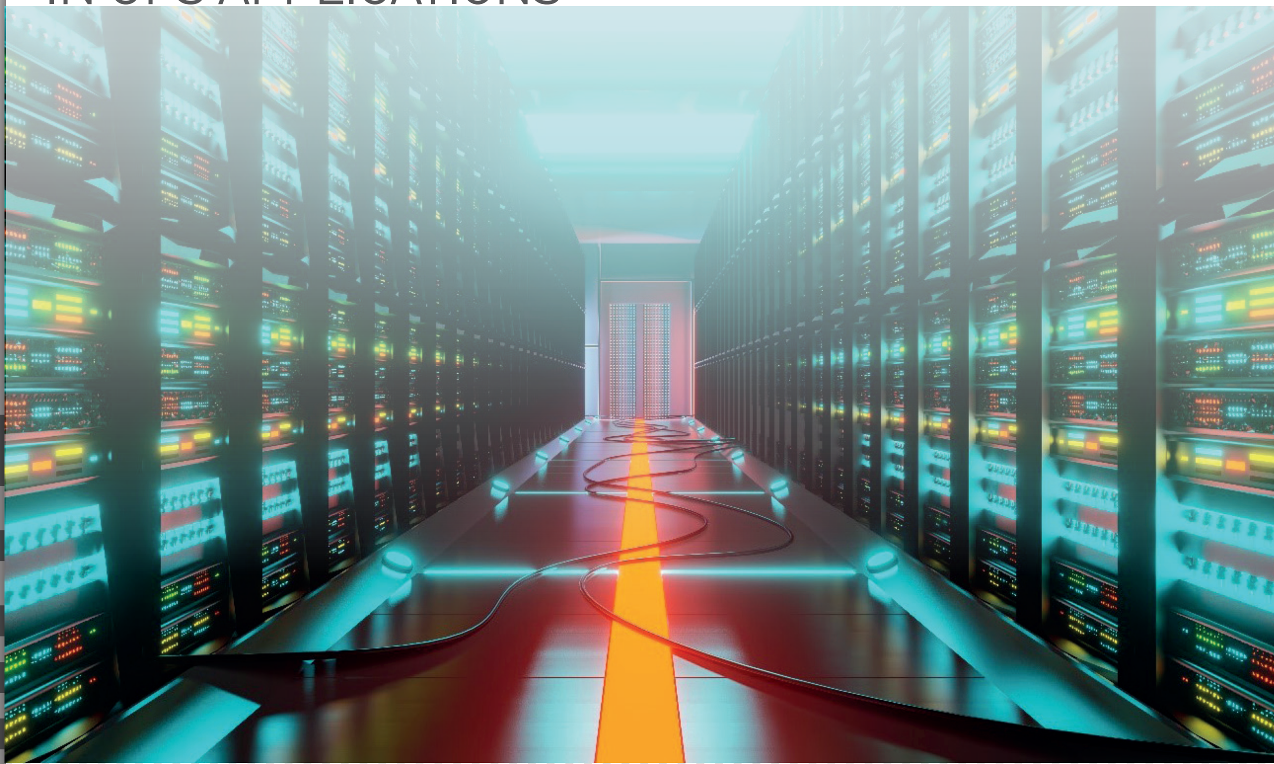
WHITE PAPER

Li-Ion vs VRLA batteries

IN UPS APPLICATIONS



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UPS AND ENERGY STORAGE

1 UPS MISSION

The main scope of the UPS (Uninterruptible Power Supply) is to guarantee continuous and high-quality energy to critical devices which cannot stop their operation. In other words, UPS filters electric disturbances from the upstream energy network, providing the best possible voltage supply to the output.

Blackouts and micro interruptions are some of the most dangerous disturbances from the energy networks and they can determine the undesired shutdown of electronic devices. For this reason, UPSs need to be connected to an energy storage which can promptly compensate the temporary lack of energy from the upstream network. Technically there are several types of energy storage but, in most cases, UPSs employ batteries.

2 BATTERIES

Batteries are often considered just as an energy storage system, like a sort of container of energy: in fact, from a physical point of view, batteries and accumulators are machines which transform (convert) chemical energy into electric energy and vice versa. This means that batteries are not only identified by energy capability but, as any other machine, they have their own efficiency, power losses, power capability, lifetime, aging factors, etc.

Accordingly, with the different applications, different batteries will have specific performances such as long endurance for long discharge or fast energy delivery, resiliency for frequent charge and discharge cycling or less sensitiveness to temperature, etc.

Historically lead-acid batteries are the most widely used, particularly VRLA technology or NiCd and NiMH. In recent times, new Li-Ion-based batteries are emerging as an interesting alternative to the traditional solution.

3 NEEDS OF THE APPLICATION

The main scope of battery sets used by UPS is to be sufficient to provide the electric power needed by the connected devices for enough time, to guarantee proper operation: this is referred to as battery energy capacity. Actually, capacity is not enough, in fact battery sets need to be compatible also with the available space in the installation site, environmental conditions (temperature, humidity, etc.), serviceability, expected lifetime and, finally, to the required total cost of ownership (TCO).

4 LIMITS OF THE SYSTEM

Generally, the longest possible autonomy is required, since the duration of a black out is typically unknown. On the other hand, long autonomy results in big capacity and big number of batteries and this is even more amplified when the power of the load increases.

Having many batteries means high footprint, high weight, high impact in installation and service activities and, accordingly with the specific technology and model, there could be additional issues to face events like gas emission, acid leakage, energy losses and ageing caused by current circulation between battery strings, etc.

In large high-power installations, even few minutes of autonomy result in high-capacity battery set, which in turn demand for planning dedicated "Battery Rooms" equipped with all the needed systems to keep them safe and monitor their proper status and operation.

From an electrical point of view, high battery capacity means high recharging energy, which might not be deliverable or worth delivering, due to additional costs for the energy needed to recharge batteries, and UPS charger limits, with possible need for UPS oversizing.

All batteries, regardless of the technology, have their own lifetime, which is typically affected mainly by operational (intensity and number of the discharge and recharge) and environmental conditions (temperature, humidity, vibrations, etc.); other factors affecting battery life are quality of the materials, design and manufacturing standards (these last three factors are closely related to the price of the battery).

The actual service life of a battery is typically shorter than UPS lifetime and this leads to consider batteries as consumable components within a UPS system, with consequent needs to deploy maintenance and replacement plans, significant costs and high commitment.

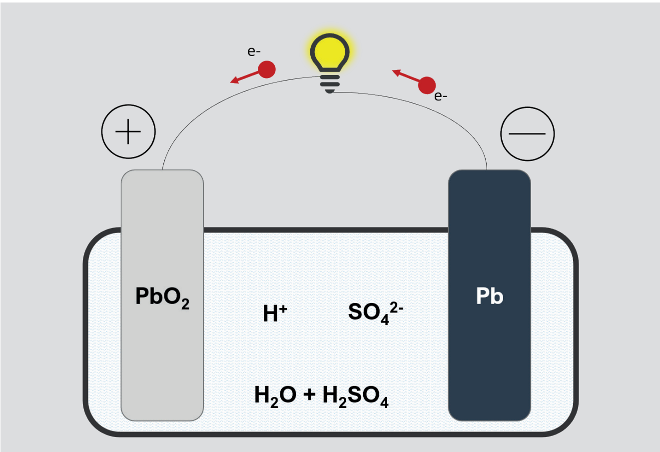
LEAD ACID IN UPS

1 GENERAL DESCRIPTION AND TYPOLOGY

The lead acid cell was invented in 1859 and it is the eldest type of accumulator used nowadays.

Two or more lead acid cells packed together and connected in series make a lead acid battery.

The working principle of lead acid batteries, as described in the picture below, is based on the reaction of metallic lead (Pb) and lead oxide (PbO2), embedded in the electrodes, and a solution of sulfuric acid (H2SO4) and water (H2O), which is referred to as the electrolyte.



$\oplus$ $PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightleftarrows PbSO_4 + H_2O$

$\ominus$ $Pb + SO_4^{2-} \rightleftarrows PbSO_4 + 2e^-$

$$PbO_2 + Pb + 2H_2SO_4 \rightleftarrows 2PbSO_4 + 2H_2O$$

Picture 1: Lead acid batteries working principle

This reaction is the same since 1859 but, in more than one century, many improvements and strategies have been studied and implemented to optimize performance and lifetime.

Nowadays there are two main typologies of lead-acid-based batteries in use:

- Flooded batteries, in which electrolyte is periodically refilled to compensate for the constant emission of oxygen gas. This is part of routine maintenance practice to mitigate failure occurrence and to preserve the expected lifetime.
- Valve Regulated Lead Acid (VRLA), which are sealed and don't need electrolyte refilling, as the internal gas recombination, recovers the oxygen lost in secondary reactions. Safety valves allow the evacuation of gasses and vapors in case of internal overheating, thus preventing the battery from the risk of explosion.

VRLA can be furtherly differentiated into two big families:

• AGM (Absorbed Glass Mat): where the electrolyte is absorbed in a matrix of thin glass fibers

• Gel: where the electrolyte is merged in a gel medium

Both technologies were developed to increase life and performance.

Finally, both AGM and gel families include many different types of models with different dimensions, geometry and number of cells.

A standard lead acid cell has a nominal voltage of 2V, whereas the operating voltage depends on the charge/discharge status of the number of cells. During the discharge phase, voltage is decreasing in time, until it reaches the so called "end of discharge" (EoD) limit. The absolute minimum EoD is 1.6V / cell, to avoid a deep discharge condition, which the battery cannot be fully recovered from.

In small to medium capacity VRLA (<200Ah) the most used battery block is built by connecting 6 cells in series, with a nominal voltage of 12V. Above 200 Ah, the dimensions of the cell increase and for mechanical reason battery blocks can be arranged in 3 cells (6V blocks) or even just one cell (2V blocks) in the highest capacity models.

Being VRLA sealed in a sturdy plastic enclosure makes them smaller and more schock resistant than flooded batteries.

Although standard VRLA enclosures have a very good resistance against heat exposure, manufacturers usually offer special versions, with certified enhanced flame resistance, in order to increase reliability and operation time in case of fire in the battery room until the flame is extinguished by firefighting systems.

In general, VRLA are very easy to use in many different applications from industry to automotive and, of course, in UPS applications.

2 TYPICAL USE OF VRLA IN UPS APPLICATIONS

As mentioned, VRLA are particularly suitable for UPS applications:

• they are compact and robust enough to be easily installed inside the UPS cabinet

• they are sealed, so the risk of acid leakage and metallic corrosion is very limited

• they are maintenance free, so users need just to replace them at the end of their life, like any consumables in UPS.

Furthermore, VRLA can be easily connected in series to reach the nominal UPS DC voltage and the string can be easily connected in parallel, to reach the enough energy capacity to provide the required autonomy.

In case of high power (>60kVA) or in case of long autonomy (>15min), VRLA can also be installed in external cabinets or open racks, in the UPS room or in a dedicated battery room.

VRLA manufacturers give all the technical information, including recharge and discharge characteristics, to use batteries at best. Users can then refer to the UPS data sheet as to recharge methods and discharge limits (cut-off voltage).

With regards to additional and advanced features, the UPS logic can perform battery calibration and battery test to monitor and to control battery conditions. Furthermore, reliable information about the battery status and expected available autonomy time can be retrieved, as well as predictive diagnostics, battery usage records and ordinary and extraordinary maintenance notification. With proper information and data to set up the UPS logic, the mentioned advanced features are available for all VRLA brands and models.

Overcurrent protection devices (typically fuses) are needed to secure the system in case short circuit. These can be installed inside the UPS or in external battery cabinets.

3 PROS AND CONS OF VRLA IN UPS APPLICATION

ADVANTAGES	DISADVANTAGES
High performance/Price ratio	Low capacity / density: large footprint and heavy weight
Mature technology, universally used and known in many technological fields: lead acid batteries are 75% of battery's world market	Short lifetime: 4 years as standard Long life: 10 years (with UPS a good practice is to replace the batteries before the end of life to have always reliable energy source in case of needs)
Mechanical robustness	Lifetime is affected by temperature: above 20°C, each 10°C increase will halve battery life
Possibility to install them with different orientation	Self-discharge: a battery, even if it is brand new, cannot be stored for more than 6 months, without irreversibly damaging it from self-discharge. The higher the storage temperature the worse the self-discharge
Easy charge and discharge management	Hydrogen emission during the recharge: risk of explosive atmosphere, need of ventilation
Simply overcurrent protection in case of short circuits or overload	Irreversible deep discharge: dedicated control and protection are needed to avoid the over discharge
Wide availability on the market with various quality level from entry level to super premium	Efficiency losses caused by internal current circulation in case of multiple strings in parallel
Wide availability of models on the market, with different performances (high power / long endurance) and life (Standard 5 years / long 10 years)	Blocks of different age cannot be used together (in series or parallel or both): the older block will decrease the life of entire battery set
Eco sustainability; today VRLA can be potentially recycled up to the 98% of their weight. Lead is recycled up to 100% ad used for new batteries (50%) and other industrial use	Unexpected leakage of the acid which must be contained to avoid corrosion and possible short circuit between the battery and the metallic containment frame

Picture 2: Main advantages and disadvantages of VRLA batteries.

LI-ION BATTERIES

1 GENERAL DESCRIPTION AND TYPOLOGY

A lithium-ion battery or Li-ion battery is a type of rechargeable battery in which lithium ions move through an electrolyte from the negative electrode to the positive electrode during discharge, and back when charging. Li-Ion batteries use a lithium compound with a metal oxide for the positive electrode and typically graphite for the negative electrode.

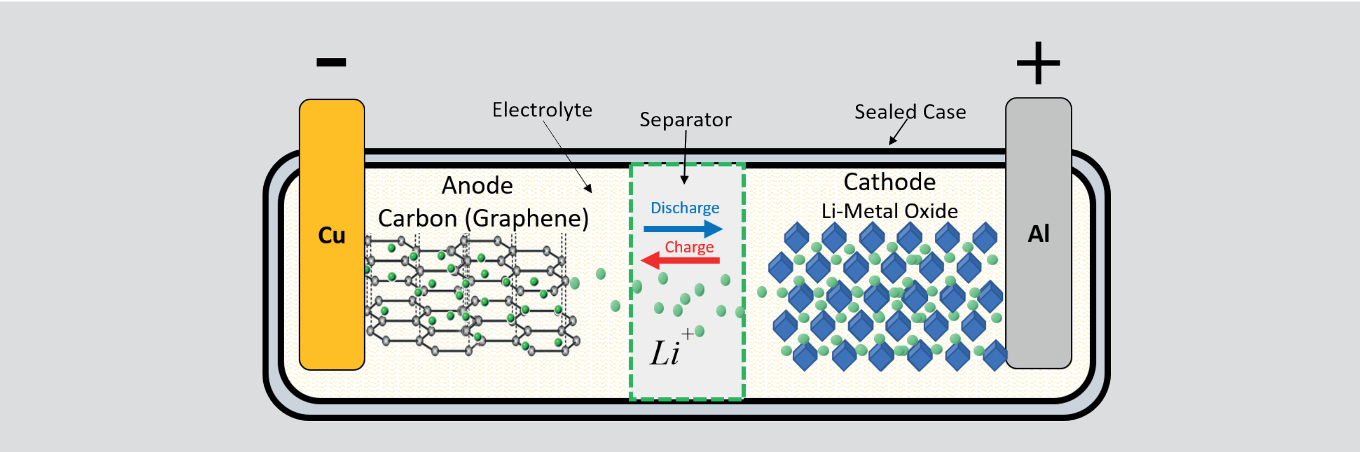


Figure 3: Li-Ion batteries chemical composition

A prototype Li-Ion battery was developed by Akira Yoshino in 1985, based on earlier research by John Goodenough, M. Stanley Whittingham, Rachid Yazami and Koichi Mizushima during the 1970s–1980s and then a commercial Li-ion battery was developed in 1991.

Today most people associate rechargeable Li-Ion batteries with personal/portable devices as they have become the rechargeable battery cell of choice in cellular phones, tablets and small personal wearable appliances. However, the breadth of Li-Ion batteries includes both non-rechargeable and rechargeable cells, using many different chemistries for use in many different applications.

More recently Li-Ion battery cells have become a more common solution in electric vehicles, e-bikes, storage systems and UPS.

Depending on the choice of the metal oxide material in the cathode, a Lithium-Ion battery's voltage, energy density, working lifetime and safety can vary dramatically. The table below summarizes and assesses the main different chemical compositions which can be used for the cathode.

ACRONYM	LCO	NMC	LMO	LFP
Full name	Lithium Cobalt Oxide	Lithium Nickel Manganese Cobalt Oxide	Lithium Manganese Oxide	Lithium Iron Phosphate
Cathode	$LiCoO_2$	$LiNiMnCoO_2$	$LiMn_2O_4$	$LiFePO_4$
Anode	Graphite	Graphite	Graphite	Graphite
Cell voltage (V)	3.7	3.8	3.6	3.3
Thermal runaway temperature (°C)	150	200	250	250
Energy density (Wh/kg)	150-250	150-220	100-170	80-140
CHEMISTRY COMPARISON				
Energy	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■	■
Power	■ ■	■ ■ ■	■ ■ ■	■ ■ ■
Life	■ ■	■ ■	■ ■	■ ■ ■
Safety	■	■ ■ ■	■ ■ ■	■ ■ ■

Picture 4: Main different chemical cathode compositions.

LCO (Lithium Cobalt Oxide)

This is one of the smallest and lightest Li-Ion battery cells and it is used in cell phones and small personal devices, etc. It has a high nominal voltage and a very high energy density, but it has a relatively short life cycle and low thermal runaway temperature thus making LCO one of the highest temperature-sensitive Li-Ion battery chemistries.

NMC (Lithium Nickel Manganese Cobalt)

This battery chemistry is light, it has high nominal voltage and energy density, long cycle life, and falls in the middle between LCO and LFP chemistries.

LMO (Lithium Manganese Oxide)

This lithium-ion cell uses manganese dioxide, Mn_2O_4, as the cathode material.

Cathodes based on manganese-oxide components are earth-abundant, inexpensive, non-toxic, and provide better thermal stability.

LFP (Lithium Iron Phosphate)

This is one of the largest/heaviest of Li-Ion battery chemistries and is used by Telcos in large energy storage applications and commercial vehicles like golf carts and forklifts.

It has a lower nominal voltage, short cycle life, but a relatively low energy density with a high thermal runaway temperature, making it one of the most (thermally) stable Li-Ion chemistries.

The common features of all these technological variants are that Li-ion batteries have a high energy density, no memory effect and low self-discharge. They can however represent a safety hazard since they contain flammable electrolytes and, if damaged or incorrectly charged, can lead to explosions and fires. As risk mitigation, a battery management system (BMS) is installed to keep the operating cell conditions within the limits and disconnect the battery pack from the UPS if any of the monitored variables exceed their operating limits.

In addition, there are different Li-Ion cell designs:

- cylindrical
- pouch
- prismatic

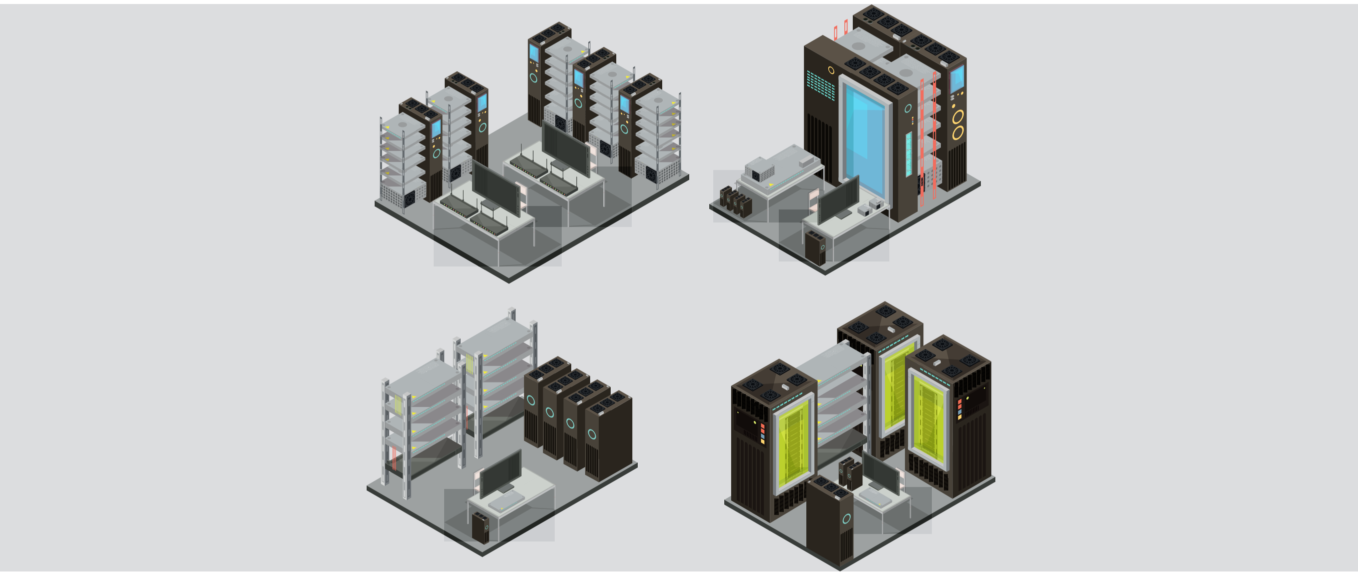
The prismatic cell design is the safest as it is equipped with several mechanisms such as a safety function layer, a multi-layered separator, a safety vent, a safety fuse and an over-charging safety device.

Picture 5: The figure shows an example of prismatic, pouch and cylindrical Li-Ion batteries.

2 TYPICAL USE OF LI-ION IN UPS

In UPS applications, the most used electrode chemical composition is the Lithium Manganese Oxide (LMO), the Lithium Nickel Manganese Cobalt Oxide (NMC) and the Lithium Iron Phosphate (LFP), which offer the best compromise between performance and safety levels currently available on the market. Li-Ion batteries are connected in series to obtain a voltage which is compatible with the UPS range and they are equipped with a monitoring unit in order to avoid over-charging or over-discharging phenomena. A voltage balancing circuit is also installed to monitor the voltage level of each individual cell and to prevent voltage deviations between different cells.

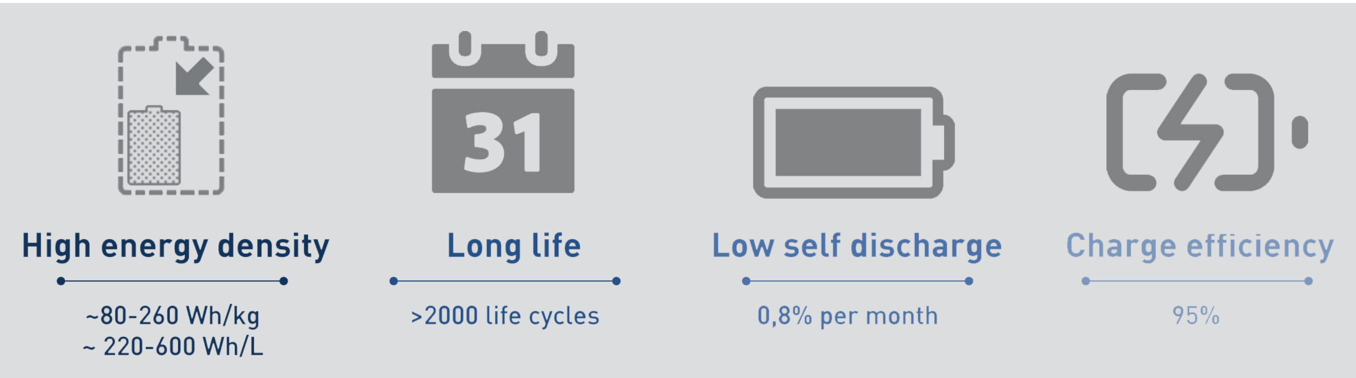
Lithium batteries are particularly suitable where the main requirement is reducing footprint and/or weight, in fact they can be up to 70% more compact than lead acid batteries and up to 78% in weight. This saves site space by allowing customers to reconfigure their deployment to increase rack space availability for IT servers and networking equipment. In addition, less size and weight can also contribute to savings in shipping, handling, and deployment costs.



Lifetime is particularly important. Li-Ion batteries have a high number of life cycles for a given depth of discharge and, depending on the chemistry, they can withstand more than 2000 charge and discharge cycles with minimal impact on capacity, allowing to reach an average lifespan of more than 15 years (at 25 °C). This is the estimated time a battery will last before it reaches 80% of its energy capacity, the typical definition of end of life for batteries. In addition, Li-Ion batteries can operate at ambient temperatures up to 40°C (104°F) with little to no impact on the performance.

LI-ION BATTERIES

The use of lithium-ion batteries in UPS applications potentially eliminates the need to replace batteries over a 10-years' period. This can be particularly interesting when the UPS is in remote locations or critical application where high availability is needed.



Picture 6: Some of the advantages of Li-Ion batteries.

From an environmental point of view, Li-Ion batteries do not cause major concerns in terms of pollution during normal use.

However, depending on the chemistry of the Li-Ion cell, they may contain rare-earth and critical-earth elements, as well as and hazardous materials, so Li-Ion batteries do have an environmental impact during raw material procurement and end-of-life management.

To date about 80% of the contents (by weight) of Li-Ion batteries is steel and copper, which is nearly 100% recyclable. Research is on-going to improve the recycling economics and governments are beginning to encourage, incent, or outright the proper collection and recycling of these batteries.

As a disadvantage, lithium chemistries are quite sensitive to operating conditions exceeding recommended limits.

Small departures of the float voltage above the recommended maximum (overcharging), discharging below the minimum cutoff voltage (over-discharging) and exceeding the maximum temperature rise of the cell might all induce thermal runaway. This is generally a catastrophic event for most lithium chemistries.

For this reason lithium battery systems usually feature an embedded battery management system (BMS) to monitor cells operating conditions and to trip the internal breakers, should any of the monitored variables exceed their operating limits.

In battery systems for UPS applications, the amount of heat generated in the cells during charging and discharging is quite significant. In fact, Lithium chemistries are exothermic on charge and discharge. That is, the involved reactions release heat as a product. This must be added to the heat generated from losses in the connections and wiring. The additional heat generated from these reactions must be managed to prevent the cell temperature from exceeding the limit above which permanent degradation of the cell will occur, possibly leading to thermal runaway.

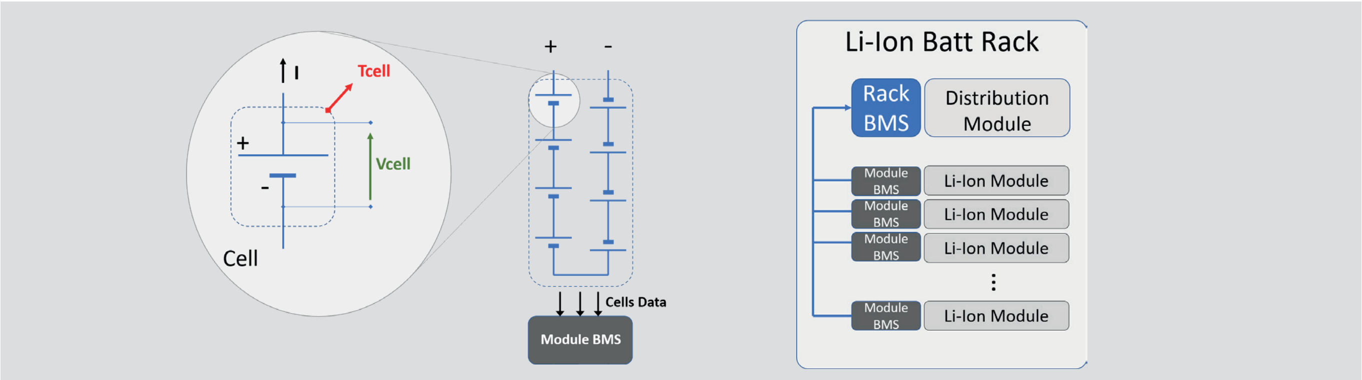
3 BATTERY MANAGEMENT SYSTEM AND ELECTRIC CONNECTION OF LI-ION BATTERY SET

As mentioned above, a Battery Management System (BMS) is used to keep monitored the thermal and electric status of the Li-Ion cells and avoid thermal runaway.

In case of multiple cells, these are arranged in packs or modules and thus installed inside racks or cabinets. The relevant BMS is composed by one or more logic systems at several hierarchical levels:

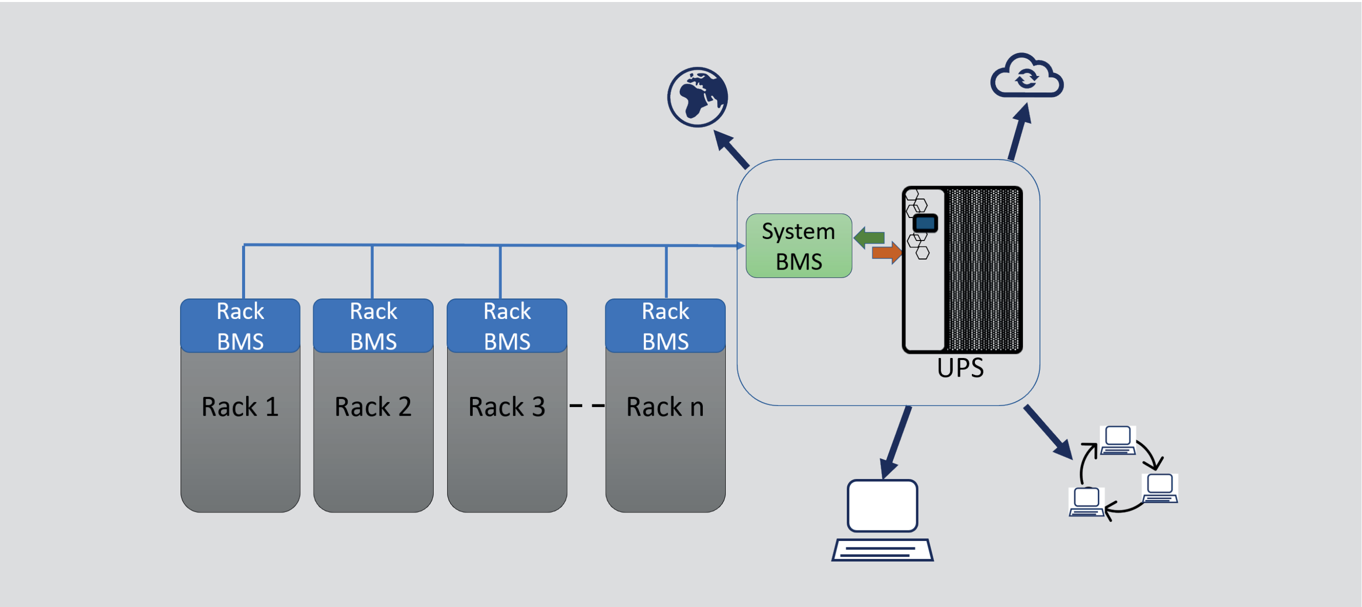
Modules BMS: it collects Voltage, Current and Temperature data from sensors connected to each cell of the modules. It can also control the string of cells inside the module, in order to equalize or exclude them.

Rack BMS: it collects all the data from BMS modules, to perform a general monitoring of the whole cabinet. In case of emergency the rack BMS can activate an automatic circuit breaker to completely disconnect the rack; in addition, it can have several interface ports to communicate the status of the rack with signals, data connection (IP Network) and HMI display. Depending on the model, the display or the data connection can allow several settings and remote control of the Li-Ion racks.



Picture 7: Rack BMS.

System BMS: mid-hi power UPS or energy storage applications often need several battery racks or cabinets, so it could be needed and useful to monitor the entire battery set with a system BMS. The system BMS is connected with each rack and it can manage all the data and control the whole system.



Picture 8: System BMS.

4 PROS & CONS OF LI-ION

ADVANTAGES	DISADVANTAGES
High capacity / density: limited footprint and light weight	High initial investment costs
Long lifetime: more than 15 Years More than 2000 charge and discharge cycles with minimal impact on capacity	New technology, not yet widely distributed on the market
Wide range of shelf temperature: can operate at ambient temperatures up to 40°C (104°F) with limited to no impact on battery performance	Mechanical shock sensitive
No self-discharge: battery can be stored more than 6 months without irreversible self-discharge	Limited charge and discharge management: discharging below the minimum cutoff voltage and exceeding the maximum temperature rise of the cell can all induce to thermal runaway
Zero hydrogen emission during the recharge cycles - No need of ventilation	Risk of fire explosion in case of thermal runaway
High margins for improvement in terms of efficiency and performance as new technology	A battery management system (BMS) is required to maintain the cell operating conditions within the limits
No need to replace batteries over a 10-year period.	Low availability on the Market with different quality and performance level

Picture 9: Main advantages and disadvantages of Li-Ion batteries.

LI-ION vs VRLA

1 PERFORMANCE COMPARISON

As shown in the previous chapters, Li-Ion and VRLA batteries are very different in terms of internal chemical nature, components and reactions. These differences are reflected in different performances, capabilities and costs between the two typologies of batteries.

In general, compared with VRLA, Li-Ion Batteries have higher energy and power density, longer life, they are not affected by self-discharge and can operate at wider temperature range. Meanwhile Li-ion can be affected by dangerous thermal runaway effects, which makes them more sensitive regarding operating temperature, intensity of charging and discharging current, mechanical shocks.

In the table below major and typical performances are compared.

PERFORMACE	VRLA	Li-Ion
Power Density	~320 W/kg	180 – 3000 W/kg
Energy Density	~ 40 Wh/kg ; 80 Wh/L	~ from 80 to 260 Wh/kg ~ from 220 to 600 Wh/L
Life cycles (discharge 1C)	400	>2000
Expected Life	5 - 10 years	15 - 20 years
Charge efficiency	60%	95%
Charging time (hours)	8	0,25-1
Self-discharge (monthly)	20%	0,80%
Cell nominal voltage	2V	3.5-3.8V
Optimal operating temperature	20-25°C	20-35°C

Picture 10: Performance comparison between VRLA and Li-Ion batteries.

2 COST ANALYSIS

Product maturity and availability of materials have a strong effect on the market in terms of prices, rules, logistics and life cycle. Compared with VRLA, Li-Ion batteries are very young on the market and they use some rare materials with limited availability or complex industrial treatment. For these reasons, Li-Ion are more expensive than VRLA (typically 3-5 times). Also, there are several differences in their end-of-life management, in fact VRLA can be mostly recycled and a mature recycling market is in place for VRLA since many years. On the other hand, end of life management in Li-Ion is still evolving and many manufacturers are investing in R&D to develop second life use, more sustainable procurement, as well as cost effective recycling processes.

In addition, it must be considered that to avoid thermal runaway and consequently dangerous issues, Li-Ion batteries are always equipped with safety equipment which monitor the battery status and secures the system in case of problems. These systems typically consist of:

- Thermal/mechanical system embedded in the cells and battery packaging
- Electronic monitoring and control systems with sensors and logic microprocessors (Battery management system BMS), which is also able to communicate info on data network and with the UPS itself
- Electric protections, like automatic breakers, controlled by the BMM and emergency fuses.

These devices contribute to increase the cost of the complete lithium – ion battery set.

On the other hand, Li-Ion have a longer life as opposed to VRLA.

In UPS applications, a good practice is to replace batteries before they completely expire, to avoid the risk of shutdown of the load in case of black out; so, if the expected life of a VRLA is 5 years, typically at the end of the 4th year it is recommended to replace batteries even if they still seem to be properly working. Battery replacement is a cost for the user not only for the cost of the new battery blocks but also for the technical intervention which needs specialized technicians, working hours on the site, possible disconnection of the load or bypass switching, etc.

UPSs can have an operating life which goes from 8 years to 15 years, accordingly with the usage, ordinary maintenance, and needs of the application: this means that VRLA could be replaced up to 2 or even 3 times. Instead, Li-ion have an expected lifetime of 10-15 years, and the replacement could be avoided during the life of the UPS. For this reason, Li-Ion batteries bring about a high reduction of operating costs and increase the availability of the whole system.

The reduced footprint, due to the high power density, also results in economic advantages both in Capex and Opex, and makes Li-Ion batteries very interesting for those applications where space and volumes are paramount, such as datacenters, compact technical room, etc. In addition, the small size and weight can also help save on shipping, handling and deployment costs.

	VRLA	Li-Ion
Raw material Production End of Life	■	■ ■
Monitoring & Safety System	■	■ ■
Maintenance	■ ■	■
Footprint	■ ■	■

Picture 11: Cost comparison between VRLA and Li-Ion batteries

3 IMPACT ON THE SYSTEM DESIGN

Every Battery system has an impact on the design of the infrastructures and surrounding systems (e.g. Electric, Ventilation, Cooling, Emergency, etc.). There are several points to be considered in the design of the system which includes batteries.

Both VRLA and Li-Ion may present dangerous voltage levels so they must be segregated in cabinets or dedicated rooms with limited access and only authorize technicians who knows how to handle and operates on batteries in a proper and safe manner. In addition, lithium batteries release heat as a product during their operation. This must be considered and added to the heat generated by losses in connections and wiring.

Batteries need also to be electrically connected to the UPS, so it is needed to design and implement dedicate DC power lines with relevant distribution and protection systems (Electric panels, Switches, Overvoltage protections, etc.). In addition, it could be needed to provide also power supply lines and data network lines in case of Battery Monitoring System (BMS). A BMS is always included in case of Lithium-Ion Batteries and can be used as option with VRLA. For BMS energy supply it is a good practice to have a double supply source, from mains grids and from UPS output, in order to have continuous control in all situations.

Also, the battery room needs monitoring and emergency systems, especially in case of big battery capacities.

It is very important to have a reliable firefighting system, designed for electric rooms with relevant sets of thermal and smoke detection sensors, and proper fire-resistant walls and doors to avoid the fire propagation. In specific case of Li-Ion, the firefighting system must have a strong capability to cool down the batteries and keep the temperature at such level as to avoid the thermal runaway which can be destructive.

In case of VRLA, to avoid risk of explosion, it is important to monitor the hydrogen concentration in the room with specific sensors and keep it within the specified safety level trough proper ventilation and air recycling.

For Lead Acid in general, it could be needed to also store in the room specific powder to neutralize the acid in case of electrolyte leakage; VRLA are sealed and not spillable, so the risk of acid leakage is lower compared with Vented Lead Acid Batteries.

As per many other electric systems, it is important to avoid high humidity level and risk of flooding, in order to mitigate the risk of short circuits or irreversible discharge and degradation of the battery life.

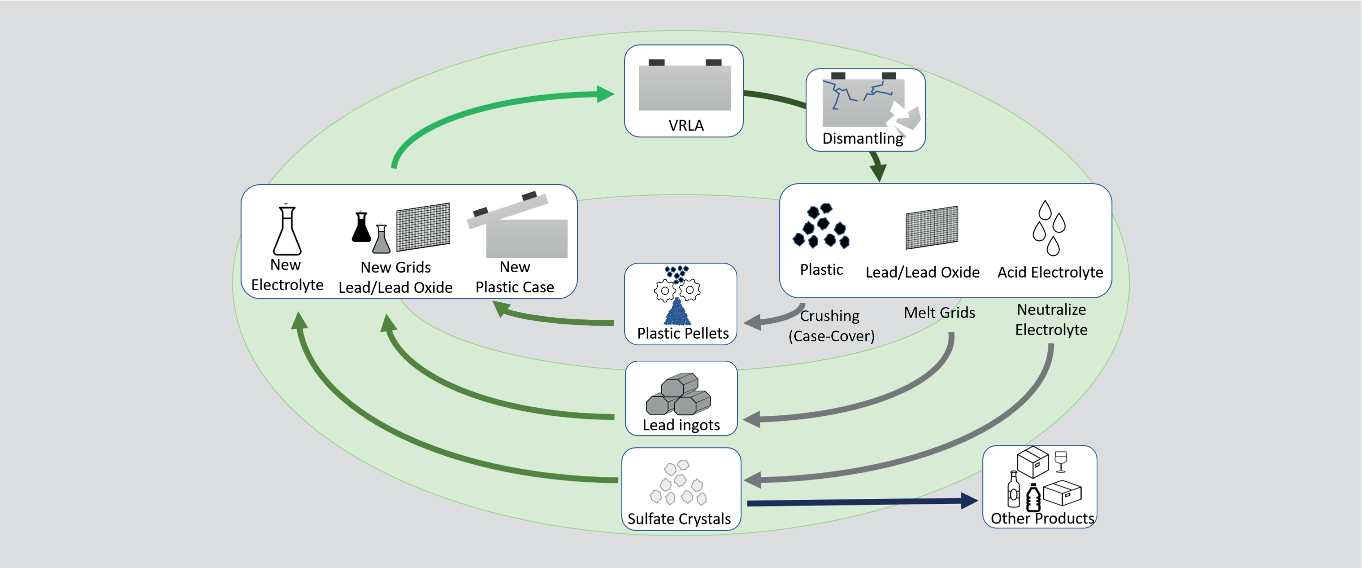
In the case of seismic area, it could be needed, or even mandatory, to install the batteries in anti-seismic racks, to avoid mechanical shocks and damage to batteries, connectors and cablings. In case of Li-Ion, this is particularly important due to the risk of internal thermal runaway caused by mechanical shock or damage of the cells enclosure.

4 IMPACT ON THE ENVIRONMENT

In general, because of the materials that constitute them, all types of batteries have impact on the environment. This involves the whole life cycle, in fact, raw materials are often toxic and, in some cases, rare. Mining can be very polluting with significant energy consumption. Raw materials need special chemical treatments and production processes which need energy and produce dangerous waste and pollution. During the use and in case of damage, batteries may release toxic materials. Finally, the dismantling needs special process to contain pollution and to recover, as much as possible, recyclable and reusable .

Of course, all the facts mentioned above may vary accordingly with the technology, the architecture and the maturity of the batteries.

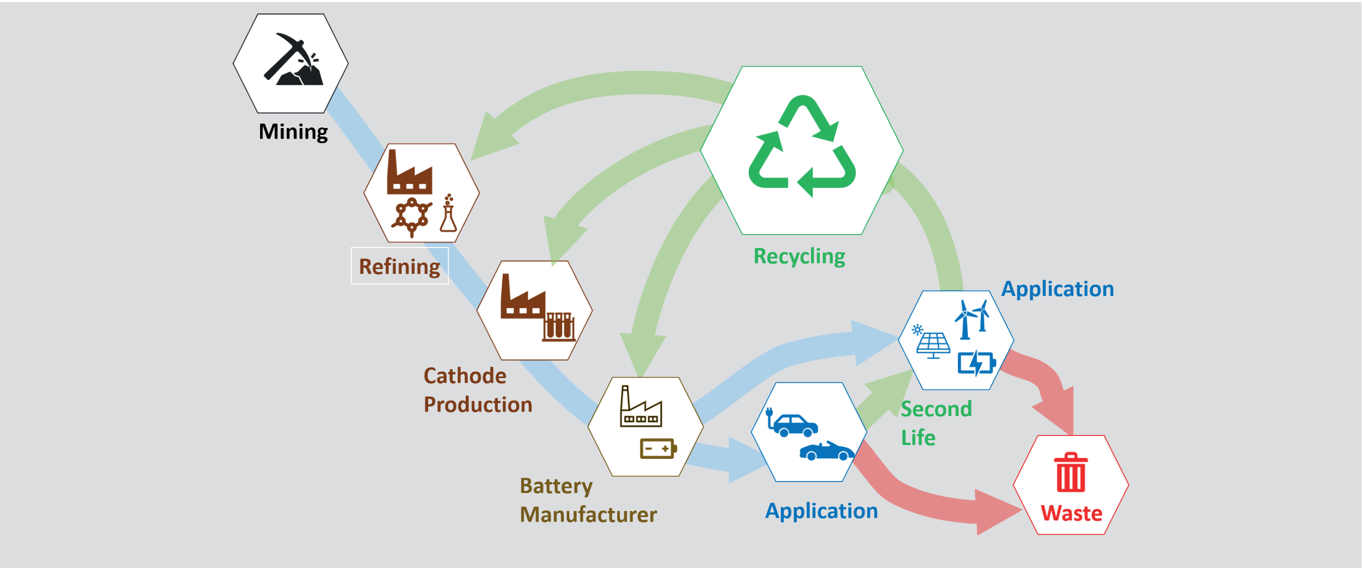
VRLA are based on lead which is dangerous for the environment and they are packed in hard and flame-resistant plastic case but, thanks to the wide and longtime diffusion on the market, these types of batteries can be almost totally recycled (up to 98%). The lead contained in expired VRLA has its own market value and it is traded and purchased to be recovered and used again and again, in VRLA or in other applications. Recycled lead is so widely used that its mining has been highly reduced over in the last years, up to the point that most of the lead present on the market is recycled. Also, the metals of the electrodes, the plastic case and the electrolyte are largely recycled. In simple words, VRLA (and in general all lead acid batteries) are totally included in circular economy, ensuring minimum ecological footprint.



Picture 12: Environmental impact of batteries

As to Li-Ion batteries the major risk for the environment comes from the electrodes (graphene, Li- metal oxide), electrolyte and other internal components. These materials are often toxic, sometimes rare, and need complex and polluting process of extraction, treatment for assembly and dismantling.

Li-Ion is a new technology which has been growing fast in the last years (mainly thanks to the electric vehicles market), so that the steps of its life cycle are in constant evolution. Technical research and development will surely result in performance improvement and safer and more common materials being used. Mass production is bringing about higher efficiency and sustainability in industrial processes. Li-Ion end of life management requires proper collecting and dismantling processes with their own costs. Recently big efforts have been made in finding new strategies and technologies to recycle or re-use Li-Ions Batteries. Among these, "second life" use is becoming more and more popular. This is about using a battery whose life has expired for the original application (e.g. EV) in another type of application, at lower power/energy level (e.g. Energy Storage).



Picture 13: An example of circular economy for Li-Ion batteries

CONCLUSIONS

1 CHOOSING THE BEST FOR YOUR APPLICATION

Both VRLA and Li-Ion batteries can be a good solution in UPS application, but which is the best depends case by case by the application itself.

The affordable cost, the high maturity and the simplicity of VRLA makes them perfect for conventional applications, with low-mid power, standard lifetime and limited budget. In this case the user of the UPS can easily find on the market, with a good price, the proper VRLA set, knowing that this set will need to be tested periodically and replaced after 4 years or 8-9 years in case of Long Life batteries.

Lithium-Ion is more expensive and needs BMS and more care to avoid the thermal runaway, but it is compact with high power density, long life and embedded monitoring system. For these reasons Li-Ion are very interesting in critical applications (often in high power and short autonomy) like data centers, where the floor occupation has high costs and savings on Opex (e.g. thanks to minimum maintenance) can compensate the cost of the batteries.

There are particular cases with high power (typically MegaWatts) the owner can use the System UPS + battery as an energy storage system coordinated with renewable energy system, with smart grid system or in peak shaving mode, with consequent optimization of the energy consumption and management. The economical savings produced by this optimized energy consumption may justify the important investment to install high power UPS and Li-Ion battery set.

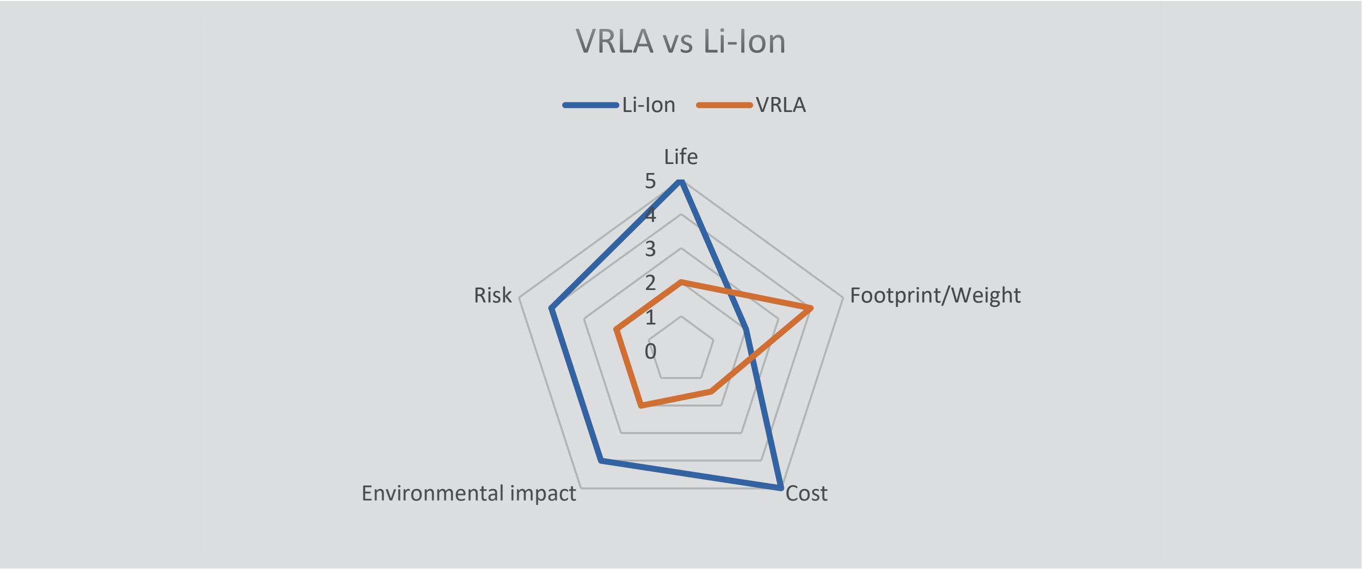
It is also possible that the expected lifetime of Li-Ion set is comparable with the expected lifetime of the UPS, in this case there is no battery replacement during UPS life the only replacement is the one of the entire system UPS + batteries (up to 15-20 years for 3PH UPS).

Long life and compactness make Li-Ion interesting also for small, mini and micro UPS, single phase from 20VA to 3000VA power. Similarly, to other consumer electronics devices (laptop, tablets, mobile, etc.), the Li-ion cells allow to have very compact and light UPS with good autonomy, easy to install in small space, under or on the desks for home or small office application or in rack cabinets for telecom, networking or server room.

As discussed in the previous chapters, all types of batteries have impact on the environment due to their components. This involves the whole life cycle, in fact, raw materials are often toxic and, in some cases, rare. Mining can be very polluting with significant energy consumption. Raw materials need special chemical treatments and production processes which need energy and produce dangerous waste and pollution.

In particular, when comparing the two technologies, Li-Ion batteries have on average a heavier environmental impact than VRLA, as they require the extraction of rare earths and virgin raw materials and at the same time cannot yet be recycled and disposed of properly at the end of their life. VRLAs, on the other hand, can use recycled lead and are part of the circular economy. Technological and scientific developments will undoubtedly reduce this gap in the future and optimize the life cycle of lithium-ion batteries in a sustainable manner.

Legrand, as a company attentive to customer needs and technological evolution, offers a complete product portfolio with both Lithium and VRLA solutions: the company's focus is to meet the demands of the market by committing itself every day to maintain high standards of quality and performance of its offer, through a constant technical improvement of its solutions without neglecting the environmental impact.



Picture 14: Comparison between VRLA and Li-Ion: main axes (spider chart)

	Li-Ion	VRLA
Life	■ ■ ■ ■ ■	■ ■
Footprint / Weight	■ ■	■ ■ ■ ■
Cost	■ ■ ■ ■ ■	■ ■
Eco-sustainability	■ ■	■ ■ ■ ■
Risk	■ ■ ■ ■	■ ■

Picture 15: Comparison between VRLA and Li-Ion: main axes (icons)

! In the pictures above, the cost is intended in terms of CapEx.

2 FUTURE EVOLUTION

The recent digital transformation and the next ecological transition are leading to a continuous growth of digital application and optimization of energy management. In this scenario, the research to new and better energy storage systems is one of the main challenges.

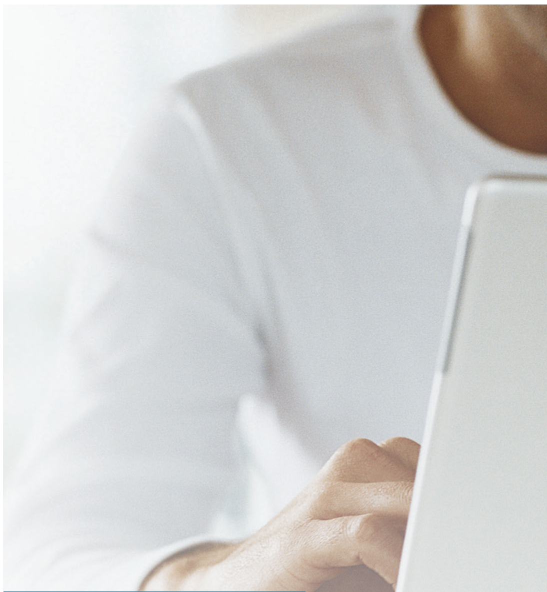
The evolution will answer not only for high performances (energy density, lifetime, safety) but also for better sustainability. Very important is the improvement of the life cycle of the batteries from sourcing of raw material to the end of life to have high recyclability and reuse way.

As said before, lead acid is mature technology with a good level of recyclability but still suffer of some inconvenience as low power density, and strong ageing. To solve these many battery manufacturers have introduced new models of VRLA based on pure lead and are continuously improving the architecture of the cells and blocks.

Li-Ion still needs several improvements for the life cycle sustainability and it is very intense the research of manufacturers for not polluting raw materials optimized industrial process and better recyclability for energy storage systems where the batteries are already in second life.

None the less, the field of battery and energy storage systems is very active and challenged, new generation of chemical accumulator are currently under development in research center, solid electrolyte and other chemical systems are studied to reach high energy density with high safety level, sustainable material and process are constantly investigated. New and innovative solutions may arrive on the market in next years.

Notes



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