there is a significant paucity of published research on the impacts of lithium mining, investigations by journalists and NGOs highlight water-related conflicts and concerns over lack of adequate compensation for the local communities with many people remaining in poverty despite decades of lithium mining in Chile, and recently in Argentina. For the bulk storage technologies, there are potential conflicts over land use in Australia that could arise from new PHES, CAES or CSP TES development and mitigation strategies should consider the economic, social and cultural impacts of developments to local communities.

Health and safety

The inadequate management of health and safety risks potentially jeopardises the viability of the emerging stationary battery industry and highlights a need to engage all relevant stakeholders to adhere to best safety-practice. The potential for thermal runaway leading to fire and explosion is

considered a very significant safety issue for the dominant lithium-ion chemistries (e.g. lithium nickel manganese cobalt oxide) and has received a lot of public attention in the context of the recall of Samsung Galaxy Note 7 smartphones. That said, the fire risks are well known and can be mitigated by design modification, appropriate installation, monitoring and management systems, as well as adherence to safety protocols at end-of-life. Because these risks potentially impacts a broad range of stakeholders from manufacturers, transport workers, retailers, installers, consumers, emergency response teams and recyclers it is a challenge to engage all actors.

Owing to the relative immaturity of the industry significant focus has been directed toward ensuring safe installation with key initiatives including the development of installation guides and Standards Australia is expected to publish a new installation standard. Other future initiatives under consideration include establishing a national energy storage register, adopting international product standards and accreditation of installers. Current observance of these best-practice guidelines is on a voluntary basis.

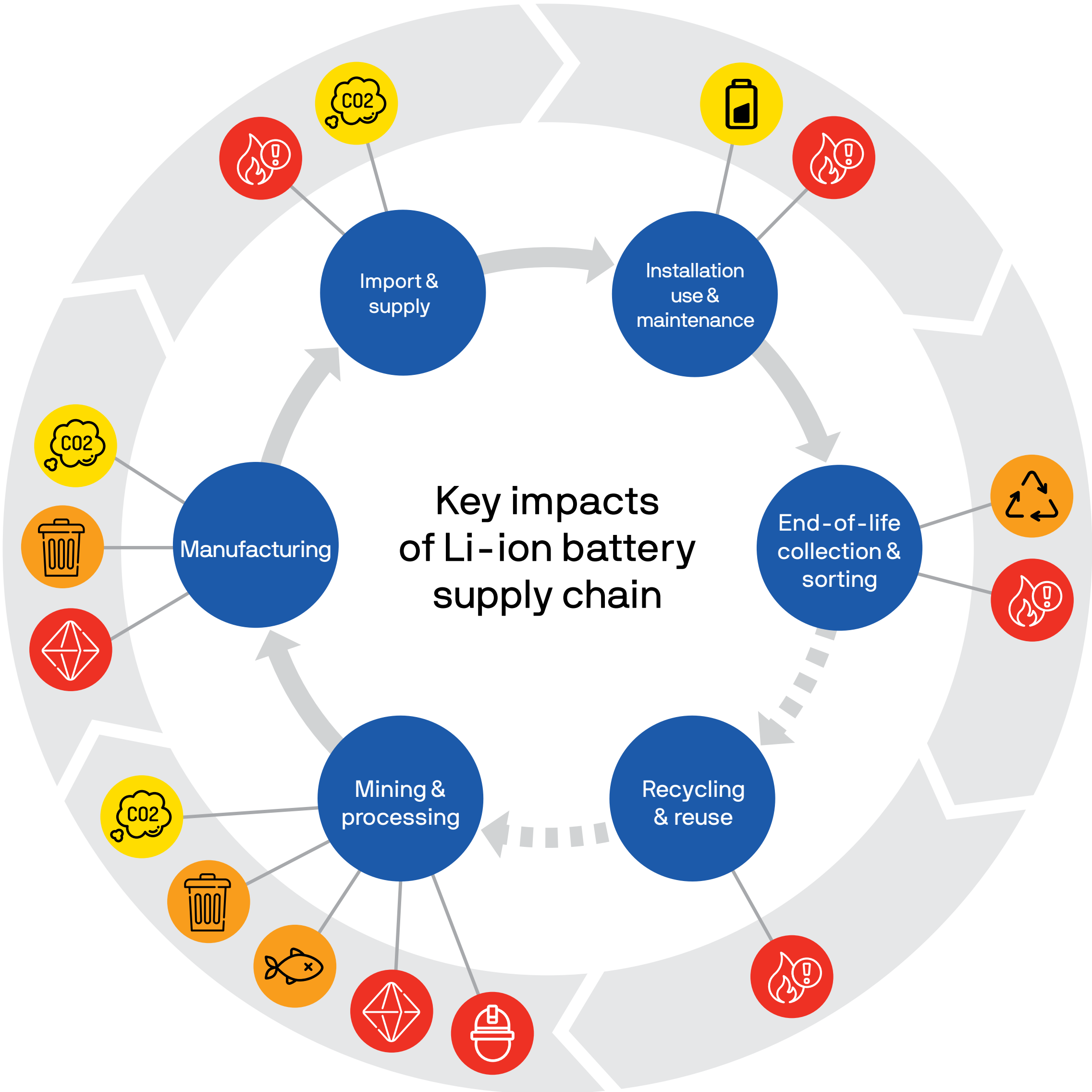
For hydrogen storage, the high flammability and mobility of H_2 molecules that can penetrate and damage internal structures, or lead to hard-to-detect leaks, present the main potential health and safety impacts; however, in the context of the likely near-term applications there are well-established management and mitigation strategies. Similarly, no high-order safety impacts are identified for PHES, CAES and CSP TES, all of which use mature technologies that are typically operated by trained workers. Workplace occupational health and safety measures are the main management strategies and the development of new policy to mitigate safety issues is not a priority.

ONLY
3-5%
of lithium-ion batteries sold onto the Australia market are collected for recycling

UP TO
80%
recycled content in lead-acid batteries

MORE THAN
95%
of platinum used as catalyst for hydrogen

Li-ion battery impacts



High impact

Medium impact

Low impact

Lifetime energy efficiency

Supply chain criticality

Recyclability

Human rights

Lifecycle GHG emissions

Material intensity

Environmental health

Health and safety

Priority interventions

It is clear that the lithium-ion battery technologies should be a priority as they present the highest-order environmental and social impacts and are likely to have high deployment and exposure to a range of stakeholders.

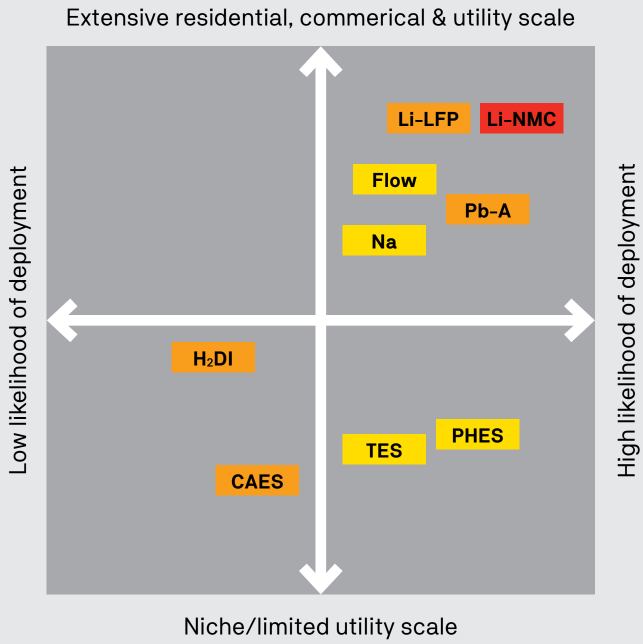
To evaluate the relative impacts and justify a priority focus for mitigation and management the overall risk and likely exposure ratings for the different technologies are located in a quadrant diagram (Figure A).

The colour of the box aligns with an overall risk rating based on the impact assessment framework (Table A). The vertical axis provides a range of likely deployments and is a proxy for level of exposure (i.e. more stakeholders are exposed for technologies deployed in residential and small commercial markets); the horizontal axis provides a range of in terms of likelihood of deployment consistent with the scenario modelling and techno-economics in WP1 and is a proxy for frequency. Those technologies clustered towards the top-right quadrant represent the greatest risk and justify a priority focus for mitigation and management.

On this basis, the priority focus for intervention is strategies that aim to mitigate the environmental and social impacts outlined above, namely:

1. Encourage the development of sustainable supply chains for metals
2. Engage the emerging battery energy storage industry actors to adhere to best safety-practice
3. Develop stewardship approaches for responsible management in use and at end-of-life

Figure A: Quadrant diagram showing relative risk and exposure ratings for the energy storage technologies (reproduced from Chapter 8)



Technologies

BATTERIES

Li-NMC	Lithium nickel manganese cobalt oxide
Li-LFP	Lithium iron phosphate
PB-A	Lead-acid batteries
Flow	Flow batteries
Na	Sodium-based batteries

BULK STORAGE

CAES	Compressed Air Energy Storage
H_2DI	Hydrogen Energy Storage (direct injection)
TES	Concentrated Solar Power with Thermal Energy Storage

1. Encourage the development of sustainable supply chains for metals

The front-end of the supply chain, particularly mining, material processing and manufacturing, has significant human rights and environmental health impacts. Most of these impacts occur outside of Australia, at different points along a complex supply chain. Furthermore, on the basis of expert stakeholder interview for this work it is apparent that they are not well known or understood by most stakeholders groups.

Australian governments and companies could take a leading role in putting sustainable supply chains on the global agenda by supporting key initiatives, including: ethical sourcing and Corporate Social Responsibility; mining and chain-of-custody standards, e.g. Australia has led the development of the Steel Stewardship Forum; national sustainable supply chain legislation; increased rates of recycling and reuse; and, new research to address the paucity of data characterising the supply chain impacts, criticality, and best approaches for mitigation.

2. Engage the emerging battery energy storage industry actors to adhere to best-practice for safety

The current focus of safety risk mitigation strategies prioritise installation, which makes sense in light of status of this emerging new industry for battery energy storage. The main initiatives are: the development of installation guides, the development of installation standards, efforts towards establishing a National Energy Storage Register, and efforts to align Australian initiatives with international product standards.

Presently, the key challenge is engaging with the industry to adopt best practice as standard development evolves. In the absence of any regulatory levers the Clean Energy Council has implemented 'battery endorsement' for PV accredited installers. Towards a more enduring (potentially regulatory) solution to encourage industry engagement and adherence to safety standards a number of industry stakeholders are advocating for changes to state and territory based electrical safety standards.

3. The development of stewardship approaches for responsible end-of-life management

Stationary storage batteries could present a significant waste management challenge or resource recovery opportunity in the coming decades. Thus, encouraging investment in end-of-life management infrastructure is an important priority as currently there is neither the economic or policy driver to incentivise investment.

To establish a product stewardship scheme there are multiple points of intervention along the supply chain (retail, installation, dis-installation, end-of-life) that highlights the need to engage a range of stakeholders. Expert stakeholder perspectives underlined the opportunity to align efforts to improve end-of-life management with complimentary ongoing efforts to ensure safety. This is because installation/dis-installation represents a shared critical leverage point for ensuring safety and establishing pathways for responsible end-of-life management; making the cost of end-of-life transparent at the point of sale (as opposed to the point of disposal) likely leads to better end-of-life management outcomes; and consistent approaches for stakeholder engagement and awareness raising is critical, e.g. protocols for information transmission along the supply chain with consistent signage and labelling. These viewpoints provide a strong rationale for action now rather than in ten years when the first installations reach end-of-life.