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PART IV

POWERING CHANGE

How batteries can foster the electric vehicle revolution

4

RECYCLING AND SECOND-LIFE SOLUTIONS AS SUCCESS FACTORS AND BUSINESS OPPORTUNITIES

The transition to EVs is widely recognized as one vital step towards a more sustainable future. But this progress comes with its own sustainability challenges, such as what to do with used batteries. At present, EV companies like Tesla and Rimac are proliferating popular culture. The electric vehicle is becoming a must-have commodity. Their rapid uptake is expected to lead to a market for second-hand EVs and their EOL batteries. Though it could change in the near future, many of these used batteries cannot be used in additional EVs. Their second life will need to be the power source for a different device. This is forecasted to lead to an abundance of older-model batteries without any immediate usage.

By definition, the current generation of EV batteries are classified EOL when their capacity is 20% lower than when manufactured. In short, battery regulations mandate a cell capacity of 80%. Any batteries below this 80% benchmark will be ready for EOL solutions. Therefore, looking at a modest outcome, it is estimated that there will be 95 GWh worth of 'retired' Li-Ion batteries by 2025[49] and between 100 to 200 GWh by 2030 based on current projections of around 10 million EVs on the roads by the end of the decade).[50]

In addition, new, tighter regulations on end-of-life EV batteries will come into force in the near future. The most notable example is Directive 2006/66/EC of the European Parliament and Council.[51] Commonly known as the "Battery Directive," it comes into law in 2022. Consequently, EOL batteries will be regulated differently from 2027 onwards. This will lead to new recycling quotas and mandatory take-back and collection programs, which will affect the entire supply chain for batteries.

"The OEMs that act now will define the supply chain according to their needs."

- Christian Michalak, Executive Vice President, Head of Intelligent Industry Germany

All of these changes are opportunities in disguise. Moreover, they present a degree of certainty businesses can utilize to strengthen long-term strategies and projections. The industry should begin preparing for the inevitable. As the number of used batteries and regulations on how to handle them increase, it will become increasingly important to have a business model that incorporates an EOL strategy. Soon, new regulations will compel everyone to act. But players who delay now may get left behind as the market gathers pace. Being active now instead of reactive later could profoundly alter outcomes. Active players can take the bull by the horns. They can become pioneers as the majority of the market is focused on ramping up primary battery production facilities.

With this in mind, we will analyze the most promising alternatives and solutions that are available today. This will give us a better understanding of their key differences, potential for growth, and practical applications. Such a proactive approach will enable us to identify the next steps for OEMs and other players who are attracted to the increasingly relevant market of EOL batteries.

[49] Capgemini (2019) [50] IEA (2021) [51] European Union: Eur-Lex (2020)

4.1 Different use cases emerging for end-of-life EV batteries

Despite recent advancements in sustainability, EV batteries have a finite lifetime. Automotive requirements for batteries are high compared to micromobility industries (e-bike, scooter applications) and also batteries in vehicles often have a thermomanagement reducing thermal degradation. In general, the end of the lifetime is defined as a 20% fall in cell capacity from the rated value.[52] When they finally reach the end of the road, there are four major management options.

1. Second-life reuse

Batteries running below 80% capacity can, by definition, still be used in less demanding applications, such as energy storage systems (ESS) or smaller mobile applications.

2. Recycling and raw materials recovery

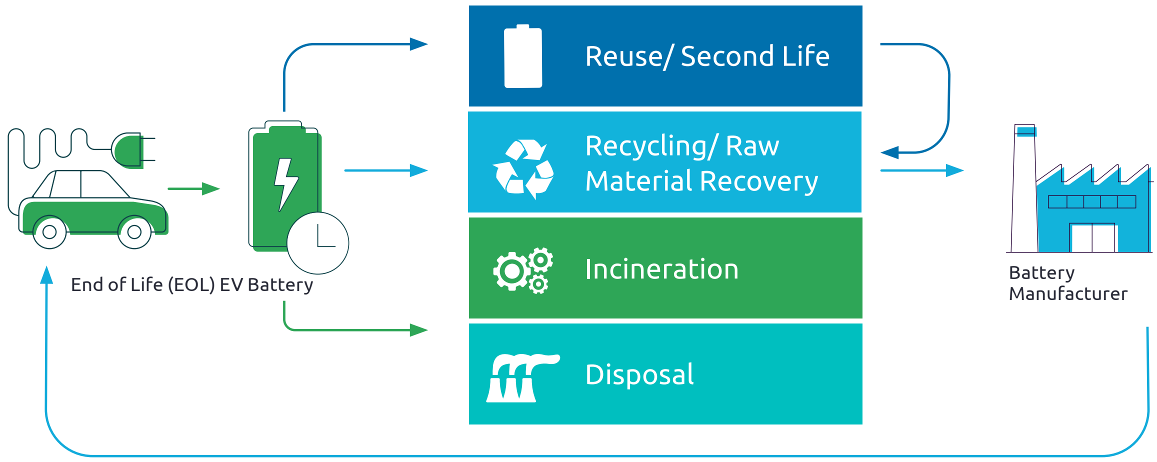
Recycling refers to the recovery of one or all raw materials from the battery after the end of its useful life.

3. Incineration

Battery materials can be used as fuel for other process. This fuel is achieved through incineration. However, the process carries the potential risk of toxic gases being released, which can contaminate the air.

4. Disposal

Disposal is considered the least energy efficient option for EOL batteries, as none of the batteries' components are reutilized. But it is often necessary, since other options can potentially expose workers to leaching chemicals and the release of electrolytes. Moreover, modern battery chemistries, such as lithium-ion, for most part, do not have truly efficient recycling facilities. As a result, discarded batteries can end up in landfills without having been through any recycling process. There is a risk that this number could increase.



What happens to a battery at EOL?

The four EOL solutions for batteries can be divided into two categories: sustainable and unsustainable. Naturally, we want to focus on the two solutions that maximize sustainability. That means ruling out both incineration and disposal. The former involves the release of harmful toxic gases for raw materials that have limited viability as fuel for other processes. The latter adheres to a set of dedicated processes. They are designed to limit the risk of human exposure to toxic chemicals and electrolytes. Though these processes are not considered sustainable, as none of the materials are reused, they are currently the predominant solution. This is because sustainable second-life and recycling alternatives are not currently economically viable or not yet suitable for mass adoption.

Second Life use cases need to be seamless, e.g. to utilize the usage in home energy storage and rely on standardization in battery design.

> *"Battery recycling and 2nd life use cases are exponentially rising in relevance."*
>
> *- Sebastian Tschödrich, Executive Vice President, Head of Automotive Global*

[52]USABC: Electric Vehicle Battery Test Procedures Manual (2012)

Key considerations

A general prerequisite for using batteries in second-life and recycling scenarios is the battery's state of health (SOH) check. This is an important step in determining remaining capacity and functional cells. The SOH check is used to evaluate the usefulness of a battery for second-life and recycling use cases. This is both cost and labor intensive at the moment.
The potential to deploy mass-market solutions here cannot be overstated. As such, technological development in SOH, now being more rapidly defined, is thriving. For example, one option is that wireless connections embedded in batteries could enable automatic and remote read-outs on a battery's vitals. The health check is a necessary step to provide a certification and battery status information for the secondary use of the batteries.

4.2 Reusing batteries

There are multiple emerging options for reusing batteries at EOL.
But overall, current solutions focus on the subsequent use of these batteries as energy stores (i.e., Energy Storage Systems (ESS) in different applications).

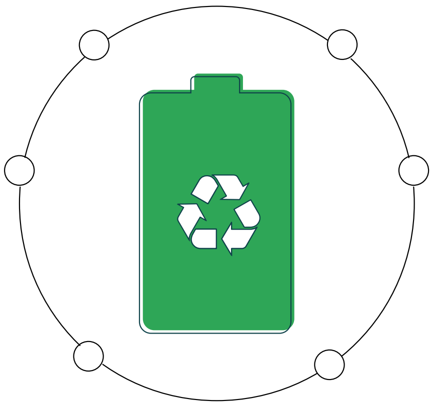
The primary reasons for the increasing relevance of energy storage are:

Energy consumption

A general increase in both the demand and usage of electricity

Increased interest in renewables

Focus on renewable energy generation and enablers (optimized production and storage of solar and wind over time)



Decentralized storage

Energy storage in remote locations, where generation it is more readily available

New technology

Smart grids, microgrids, V2X, V2G, and participation in energy markets via storage and usage

Peak-load shifting

Discharging and storing batteries during peak times and charging them when demand is low for electricity

Market activity

Leveraged price sensitivity (e.g., charging for EV storage when electricity is cheap and selling energy when electricity is expensive)

"The battery health check is crucial to enable second life use cases."

- Simon Schäfer, Manager, CX E-Mobility

Popular use cases

Of all the use cases currently being explored, most of the players in this industry opt for three that are dedicated to reusable batteries. The three use cases are:

1. Mobile applications

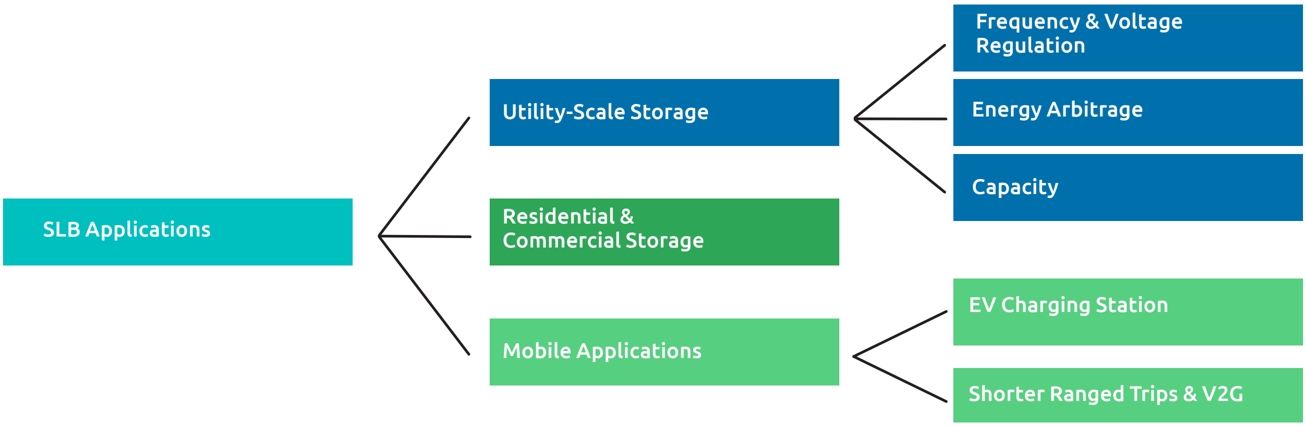
- Batteries or their parts can be reused in the mobility space, where less storage is required (e.g., small BEV, PHEVs, and micro mobility applications, such as scooters and bikes)
- EV Charging stations (buffer storage)

2. Utility-scale storage

- Frequency and voltage regulation (peak loads)
- Energy arbitrage (leveraging price differences in markets to reduce the cost of electricity)
- General capacity increase of storage systems (meeting the demand for additional storage systems, such as the relevance in storage of electricity generated through solar and wind)

3. Residential & commercial storage

- Both home and enterprise energy storage are increasingly popular



Applications of SLB

As reusable batteries support goals and respond to regulatory pressure, the market receives an influx of new players. Naturally, the number of active OEMs is set to increase.
For EOL solutions to be successful, manufacturers need to incorporate them during the conceptualization phase. This opens the door for competitors with a pioneering mindset. Consequently, these OEMs initiate an avalanche of innovation. Mobility players benefit from the arrival of new OEMs, all of which are able to cut long-term overheads and deliver more sustainable transportation. But that's not all. The people either being transported or receiving deliveries can benefit from greener and more efficient utilities, such as energy grids and supply chains. Of course, battery production companies also stand to benefit tremendously from this new paradigm. Their batteries will have resale potential, meaning they can justify price shifts and consider buy-back options. Finally, many start-ups and SMEs with pioneering storage systems and the like will treat reusable batteries as new avenues for growth. Evidently, the market for second-life batteries is one of the most exciting sustainable solutions in recent years. Advances in technology and an influx of new players have stimulated a thriving industry. However, there are still no entirely mainstream solutions.
The majority of existing initiatives are still primarily focused on research projects or early-stage trials. Exploration of opportunities in this space are active in all major regions of EV development: North America, Europe, and Asia.

Notable second-life projects – Europe

Stakeholders Involved	Project/ Initiative Category	Project/Initiative Description	Year	Location
ECO STOR, NUVATION ENERGY	Large-Scale Energy Storage	Nuvation Energy and ECO STOR collaborated in the development of three energy storage systems to be deployed in Norway. Nissan Leaf battery packs will be utilized for large-scale energy storage. Two 50 kW / 150 kWh systems provide demand charge management to an office building and a school respectively. One 1 MW / 700 kWh containerized energy storage system provides transmission and distribution upgrade deferral services at a utility grid substation.	2021	Norway
EATON, NISSAN, BAM	Energy Storage (Microgrid)	The project is a collaboration between the Johan Cruiff Arena, Eaton, Nissan and BAM for one of Europe's largest microgrids using a hybrid first-life and second-life EV battery system in a commercial building.	2021	Netherlands
RENAULT, CONNECTED ENERGY LTD	Large-Scale Energy Storage	Renault and Connected Energy partnered for the development of sustainable and efficient ways of using electric vehicle batteries at the EOL of EVs to supply innovative and more affordable vehicle charging solutions. The batteries were supplied by Renault and were used in Connected Energy's E-STOR for stationary storage in electric vehicle charging.	2016	United Kingdom
MITSUBISHI. PSA EDF, FORSEE POWER, MMC	Energy Storage	A demonstration project by Mitsubishi and PSA for a high voltage, a low voltage and a bi-directional battery energy system to demonstrate efficient and economically feasible energy management practices based on the optimization of electricity storage, charging and generation technology with respect to existing demand.	2015	France
DAIMLER GETEC, REMONDIS, ENBW	Energy Storage	Battery storage unit with a total capacity of 13 MWh. Degraded EV batteries from Daimler EV models were used for second life application of grid energy storage. The batteries will be connected to the grid and the output will be sold on the German electricity balancing sector.	2015	Germany
BMW/ VATTENFALL, BOSCH	Energy Storage	A 2 MW, 2,800 kWh energy storage system comprised of 2,600 battery modules from more than 100 electric vehicles.	2016	Germany
AUDI, ENBW	Grid Stationary Storage	A storage facility, deployed by Audi and German Utility EnBW, useds second-life EV batteries from Audi to store power from EnBW's wind and photovoltaic parks. The facility is located at EnBW's CHP plant in Heilbronn and offers services to municipal utilities, industrial companies and operators of decentralized generation plants.	2020	Germany
STREET SCOOTER, DHL	Energy Storage	DHL uses Second Life batteries to create buffer storage, saving up to 20.000 tCO2 per year in one building.	2021	Germany
BETTERIES, MOBILIZE BY RENAULT GROUP	Modular Energy Storage	The german start-up betteries established a partnership with Mobilize to built a remanufacturing center at Renault Group. The battery upcycling process uses modules from Renault electric vehicles to assemble second life energy modules. Using vehicle data, monitoring, control and prediction the second life application uses technologies to enable a second usage and possibly a certification and warranty.	2021	France/ Germany

Notable second-life projects – Asia

Stakeholders Involved	Project/ Initiative Category	Project/Initiative Description	Year	Location
TOKYO ELECTRIC POWER HOLDINGS (TEPCO)	Grid Stationary Storage	The utility launched a storage battery business utilizing used EV batteries from China. The batteries will be purchased from trading companies in China, and around 20 to 30 EV batteries will be assembled into a containerized energy storage system for renewable-energy plants. Trials started in 2020 and full deployment is planned in 2021.	2020	Japan, China
HONDA, CATL	Second Life Research	Honda acquired 1% of CATL to attain a stable supply of EV batteries and to explore areas such as recycling and reuse.	2020	China
NISSAN SUMITOTO (4R ENERGY), GREEN CHARGE NETWORK	Solar-plus-storage	16 Nissan Leaf LIBs of 600 kWh/400 kWh were provided by Nissan, that will regulate energy from a solar plant.	2015	Japan

Notable second-life projects – United States

Stakeholders Involved	Project/ Initiative Category	Project/Initiative Description	Year	Location
HYUNDAI MOTORS, UNDERWRITER LABORATORIES (UL)	Energy Storage	Hyundai and UL signed a memorandum of understanding for enabling safe deployment and use of second-life battery storage systems. The collaboration initiative will include a safety testing and assessment, a North America product demonstration project, and evaluation process development.	2021	USA
GENERAL MOTORS, ABB	Solar-plus-storage	ABB and General Motors collaborated to demonstrate the use of second-life batteries for residential use. 5 Chevrolet Volt LIBs, 74 kW solar array & two 2 kW wind turbines were used to power a General Motors office building site.	2015	USA
BMW, PG&E	Pilot Storage Project	BMW collaborated with PG&E to provide nearly 100 BMW i3 batteries, equaling to around 100kW of grid resources.	2017	USA

Impact of second-life batteries

One of the key characteristics of a sustainable solution is its multifaceted results. One cause often leads to many effects. This is especially true of second-life batteries, which have the potential to transform our everyday lives.

Here are the primary points of impact:

1. Environmental impact:

- Battery material can be reused instead of producing new batteries dedicated to applications.
- Battery packs can be used as storage systems to enable the transition of renewable energy (increasing the storage of generated renewables, especially decentralized).

2. Reduced cost of EVs:

- One major expense for EVs is the battery. With reusable model, either the whole batter or some of its parts can be reused and commercially utilized. This reduces the TCO of the EV. Clear commercial models have not yet been established (e.g., customer cashback for the battery or OEM collection). To highlight potential solutions here, taking the battery back could mean "pocketing" the value of the second-life battery or calculating it into the selling price of the EV).

3. Decreased cost of ESS:

- Reuse batteries can be used as energy storage systems.
- Though already attractive, reduced costs can bolster the relevance of ESS. This leads to greater support for market demand.

4. Technology push and support of transitioning EVs

- There is increasing potential for remote, fast-charging solutions (e.g., adaptive solutions, such as those developed by EON).
- New charging technologies can emerge across the board, including vehicle-to-grid and bidirectional charging. Thus, participation in energy markets, such as microgrids, will be a common occurrence.

"Modern cell chemistry and advanced battery analytics provide the necessary technical prerequisites for successful 2nd life applications.Further enhancements are necessary in standardized interfaces of battery management systems on module and pack level. The planned new EU Battery regulation is potentially the expected framework under which new successful business models can evolve. "

- Marcus Fiege, Senior Solution Architect E-Mobility, Capgemini Engineering

Key considerations

When it comes to reusing batteries, there's no one-size-fits-all solution. For one thing, dedicated use cases depend on the remaining quality of the battery (i.e., the battery's SOH), its dimensions, chemical composition, and the underlying battery design and architecture. Moreover, second-life batteries now require special consideration. Advanced technology is beginning to increase the average lifetime of batteries. Much of this technology is still in its infancy. But it's electrifying industry experts around the world. One such example is the future of LFP batteries.

LFP batteries are at the forefront of extended longevity. The longer a battery's lifetime, the more likely it is to endure and perhaps even exceed a vehicle's lifetime. For EV battery manufacturers, such an achievement gives them unparalleled bragging rights. Consumers want to avoid hidden costs wherever possible. Moreover, a vehicle that require a midlife battery change defeats the purpose of electric vehicles. If a manufacturer can tick all of these boxes, they will command the kind of respect that justifies price shifts. As the life of the battery begins to exceed the life of the vehicle, alternative second-life applications become a secondary consideration. For example, if the LFP battery still operates at over 80% capacity, it could potentially be transplanted into another vehicle. Of course, all of these developments precede recycling options. With this in mind, second-life solution cannot be considered the be-all and end-all for batteries. Rather, it must be considered part of a comprehensive approach to EOL.

4.3 Recycling batteries

The recycling of EV batteries is especially relevant when second-life use cases are no longer an option due to reduced energy density or capacity. Disposing of batteries should be avoided at all costs due to its extremely hazardous effect on our surroundings. Heaps of electronic waste containing lead and other toxic chemicals can pose a danger to both people and the environment.

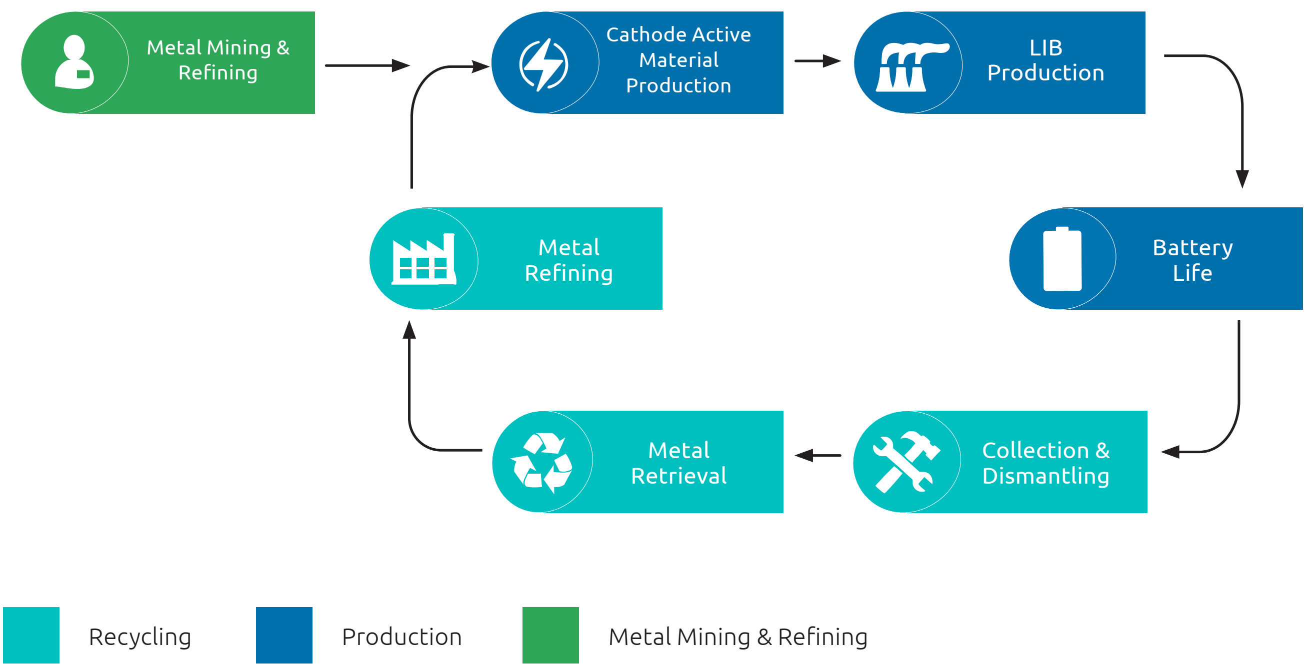
Disposing of batteries wastes many precious and often expensive materials used in their production. Same with metals that have highly fluctuating prices like cobalt or nickel. All of these should be recovered. This way we can avoid relying on unstable deliveries and companies with questionable backgrounds that often make use of ethically problematic practices that plague large parts of the mining industry. This also helps European OEMs become more independent regarding raw materials, given their common geographical disadvantages.

When it comes to sustainability, recent cases show improvements in the circular economy and supply chain where materials from EV batteries are more often reused, repaired, refurbished, and recycled to create a closed loop. The need for new materials decreases, while the 2nd life of batteries increases.

Putting a large focus on sustainability can work wonders when it comes to the living quality of local communities in areas where many of the materials mentioned above are mined. This includes avoiding involuntary resettlement, artisanal mining, harming indigenous people. If we keep successfully implementing all the good practices we have mentioned, we can minimalize the damage to these communities, while making everything more cost efficient in the long-term.

Right now, manufacturers are collaborating to explore the most promising recycling methods to identify a sustainable and economically feasible approach. The main challenge in the entire process is the fact that recycling batteries is simply not yet profitable due to inefficiencies, safety hazards, logistical challenges related to collection and transportation, and the evaluation of battery SOH which is the prerequisite for recycling cell materials.

According to the current estimation, EV battery recycling shows chances of profitability from 2025 onwards, in large part thanks to its widespread adoption and scaling effects. Countries like China are already showing great promise in that regard.



General process of recycling

Even though China remains one of the leading markets here, there's a huge future potential for Europe and North America, especially if they begin to act now. Establishing all necessary structures and systems will be vital to avoid falling behind in battery recycling and to have a chance at becoming future leaders.

Before looking at different recycling alternatives and initiatives let us highlight the geographical differences, with a focus on the US and EU, from a regulatory perspective.

TOPIC	US	EU
Directives	Directives in first, selected states regarding recycling	Overarching battery directive 2006/66/EC that covers collection rates, recycling efficiencies and mandatory usage of recycled material (directive to be approved by parliament in 2022)
Current recycling efforts	No/limited effort in the U.S. only specific states are putting policies in place and supporting the circular economy of batteries (e.g., California, Hawaii, North Carolina) important is that of the states, e.g., California (100% recycling and reuse) are showing effort, which is by far the most prevalent state in terms of EV adoption support and budget for research initiatives in recycling design for recycling and reuse is explored by leading manufacturers (e.g., Tesla, Ford, GM), but vast majority of battery manufacturers follow linear economic models (no circularity); but mostly driven by federal funded initiatives and pilot projects	Limited recycling due to cost and technological challenges (e.g., only 12% Aluminum, 22% cobalt, 8% manganese and 16% nickel are recycled) investment and regulations are in place or being developed for infrastructure building the base to enable growth and stability of the market extended producer responsibility (ERP): battery and component manufacturers are already responsible for waste management (particularly funding of collection and recycling programs)
Mandatory recycling efficiencies	–	2025 Recycling efficiency lithium-ion batteries: 65% by 2025 Material recovery rates for Co, Ni, Li, Cu: resp. 90%, 90%, 35% and 90% in 2025 ----- 2030 Recycling efficiency lithium-ion batteries: 70% by 2030 Material recovery rates for Co, Ni, Li, Cu: resp. 95%, 95%, 70% and 95% in
Mandatory recycling efficiencies	–	2030 and 2035, with 12% cobalt; 85% lead, 4% lithium and 4 % nickel from January 1st, 2030, incrementing up to 20% cobalt, 10 % lithium and 12% nickel from January 1st, 2035.2030

Comparative analysis of US and EU recycling

Having looked at the regulatory perspective, let's now turn to the technological side.

Three main processes, and a combination of the processes, are used for commercially recycling and extracting raw materials from end-of-life Li-Ion EVs, consumer electronics or 2nd life users.

The first such process is pyrometallurgy, used mainly for dismantled batteries, which are smelted so that their carbon-based compounds are burned. The alloy of valuable metals that we want to extract is treated with hydrometallurgical processes.

Next, we have hydrometallurgy, a three-step process consisting of leaching that dissolves metals, purification that separates them through chemical reactions, and metal recovery.

Finally, there is direct recycling with the goal of recovering functional cathode particle without degradation into elements. This one is showing quite promising results, but the restoration of initial capacity must still be proven.

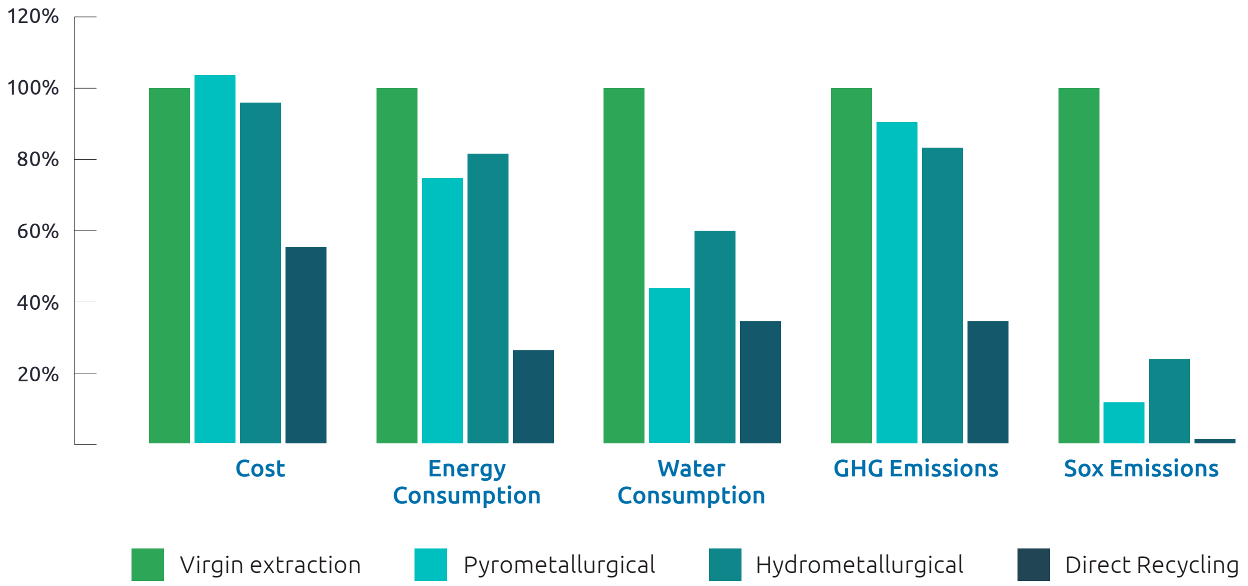
So far, there is no consensus as to which method is the most environmentally friendly and most effective. However, the two main dimensions of comparison are economic feasibility and sustainability. The following data presents a holistic view of the pros and cons of the three methods.

Processes	Pros	Cons	Recovered Materials	Recycling Companies
Hydrometallurgy	• Method is applicable to any battery chemistry and configuration. • Separation and the recovery processes are flexible to target specific metals. • Has high recovery rates for lithium. • Purity index is relatively high. • Energy efficient and no air emissions.	• The process has high operating cost, therefore not economical for lithium iron phosphate (LFP) batteries. Only feasible for Co and Ni batteries. • Cathode is broken down by acid. • The volume of process effluent to be treated, recycled or disposed is • high. • Anode materials such as graphite and some conductive additives are also irrecoverable.	• Copper • Aluminum • Cobalt • Li2CO3 Anode is destroyed	• Shenzhen Green Eco-manufacturer Hi-Tech Co. (China) • Retriev Technologies (Canada) • Recupyl S.A. (France)
Pyrometallurgy	• Expensive clean-up system is needed to avoid toxic air emissions.	• Expensive clean-up system is needed to avoid toxic air • emissions. • Economical for batteries with Ni and Co. • Is unable to recycle Li, Al or organics. • Is a capital and energy intensive process. • Requires further refinement for the extraction of elemental metals from the alloys.	• Copper • Nickel • Cobalt • Iron (partially) Anode is destroyed	• Umicore (Belgium) • JX Nippon Mining and Metals (Japan)
Direct Recycling	• Almost all battery materials can be recovered • Battery retains cathode structure • Feasible for LFP batteries • Enables the recycling of manufacturing scrap as well.	• Recovered material may not perform as well as virgin material. • Blending cathode materials could diminish value of recycled product. • Intricate and complex mechanical pre-treatments and separations are needed. • Process is not scaled up to industrial level yet	• Almost all components are recovered except separators	• OnTo Techb (USA)

Comparative analysis of recycling methods

The sustainability of recycling methods becomes apparent when compared to the detailed analysis of virgin extraction. Where cost is concerned, only pyrometallurgical recycling exceeds virgin extraction.

In every other category, the three methods of recycling show significantly lower values than virgin extraction. But the most noticeable difference by far is the value of direct recycling.



Benchmarks for Recycling methods

Key considerations

So, what has be done to increase the relevance of recycling EV batteries? The first set of actions is related to cost and profitability, since these show many areas in dire need of improvement. To achieve profitability, we need to take chemistry, location, and the entire process of recycling into account. This can be further accelerated by identifying standardized procedures and material extraction technologies – both of which will benefit a lot from a close collaboration between manufacturers and technological leaders. Standardization, in particular, is crucial for the current manual, labor- and cost-intensive process of disassembling the battery packs.

The second set of actions is related to purification processes and technologies. The best idea here would be to focus on identifying the technology set that enables the generation of pure materials that can be used in a closed loop to realize circular economy and supply chain potentials in the production of batteries. This technology should also be sustainability friendly, as the current state of battery manufacturing doesn't help a lot with their recycling and second-life goals.

4.4 Second-life and recycling potential

The OEMs of tomorrow must begin to consider the impact of EOL scenarios for batteries. Following such paradigm shifts as the 2016 Paris Agreement, businesses everywhere began thinking about how to meet and take advantage of new sustainability regulations. As a result, rechargeable batteries were put on pedestal and championed as one way to reduce emissions worldwide. And yet, there is still much work to do.

For a start, increased scrutiny of the lithium mining process is driving the demand for sustainable solutions. At present, innovations in end-of-life processes are among the most viable. But EOL must not be an afterthought. Rather, the maximum efficacy of such applications depends on considerations during the design stage. As such, the whole industry can benefit from second-life and recycling solutions.

The implementation of sustainable manufacturing will contribute to the longevity of the industry, making the transition from burgeoning to booming.

What second-life and recycling can do for OEMs:

Rapid growth in the EV market

In 2020, the compound annual growth rate for the global EV market was up 43% from 2015. It is expected to climb a further 47% by 2030. This in turn will lead to a 47% increase in battery demand worldwide.

Emerging application

Far from being the solutions of the future, EOL applications are already being implemented by forward-thinking OEMs. For example, battery parts are being harvested for use in devices with lower storage requirements, such as scooters and bicycles.

Demand driven by energy storage

At present, surplus energy and batteries need to be stored in special facilities. But this infrastructure is still being developed. As the number of batteries in circulation increases, so will the demand for second-life and recycling solutions.

Fluctuations in the materials market

Like all precious metals and minerals, the materials used in batteries are not easy to come by. As such, their market value varies depending on its scarcity.
This stimulating innovation in battery chemistries. For example, LFP chemistries are being used as more affordable options for entry-level car segments.

Restrictive regulations strengthen growth

Regulations can be a hindrance. But with sustainability mandates set to touch all industries, there is great potential for growth. OEMs that adopt a new business model now can be better positioned to react to the increasingly restrictive regulations of tomorrow.

The ground up approach

The viability of EOL solutions depend on their level of integration – the earlier in the process the better. As such, OEMs are uniquely positioned to use these solutions as vectors for growth. For example, DfR requires players to completely rethink batteries from the ground up. This means efficiency can be built into every phase of production.

Underestimated growth

There is still a great deal of naivety in this space. Despite the inevitability of the shift in practices and operations, many players refuse to act on the opportunity. Despite delivery times of over two years, many well established players continue to focus on the production of batteries for new EVs. This leaves the market a lot of untapped potential.

As is often the case, there is no single solution for battery sustainability. It's not an either-or scenario. Rather, each specific case has its own requirements.
It is essential that OEMs begin with a holistic strategy that includes both second-life and recycling solutions. A successful strategy must include an evaluation and analysis of the various dedicated use cases, industry players, and target markets. But this is only the bare minimum. An effective business model must also consider the development of economic validity and scalability, battery health, type, and specifications (mainly SOH); existing and emerging regulations, and company goals
(e.g., instituting a circular economy and improving sustainability).

Valid use cases are currently being explored and leveraged. However, there are some sticking points.
For example, second life and recycling are still rather expensive processes. This is especially true of the refurbishment and disassembly of current battery packs. Processes are not yet streamlined, and standardized solutions remain

economically impractical. Though it is true no dominant solution exists, there are exciting developments in the works.

Challenges for a large-scale application of end-of-life use cases remain to be solved, increasing the relevance of a strong partner ecosystem and specific investments. Especially economic improvements to the comparably high costs of realizing end-of-life use cases, processes, and technical advantages are required to achieve the large-scale adaptation of use cases. Establishing dedicated partnerships (e.g., via investments, joint ventures, and strategic partnerships or collaboration) and sourcing strategies enable industry players to provide and scale second-life applications and recycling facilities in a joint effort. This is done by leveraging dedicated solutions for different players (e.g., via the standardized evaluation of battery state of health, which is one of the baseline requirements of end-of-life applications).

Business model outlook

Though it is still early days, exploration of new business models is beginning to show great promise for the industry's main players.
As businesses take bolder steps in the direction of sustainability, OEMs will be able to leverage new use cases. The uptake of technology and the development of smart grids will open up new revenue streams for businesses with revamped models. Decentralized storage space is just one example of future potential.
Of course, the viability of these models can only be determined after careful evaluation; however, initial analysis points to advantageous adoption.
In ECO STOR and Nuvation Energy's case, a model that included large-scale energy storage resulted in changes in demand and optimization at a utility grid substation.

"New revenue streams await OEMs with revamped business models."

- Dr. Philipp Haaf, Director, Head of Electric Mobility

All evidence suggests the adjustment of a business model is imperative for companies looking to achieve better alignment with sustainability goals.
The transformative potential of second-life and recycling solutions can only be maximized when built into a business model.
Back in 2015, Daimler GETEC, Remondis, and EnBW were early adopters. Today, the industry's biggest players have taken the same approach. Nissan, Honda, and Tokyo Electric Power Holdings (TEPCO) have all adjusted their operations and continue to invest in the new model. The future has a lot "in store" for EOL growth opportunities.

5 CONCLUSIONS

In the future, battery cells could be indistinguishable from the perpetual energy engines of science fiction. Such progress is a direct reaction to a unified cultural and regulatory paradigm shift.

The Paris Agreement and other low-carbon conventions have made the transition to electric vehicles a fixed horizon. Consequently, the world has embraced the need to phase out fossil fuels as quickly as possible. Ubiquitously accepted as a viable alternative, advanced batteries are leading the charge toward a more sustainable future. But the transition is not readymade. There is much room for improvement where the extraction of raw materials is concerned. In fact, this is one of the mandates handed out in Paris. But far from hindering development, the regulation has stirred an energetic response throughout the industry.

Investors rarely discover a sure thing. But with decarbonization already written into law, research and development in battery tech has moved into top gear. In an effort to mitigate the environmental impact of batteries, solutions are being developed at both ends of the process. Mining facilities are looking into more sustainable methods of extraction, such ethical cobalt and water management. Producers and manufacturers, too, are looking at ways to reduce the need for additional batteries, such as greater capacity and end-of-life solutions. The net result is a projected 700-fold increase in greener, recyclable batteries by 2040.

This mass adoption will lead to evolution right across the board. Urban infrastructure will undergo a profound transformation, overhauling energy grids and integrating charging stations. Noise and air pollution will reach levels of wellbeing not experienced since before the industrial revolution. Best of all, societal obligations placed upon businesses will power improvements in the public sector.

As noted, the rise of EV batteries is expected to reach every corner of industry. In this point of view, a great deal of potential for the future battery market has been explored. In conclusion, the following can be expected in the near future:

- The emergence of a battery value chain ecosystem
- Sustainable battery chemistries
- New modes of raw material sourcing
- Blockchain-facilitated transparency or a digital product passport with information about the battery history and tracing
- Fluctuations in the raw materials market
- New priorities for research and development
- Sustainable practices built into design
- Fully digitized and recycling-ready producers
- Second-life and recycling as vectors for overall business development
- New second-hand markets for batteries and vehicles

As batteries improve and even exceed our expectations, existing industries will begin to mature. For example, recycling processes will be refined and improved to accommodate the increased production of batteries. Moreover, new industries will reach maturity. Second-life options for batteries are already on the rise. But as our batteries begin outliving their hosts, they will need to be transplanted into other devices or used as grid storage.

The sooner OEMs can incorporate these strategies, the better positioned they will be to explore the highway of certainty for EV. With batteries being one of the most promising alternatives to fossil fuels in the passenger automotive sector, they are sure to maintain a thriving industry and accelerate the arrival of our greener future.

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