Understanding the Total Sustainability Impact of Li-ion UPS Batteries

White Paper 71

Version 1

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Executive summary

Interest and demand continue to grow for lithium-ion batteries as a replacement for VRLA batteries for UPS applications because of benefits such as smaller size and longer life expectancy. But there are many questions decision makers still have regarding the impact these batteries have on sustainability. The full environmental and social impact includes mining practices of the raw materials, the manufacturing process of the batteries, operations, and how to re-purpose or recycle them when they reach the end of their useful life. In this paper, we demonstrate that, while not a black and white topic, on balance, li-ion has an overall lower impact compared to VRLA over the complete lifecycle today, and we anticipate this to further improve in the future. For each life cycle phase, we describe best practices and attributes to look for in vendors and providers to ensure responsible, ethical, economical, and sustainable solutions are deployed.

Introduction

Since their invention in 1985, Lithium-ion (li-ion) battery technology has advanced significantly and is now capable of being used in applications that historically have been supported by lead acid or valve-regulated lead-acid (VRLA) batteries. One such application is uninterruptible power supplies (UPSs) in data centers[1]. But as the industry increasingly transitions to li-ion battery technology for these UPS applications, there is interest in understanding and questions that arise regarding the sustainability[2] implications of the transition. And as data center owners drive towards sustainable lifecycle practices, this topic increasingly comes up.[3]

VRLA batteries have been used in data centers for decades, and as such, the hazards and environmental issues associated with them are well known. The industry is experienced in managing these batteries throughout their life cycle to minimize their environmental impact. On the other hand, the hazards and environmental issues associated with li-ion batteries are both less known and different than their lead acid counterparts, *and* the industry is still evolving. This makes it challenging to make an informed choice between the two battery technologies on the basis of environmental sustainability.

Decision makers are raising questions or concerns about the wisdom of selecting li-ion over VRLA, due largely to claims of child labor in the extraction of cobalt used in some chemistries of li-ion batteries, excessive carbon intensity to manufacture these batteries, concerns regarding their safety in transport and in use, and concerns regarding end of life management. These claims typically give an incomplete picture because they only focus on certain (negative) aspects of li-ion batteries rather than viewing it holistically over the life compared to VRLA technology.

We conducted a quantitative study comparing VRLA to Li-ion batteries to assess the sustainability impact over their life cycle, also known as a life cycle assessment (LCA). **Figure 1** summarizes the findings and shows that **li-ion has a lower environmental impact than VRLA in eight of the nine categories, including carbon emissions**. White Paper 91, *Quantitative Life Cycle assessment (LCA) of VRLA vs. Li-ion UPS Batteries*, walks through this analysis in depth.

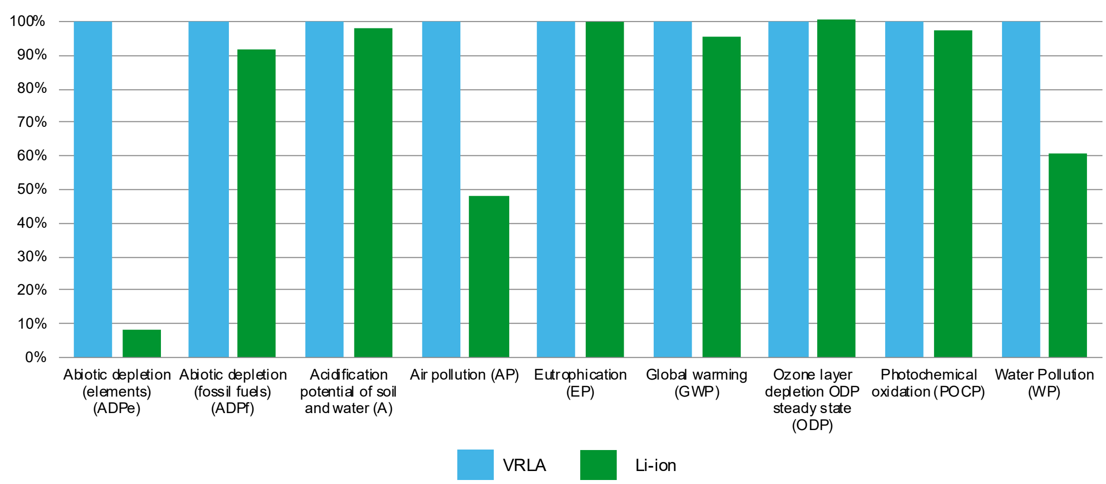


Figure 1

Results of quantitative analysis comparing VRLA and li-ion batteries on nine environmental sustainability metrics

Source: Schneider Electric White Paper 91

[1] Other applications include electric vehicles and battery energy storage systems. See White Paper 229, *Battery Technology for Data Centers: VRLA vs. Li-ion*, and White Paper 231, *FAQs for Using Lithium-ion Batteries with a UPS*, for more information on the technology differences and drivers.

[2] In 1987, the United Nations Brundtland Commission defined sustainability as: "Meeting the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability includes three main categories: environmental, social, and governance (ESG).

[3] White Paper 64, *Four Key Drivers for Colocation Data Centers to Prioritize Environmental Sustainability*, describes the reasons behind this increasing trend.

The full environmental impact includes mining practices of the raw materials, the manufacturing process of the batteries, operations, and how to repurpose (through secondary uses) and recycle them when they reach the end of their useful life in UPS applications. Embracing the circular economy and managing each phase of the life cycle is critical to sustainable design and operation. Figure 2 illustrates the key categories across the life cycle diagram where sustainability differences should be understood between VRLA and li-ion.

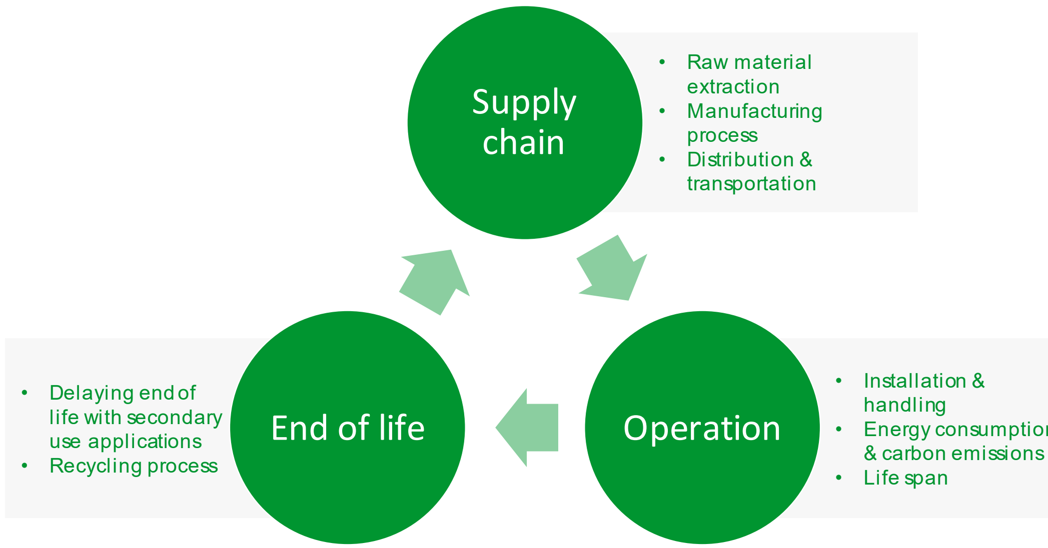


Figure 2

All stages of the battery life cycle have an impact on sustainability

In this paper, we discuss how these factors impact the environment today as well as our expectation for the future. For each, we describe practices and attributes to look for in vendors and partners to ensure responsible, ethical, economical, and environmentally sustainable solutions are deployed.

Supply chain

Many of the sustainability questions that arise relate to the battery supply chain. This includes (1) raw material extraction, (2) the manufacturing process, and (3) the distribution and transportation of the batteries after they are manufactured. Below we explain the sustainability impact at each phase, discuss some common misconceptions, and describe how VRLA and li-ion batteries differ.

Raw material extraction

The raw materials needed in the manufacturing of new batteries can come either from **mining the materials** or **extracting them from recycled materials**. In the case of VRLA batteries, the recycling system is almost an ecological closed loop. The plastic parts of the battery are recycled into more battery plastic. The sulfuric acid is collected and resold as commodity acid. The lead is smelted and returned back to batteries or applied to other uses of lead. According to a study conducted by Battery Council International (BCI), Chicago, and Essential Energy Every day, lead batteries have a return for recycling rate of 99.3 percent, making them the No.1 recycled consumer product in the U.S.[4] The recycling is highly regulated in the US and EU and well established internationally, but with need for more regulation (see the **Toxicity** section below). By partnering with reputable UPS suppliers or battery manufacturers, most VRLA battery owners can dispose of their spent batteries free of charge.

[4] https://www.recyclingtoday.com/article/battery-council-international-lead-battery-recycling/

Li-ion battery minerals are largely obtained through mining since recycling practices are still developing. Later, in the "End of life" section of this paper, we discuss the implications of this further.

When contrasting the sustainability implications of VRLA to li-ion during raw material extraction, there are three main considerations:

- the **toxicity** of the processes
- the safety and ethics of the **mining practices**
- the **mass of material** needed

Toxicity – During raw material extraction of VRLA batteries, including the recycling process, lead is released and can have a significant health impact. World Health Organization summarized these concerns in a 2017 report, Recycling used lead-acid batteries: health considerations. "Recycling used lead-acid batteries is of public health concern because this industry is associated with a high level of *occupational exposure* and *environmental emissions*. Furthermore, there is no known safe level of exposure to lead, and the health impacts of lead exposure are significant. Based on 2016 data, it is estimated that lead exposure accounted for 495,550 deaths and 9.3 million disability-adjusted life years (DALYs) lost due to long term impacts on health, with the highest burden in low- and middle-income countries (IHME, 2016). Young children and women of childbearing age are particularly vulnerable to exposure to, and the toxic effects of, lead."

It's been clear for many decades (and even centuries[5]) that the toxicity of lead is hazardous to human wellbeing. Over the years, we saw many public health movements to remove it from gasoline, paint, solder, water-system piping, and so on, to avoid air and water contamination. The toxicity of lead is the reason VRLA battery manufacturing and recycling processes are so regulated in many parts of the world. Processes include the wearing of respirators, constant cleaning, air filters/controls, etc. to prevent lead from escaping into the environment. But there is still environmental contamination and human exposure happening at mines and recycling facilities in countries where it is poorly regulated, as the World Health Organization (WHO) report referenced above noted. **Figure 3** shows the many points where lead is released in the recycling process.

For the reasons above, we've seen the elimination of lead in many aspects of our lives as safer alternatives became available, and we can expect that same trend to continue in other applications, such as automobiles and UPSs/energy storage.

While regulatory bodies across the globe classify lead acid batteries as toxic hazardous materials with health and environmental implications, li-ion batteries, which contain less toxic metals, are generally classified as non-hazardous waste. One example of such a test used to classify a battery as hazardous or not is the Toxicity Characteristic Leaching Procedure, also known as TCLP testing. This analysis simulates conditions within a landfill and determines which of the contaminants identified by the United States Environmental Protection Agency (EPA) are present and at what concentrations. [6]

[5] https://environmentalhistory.org/about/ethyl-leaded-gasoline/lead-history-timeline/

[6] https://leadlab.com/what-is-a-tclp-test/

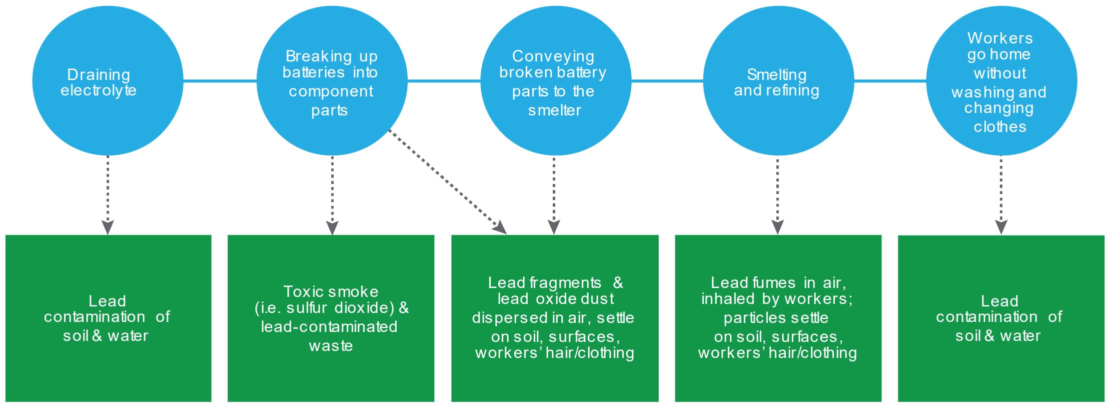


Figure 3

Points where lead is released during the recycling process

Source: World Health Organization, [Recycling used lead-acid batteries: health considerations]

Mining practices – While the raw materials within li-ion batteries don't have the same toxicity concerns as batteries with lead, the mining practices have raised concerns over social and environmental impacts. Most of the questionable mining practices are based on li-ion battery chemistries that include the raw material cobalt, an ingredient often used in larger 3-phase UPS batteries.[7]

Cobalt is largely mined in the Democratic Republic of Congo. Mining is not always regulated, and some mines and smelters may conduct unethical labor practices, including the use of child labor and unsafe work conditions. The Responsible Minerals Initiative has a process where smelters and refiners can register their organization and they get 3rd party independently audited to confirm ethical practices, in line with current global standards. It's important to look for UPS vendors that only source batteries from manufacturers/distributors that only source materials from mines and smelters that are part of this initiative (and can prove it with documentation), to ensure ethical practices. Since supply chains evolve over time, it's also important to ensure vendors are using providers that are annually recertified.

The mining of lithium has also been criticized as having a negative environmental impact. Because today it is largely sourced from mining (since recycling processes are still developing), there are some parts of the world where the mining practices are not sustainable. For instance, in the Atacama Salt Flats in Chile, which has the greatest source of the world's lithium (see **Figure 4**), "the region's ecosystem is fragile and there is lack of consensus regarding the impacts and risks of lithium mining and other economic activity in the region. Potential risks from changes in water and brine table levels could potentially harm the ecosystems and affect local livelihoods."[8]

But the demand for li-ion batteries, driven largely by the rapidly growing electric vehicle (EV) market, is moving the industry towards more stringent requirements for miners to improve the sustainability of the EV supply chains. UPS applications will benefit from that momentum. And as the recycling practices mature, we will move to a more circular economy with a larger percentage of the raw materials obtained from recycled sources.

Even with the current state of development of these mining and recycling practices, the environmental impacts of li-ion batteries are still lower than their VRLA counterparts. Specifically, this is due to the toxicity of lead. The analysis in White Paper 91,

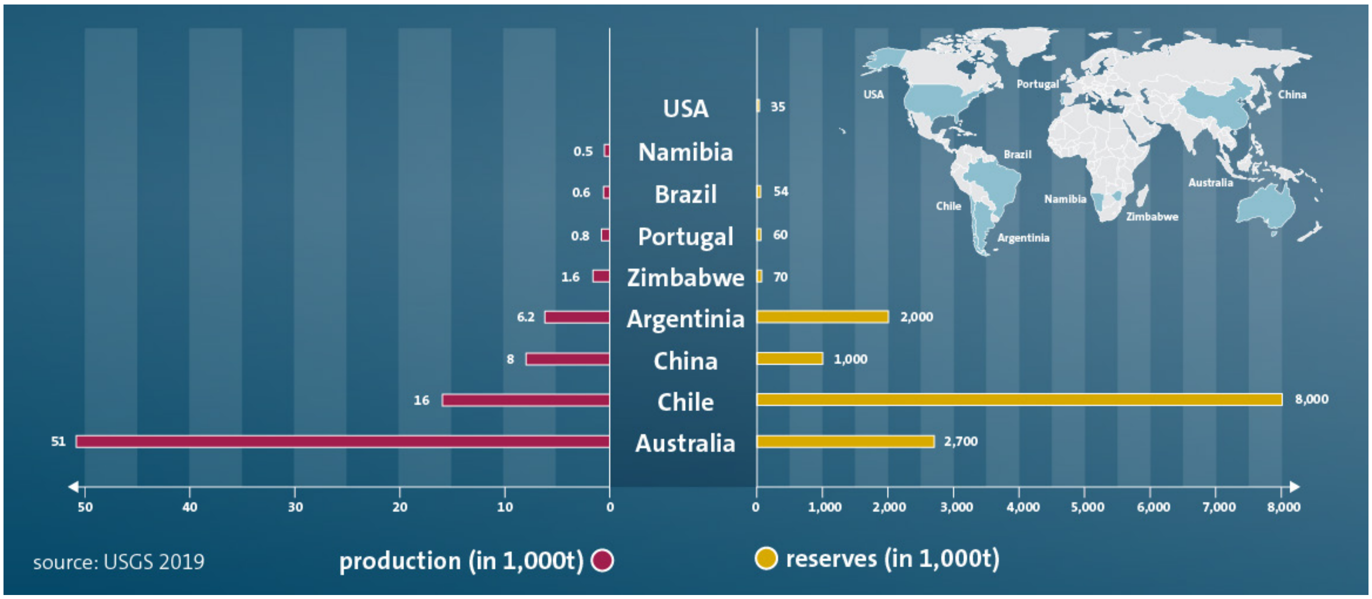
[7] See Schneider Electric White Paper 284, *Considerations for Selecting a Lithium-ion Battery System for UPSs and Energy Storage Systems*, for more about chemistries.

[8] https://www.globalminingreview.com/environment-sustainability/09062021/companies-start-partnership-for-sustainable-lithium-mining-in-chile/

Quantitative Life Cycle assessment (LCA) of VRLA vs. Li-ion UPS Batteries, quantifies these environmental impacts, and shows that lead has greater water and air pollution impacts due largely to lead's toxicity (See **Figure 1**) .

Figure 4

Countries with major lithium production and reserve
Source: Volkswagen AG 2021



Mass of material – The other key environmental risk factor for raw material sourcing is the amount of material needed. The energy density of a li-ion battery compared to its equivalent VRLA battery drives a significant reduction in size and weight. For example, a 1MW UPS battery with 6 minutes of runtime may have a battery solution weighing over 11,340 kg (25,000 lbs), vs a li-ion battery weighing only 2,767 kg (6,100 lbs)[9]. That's a significant reduction of 300%.

KEY TAKEAWAY – The smaller mass of material and significant decrease in toxicity of li-ion results in lower environmental impact overall in the material sourcing phase of the battery life cycle.

Manufacturing process

The variables that drive environmental impact differences for VRLA and li-ion batteries during the manufacturing process include:

- The battery "system" component requirements
- Manufacturing process complexity
- Lifespan impact

The battery "system" component requirements – Li-ion batteries are not able to withstand the same level of variation of charging/discharging parameters as VRLA batteries. Because lithium battery cells are very sensitive to environmental factors (i.e. voltage, temperature), the battery system is more complex to ensure its safety.

[9] White Paper 229, Battery Technology for Data Centers: VRLA vs. Li-ion, https://www.se.com/us/en/download/document/SPD_VAVR-A5AJXY_EN

Table 1 illustrates the components needed for both VRLA and li-ion battery systems.

Table 1

Battery "system" components comparison

VRLA system	Li-ion system
• Enclosure • Battery cells • Connections/busbars	• Enclosure • Battery cells • Connections/busbars • Battery-level BMS • Rack-level BMS • System-level BMS • Switchgear • Power supplies

As shown in the table illustrates, there are added components like battery management systems (BMS) at various points in the system – for individual batteries, for the collection of batteries in a rack/enclosure, and for the overall system; there is also switchgear needed to manage electrical flow to/from the batteries and power supplies for controlled charging. These additional components are designed into the system to ensure safety and longevity of the battery. But this equipment overhead adds to the complexity of the manufacturing, as we describe next. *Note, some VRLA battery systems do include BMSs and system-level sensors, which adds to the manufacturing complexity of VRLA, narrowing the difference between the two battery types.*

Manufacturing process complexity – The manufacturing process of VRLA batteries is simple in comparison to that of li-ion batteries. VRLA processes are very mechanical and involve primarily casting or stamping operations[10]. On the other hand, with li-ion, manufacturing circuit boards (the BMSs), switches, and power supplies requires a more complex and diverse supply chain with more comprehensive and intensive operations. Manufacturing integrated circuits requires micron-level tolerances, micro lasers to cut things, and other advanced technologies. These carry a greater environmental burden – in terms of air pollution (i.e. ozone depleting substances in the manufacturing of circuit boards), carbon emissions, and water pollution – when you compare it on a 1 to 1 battery basis. This is where many of the questions stem from.

Lifespan impact – Although this is largely an "Operations" discussion and will be covered in greater detail in the next main section, the lifespan impact is an important factor in the environmental impact of the manufacturing processes. Although as we said earlier, on a 1 to 1 or unit for unit basis, the li-ion has a greater environmental impact than VRLA, the reality is that this is a *biased comparison*, given the performance attributes of the batteries. **When we consider the environmental impact of manufacturing not only the initial VRLA batteries, but also their replacements over a typical UPS life (often 2 replacements in 10 years), the environmental impact of manufacturing looks very different.** The formulas in **Figure 5** convey this important consideration. You may be led to the wrong conclusion if you just evaluate one for one battery solutions. This is analogous to making design decisions on capex vs. TCO.

[10] https://www3.epa.gov/ttnchie1/ap42/ch12/final/c12s15.pdf

Figure 5

Properly defining the boundaries (to include initial batteries AND necessary replacements) in an environmental impact analysis is crucial to a meaningful conclusion.

A paradigm shift for comparing environmental impact of batteries

1 FOR 1 ✗	Environmental impact of **1** VRLA system	***Less than***	Environmental impact of **1** li-ion system
NEEDS OVER UPS LIFETIME ✓	Environmental impact of **1 initial** **+ 2 replacement** VRLA systems	***Greater than***	Environmental Impact of **1** li-ion system

For example, this is important for companies looking at embodied carbon footprint of the two approaches as part of their decision criteria. If you don't take into account the proper boundaries (the complete life cycle), and instead look only at the differences in manufacturing one li-ion vs. one VRLA, you may misinterpret the results and head down the wrong path to a solution that, in fact, has a greater embodied carbon footprint.

KEY TAKEAWAY – For typical installations, when replacement batteries over the UPS lifetime are considered, the environmental impact of manufacturing for li-ion systems is less than VRLA systems, even with the added equipment overhead for li-ion.

Distribution & transportation

The concerns often brought up regarding li-ion batteries and transportation have to do with safety because of the transportation "incidents" we hear about in the news. Li-ion batteries are categorized as "dangerous goods" by international regulations and by many transport companies, and therefore, strict regulations and processes make transporting them more complex. For instance, specialized transportation is required, with temperature and pressure-controlled spaces, which drives up the cost to ship li-ion per kg. It's a learning curve for many companies, and it's important to align with vendors and suppliers that have expertise in handling them.

As discussed earlier, the higher energy density of li-ion results in a significantly lighter weight (typically 60-80% less) compared to VRLA, so although the cost/kg may be greater, it is offset by the lighter weight. Environmental impact from the transportation and distribution of batteries is also driven largely by the size and weight of the batteries.

KEY TAKEAWAY – Although the complexity of distribution & transportation is increased, the lighter weight of li-ion over VRLA enables a reduced environmental impact.

Operation

The operations or "use" phase represents the bulk of the sustainability impact over the battery life cycle. Below we describe key environmental considerations from (1) installation & handling, (2) energy consumption, and (3) lifespan differences that result in a lower overall impact for li-ion.

Installation & handling

The concerns often mentioned regarding li-ion during installation and handling revolve around safety (i.e. dealing with fire codes), not environmental sustainability. This topic of safety and the unique code requirements of li-ion will be addressed in a future white paper.

The differences in environmental impact that occur during installation and handling of VRLA vs li-ion, although fairly small, is mainly driven by battery weight differences. For instance, since li-ion is a lighter solution, the solution can often be carried into place from the loading dock vs. driven with a forklift that uses fuel or electricity. The differences also result from the fact that over the life cycle, with VRLA, there are replacement units that must be installed/handled, whereas li-ion batteries generally last the life of the UPS.

KEY TAKEAWAY – Although a minor impact overall, the lighter weight and need for less or no li-ion battery replacements results in decreased environmental impact during installation & handling compared to VRLA.

Energy consumption & carbon emissions

The environmental indicator most questioned with regard to energy consumption is global warming potential (GWP) or the scope 2 CO2e emissions[11]. The magnitude of the carbon footprint that results from the energy consumption depends on two key factors:

- the generation sources for the electricity consumed, which varies significantly from state to state and country to country. The **emissions factor** (kg CO2e/kWh) is greater when sources of generation include coal, natural gas, and oil; it is lower when it includes renewable sources like solar, wind, and nuclear. The emissions factor (a rate) is the same whether you deploy VRLA or li-ion batteries, but the total emissions will differ.
- the **energy losses** (kWh), include the fixed losses from trickle charging the battery, and the transient losses from discharging or charging the battery after a power outage. For a given emissions factor, the percent reduction in emissions is directly proportional to the reduction in losses.

With a goal of achieving net-zero emissions for so many businesses, we are often asked about the impact li-ion technology has on reducing emissions. UPSs are use-driven products from a CO2e emissions standpoint. In fact, more than 90% of a UPS's emissions occur in this phase of the life cycle, because of its energy consumption. Batteries represent a small portion of this energy consumption.

When comparing the two types of batteries, li-ion consumes less energy than VRLA batteries during operation. This is because of battery chemistry differences that

[11] https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance#:~:text=Scope%202%20emissions%20are%20indirect,of%20the%20organization's%20energy%20use.

result in slower self-discharge rates.[12] Batteries must be charged to offset their rate of self-discharge. Typical losses over the lifetime of a VRLA battery are 0.2% of the rated UPS capacity, whereas for li-ion, it is roughly half of that energy, or 0.1%.

KEY TAKEAWAY – Roughly half the energy is needed for keeping li-ion batteries charged compared to VRLA, resulting in a decrease in CO2e emissions during the lifetime operation of the batteries.

Life span

As we briefly mentioned earlier in the manufacturing process section, lifespan is the key enabler to the environmental impact differences of li-ion over VRLA. Li-ion has slower degradation (more discharge cycles) than VRLA batteries. The differences in cycle life become even greater at higher operating temperature, as VRLA are highly sensitive to operating temperature.

Because of these differences, VRLA batteries are generally specified for a service life of 3-5 years, whereas li-ion are specified at 10+ years (actual timeframe depends largely on power quality and how frequent the battery gets discharged/charged). In the life expectancy of a UPS, this often means 2 VRLA battery replacements when none are needed for li-ion. For every replacement VRLA battery solution, the impact on sustainability is multiplied – more manufacturing waste impacts, more distribution/transportation impacts, more installation & handling impacts, and so on. The "*Lithium-Ion vs. VRLA UPS Battery TCO Calculator*" TradeOff Tool demonstrates the impact on energy consumption and allows you to vary the assumption of how long each battery technology can remain in operation before replacement. The sustainability impact looks very much like the cumulative TCO chart. While it starts out higher on day 1, over time, as replacements of VRLA are needed, li-ion generally becomes the better alternative.

TAKEAWAY – Li-ion's longer lifespan than VRLA enables lower sustainability impact during operation. The more replacements of VRLA needed over the UPS lifetime, the better li-ion performs.

End of life

Many of the questions about the sustainability impact of li-ion focus on end of life and recycling. With VRLA batteries, the recycling practices are mature. Cost effective processes lead to a high percentage of recycled materials. Vendors like Schneider Electric have well established collection, re-use and recycling processes for more than 98% of the VRLA UPS batteries we place in the market.

With li-ion, on the other hand, the industry is still maturing, which is why many questions arise. It's important to find a vendor that is committed to providing their customers with products that support the same type of circular economy as with VRLA batteries. A key part of this is ensuring that products are managed at their end of life. This begins with a safe takeback process for defective and end of life batteries. This requires knowledge and partnerships in transportation logistics of battery systems subject to stringent safety requirements, and a commitment to customers that the vendor will recover the batteries when it can no longer serve its primary function.

[12] https://www.myussi.com/glossary/battery-self-discharge/

There are two key elements to ensuring a sustainable end-of life for li-ion batteries once a vendor takes back the systems. The vendor must be committed to:

- qualified secondary uses that delay end of life
- sustainable recycling processes

Delaying end of life with secondary use applications

Since the lithium-ion battery industry is still maturing and the economics of recycling are not particularly favorable, end of life options are not as sustainable and cost effective as they will be in the future. Some companies are promoting a delayed end of life strategy to ensure that *when* units have to be managed, the necessary recycling infrastructure is in place. Delaying end of life serves as a bridge to full circularity.

The electric vehicle (EV) market, which represents the greatest percentage of li-ion batteries, is paving the way for second use applications. It is therefore beneficial to find UPS vendors that are aligning with and leveraging the efforts of this market, in terms of processes. The economics of "second life" represents a promising means of extending the time before the batteries must be recycled, to allow time for the economics to become more favorable.

Batteries fall into two general categories – energy batteries and power batteries, with "energy" batteries being optimized for long runtimes and "power" batteries being optimized for short duration runtimes. Secondary uses as "energy" batteries are possible because even when power batteries have degraded to (i.e. to 60%-70%), and they are no longer suitable for UPS applications, they can still offer significant benefit.[13]

The National Renewable Energy Laboratory (NREL) conducted an analysis on the feasibility of such applications when EV batteries reach the end of their useful life. They found that "the most promising application identified for second use batteries is to replace grid-connected combustion turbine peaker plants and provide peak-shaving services." In applications like this, second use lifetimes can be on the order of 10 years, meaning batteries won't need to be recycled for 20+ years from their initial first use. Their analysis also demonstrated the significant value to the broader community in terms of reduction of greenhouse gas emissions and fossil fuel consumption, as well as deferral of battery recycling.

There are also niche markets for using the li-ion power batteries as energy batteries in their second use. A short list of possible second uses is below, but this is far from an exhaustive list, as many more applications exist, and the list will continue to grow.

- Microgrid applications
- Agriculture applications, to peak shave the spikey energy use of machinery
- Transportation uses, such as powering interior comfort electronics of tour buses
- Hospital uses, such as to support emergency lighting
- Home energy storage applications

[13] See White Paper 229, Battery Technology for Data Centers: VRLA vs. Li-ion, for a description of energy vs. power cells.

Developing infrastructure to support the logistics, evaluation, and repurposing of the batteries is crucial to a successful second life system. This includes the testing of batteries to ensure they are capable of providing a second life and identifying and/or qualifying new applications for these batteries. UPS vendors must be committed to second life and partner with the right organizations, to ensure (1) their batteries that they take back conform to standards & are certified, and (2) qualified second use applications are suitable.

Conformance to standards: In 2019, UL announced a new standard, UL 1974[14], the Standard for Evaluation for Repurposing Batteries. This is focused first on the effective reuse of EV batteries for energy storage systems and covers the sorting and grading process of batteries that were originally configured and used for other purposes and that are intended for a second use application. It is important to be aligned with UPS vendors that will ensure standards are met in terms of safety and performance.

Suitable second use applications: UPS vendors in collaboration with external partners can make sure batteries can be safely and effectively repurposed. Vendors must be committed to only shipping batteries (reclaimed from customers) to providers of validated 2nd uses and not simply rely on claims of 2nd use.

This secondary use trend was very similar to VRLA many years back when the value of lead was much lower than it is now and the return on lead acid batteries from recycling was much lower. There was a very active second use market where companies collected lead acid batteries, tested them, and sold them into markets that required large quantities of low-cost batteries. The most common was for certain emergency lighting applications. Around 10-15 years ago, the value of lead became high enough that there was more value obtained from recycling than from reuse. That trend has continued such that the worldwide reuse market doesn't really exist right now.

KEY TAKEAWAY – UPS li-ion batteries have the opportunity for a 2nd life so it can continue to provide value beyond its first designed purpose. Using UPS vendors that are committed to this ensures batteries made today will reach true end of life when the economics of recycling are cost effective.

Recycling process

Li-ion battery recycling is in its infancy and therefore the subject of growing concern. "There are many reasons why li-ion battery recycling is not yet a universally well-established practice," says Linda L. Gaines of Argonne National Laboratory[15]. A specialist in materials and life-cycle analysis, Gaines says the reasons include technical constraints, economic barriers, logistic issues, and regulatory gaps. This means that today, much of the li-ion battery materials are incinerated with low recovery rates. There is a high degree of confidence, however, that the industry will mature to minimize the impacts these batteries will have on the environment because:

- **Robust processes aren't needed for a number of years:** the life expectancy of li-ion batteries of 10+ years, plus time used in 2nd life applications.
- **The value of the metals is increasing:** this is in part due to mining/extraction becoming more restricted (by 2030, cobalt and lithium will be harder to get

[14] https://www.ul.com/services/second-life-electric-vehicle-battery-repurposing-facility-certification

[15] https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28

from mining, and recycled materials will become the primary means to obtain those materials); but also because the demand for li-ion batteries is growing; so while the cost of extraction today is less costly than recycling, that statement will not be true in the near future.

- **The EV market is driving investment and research:** with the growth of EVs, and realization of the potential end of life impact, technologies and infrastructure are emerging to maximize recycled materials and minimize cost.
- **Regulations will further drive the recycling maturity:** "The U.S. Environmental Protection Agency has created alternative regulatory controls for recycling certain materials, like lead-acid batteries, to encourage the collection and recycling of hazardous waste. A similar designation for lithium-ion batteries could reduce liability concerns and make the economics of recycling more desirable."[16] Other countries such as South Korea and Canada also manage recycled materials with alternative programs in ways that reduce the regulatory burden and promote recycling.
- **New recycling technologies are emerging:** Alternative approaches to incineration are proving to recover more of the battery materials which result in more recovered value at the end of the process.

There are two main approaches to li-ion recycling discussed today – Pyrometallurgical and Hydrometallurgical. **Table 2** summarizes these approaches at a high level.

Pyrometallurgical methods collecting heavy metals in the ash, are most used today. But companies such as li-cycle are making significant advancements for the industry. Their hydrometallurgical process, for example, claims to support all chemistries and formats of li-ion batteries, recovers 95%+ of the constituent materials found in lithium-ion batteries, and avoids landfilled waste during the process. Through hydrometallurgical process, the cathode and anode materials can be processed into battery grade end-products for reuse in lithium-ion battery production or other applications in the broader economy.[17]

Table 2

Two methods of recycling

Comparison	Pyrometallurgical	Hydrometallurgical
Approach	A process that uses the application of heat (incineration, smelting) for extraction and purification of metals.	A process that uses water as a solvent to extract and recover valuable elements from complex mixes of compounds.
Advantages	Simple and efficient process for recovering cobalt and nickel	High recovery rate of metals High purity output Low energy consumption
Disadvantages	Small percentage of battery is recovered Lithium and manganese are not recovered More waste gas and cost of waste gas treatment	Greater amount of wastewater Longer, more complex process

[16] https://www.nrel.gov/news/program/2021/pathways-to-achieve-new-circular-vision-for-lithium-ion-batteries.html

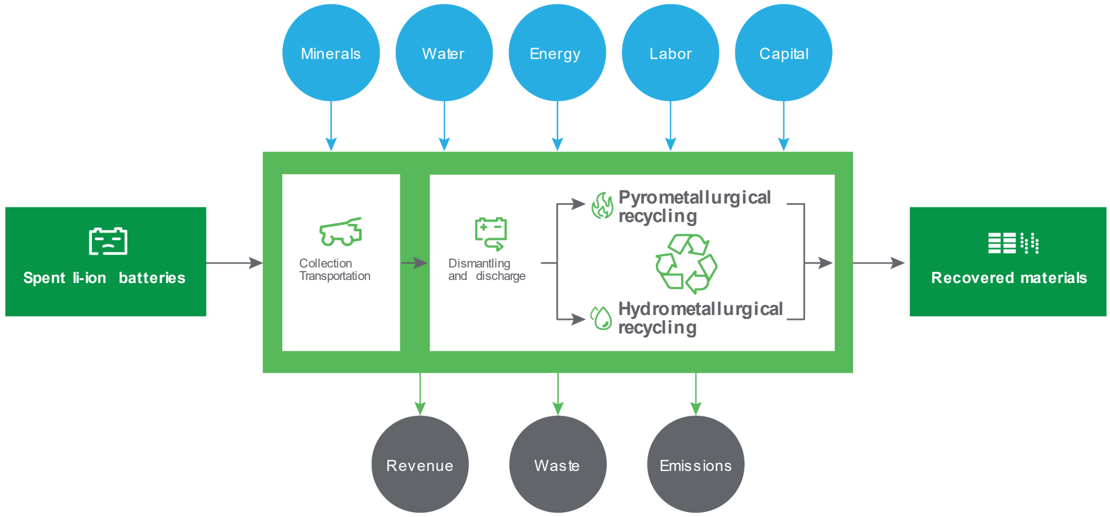
[17] https://li-cycle.com/technology/

A successful recycling system depends on more than just the right technology though. The recycling process must consider transportation costs, locations of recycling facilities, pre-processing costs to disassemble and discharge the batteries, the efficiency and cost of the recycling process, the environmental impact of the processes, as well as the battery chemistry. The diagram in **Figure 6** illustrates these considerations.

Figure 6

Factors in recycling li-ion batteries

Source: [Recycling strategies for End-of-Life Li-ion Batteries from Heavy Electric Vehicles]



Vendors like Schneider Electric are committed to working with recycling processors/logistics firms as well as the recycling companies to ensure a circular process going forward. While there are certainly some complexities, the processes and economics are beginning to align. The end goal is a cost effective, simple, timely, and sustainable process. A vendor committed to end of life management of their customers' systems should be fully transparent and be able to show their documented processes and partnerships and provide proof of validation/certificate that their batteries are being recycled in the way described (i.e. long-term contracts). They should also be committed to evolving their processes as technology improves.

KEY TAKEAWAY – While the recycling infrastructure is not mature today, given the longevity of li-ion batteries, by the time new batteries reach end of life, we believe a fully functioning recycling system will exist for a sustainable end of life at minimal to no cost.

Conclusion

As interest and demand continue to grow for li-ion batteries over traditional VRLA batteries for UPS applications, concerns are arising about the circularity of these systems including questions about the carbon impact of producing these batteries, their operational impact, and their limited recyclability. In this paper, we discussed the impacts over each phase of the li-ion life cycle. **Although there are certain aspects with higher impact than VRLA batteries, overall, li-ion has a lower environmental impact over the life cycle,** and we anticipate this to improve further in the future. The key take-aways are as follows:

- **Raw material extraction** – The smaller mass of material and significant decrease in toxicity of li-ion result in lower environmental impact overall in the material sourcing phase of the life cycle.
- **Manufacturing process** – For typical installations, when replacement batteries over the lifetime are considered, the environmental impact of manufacturing

for li-ion systems is less than VRLA systems, even with the added equipment overhead for li-ion.

- Distribution & transportation – Although the complexity of distribution and transportation is increased, the lighter weight of li-ion over VRLA enables the environmental impact to be reduced.
- Installation & handling – Although a minor impact overall, the lighter weight and need for less or no li-ion battery replacements results in decreased environmental impact during installation and handling compared to VRLA.
- Energy consumption and carbon emissions – Roughly half the energy is needed to keep li-ion batteries charged compared to VRLA, resulting in a decrease in CO2e emissions during the lifetime operation of the batteries.
- Life span – The longer lifespan of li-ion enables improved operational efficiency and overall lower sustainability impact. The more replacements of VRLA needed over the lifetime, the better li-ion performs.
- 2nd life applications – UPS li-ion batteries have the opportunity for a 2nd life so it can continue to provide value beyond its first designed purpose. Using UPS vendors that are committed to this ensures batteries made today will reach true end of life when the economics of recycling are cost effective.
- Recycling – While the recycling infrastructure is not mature today, given the longevity of li-ion batteries, by the time new batteries reach end of life, we believe a fully functioning recycling system will exist for a sustainable end of life at minimal to no cost.

Vendors that are committed to circularity for their customers will transparently share information at the detailed level and commit resources and work with leading edge partners to ensure responsible, ethical, economical, and sustainable solutions are deployed.

About the authors

Ray Lizotte is a Senior Sustainability Engineer and Senior Distinguished Engineer (Edison Level II) at Schneider Electric. He directs efforts to design and develop product offers that meet global regulations such as European ROHS and REACH directives. He specializes in making products more sustainable through less toxic and greener materials and application of circular end-of-life approaches. For the past few years, he has been working with the company's procurement organization to responsibly source conflict minerals including cobalt. He has been involved in sustainable product design for the past 30 years. Ray studied environmental engineering at MIT where he graduated with a BS in 1985.

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