Global
Sustainable Electricity
Partnership

2nd Life Batteries

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A white paper from Storage Technological Community

Global Sustainable Electricity Partnership

A white paper by the GSEP Storage community

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2nd Life Batteries: White Paper Outline

Introduction

Economics

Enabling factors and limits

Sustainability and Circularity

Cross-sectors synergies

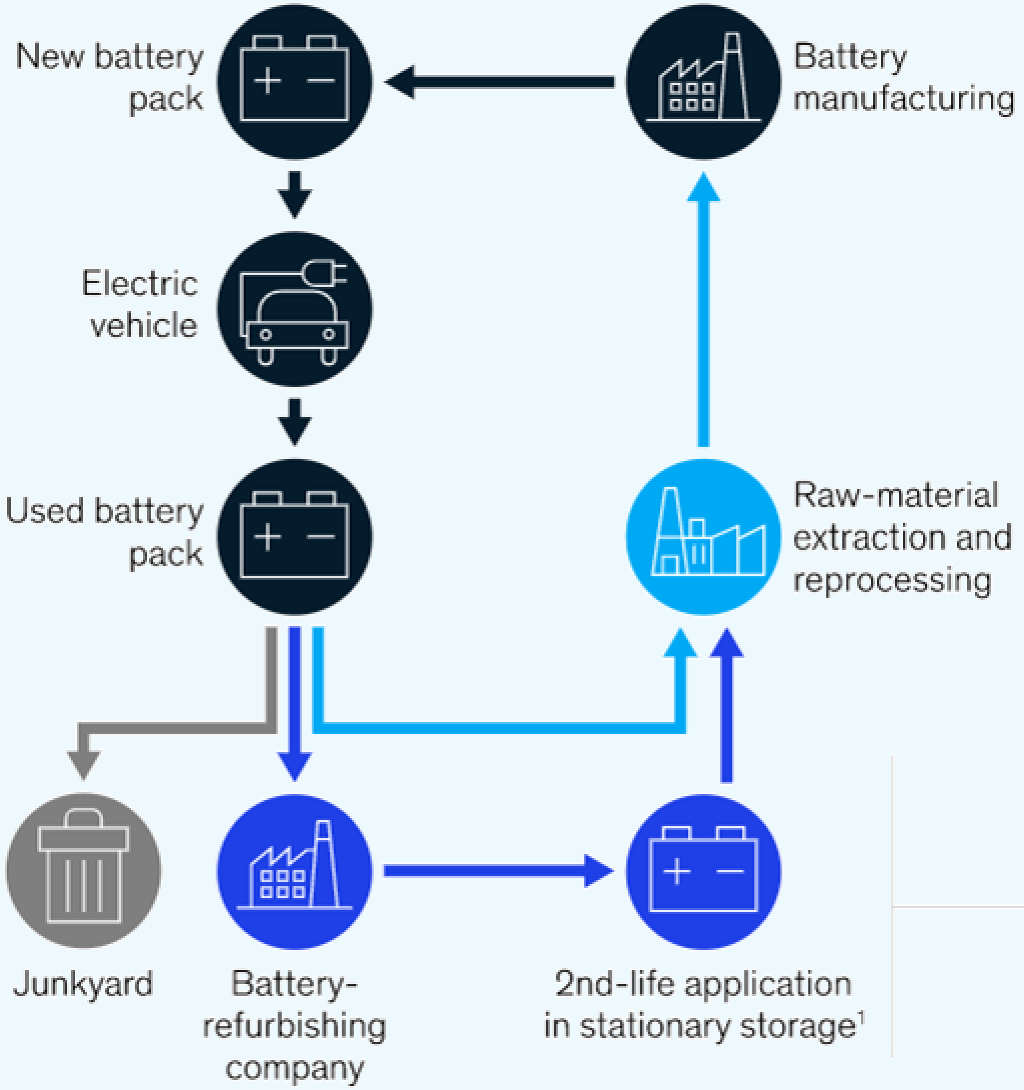
2nd Life Batteries: *Introduction*

Introduction

- What we mean with «2° life batteries»
- Approaches to 2° life applications
- GSEP Storage Tech Community experience on 2° life projects

Introduction

What we mean with 2nd life batteries?



When an EV battery reaches the end of its useful first life (e.g. maintaining 80 percent of total usable capacity and achieving a resting self-discharge rate of only about 5 percent over a 24-hour period), manufacturers have three options:

1. Simple disposal, that most frequently occurs if packs are damaged or if they are in regions that lack necessary market structure. In most regions, regulation prevents mass disposal.
2. Recycling, to recover in particular highly valued metals such as cobalt and nickel, especially thanks to most innovative processes, like hydrometallurgy
3. Before recycling, reuse the batteries in stationary applications, where reduced performances capabilities are still valuable

Source: McKinsey

Introduction
Approaches to 2nd life applications

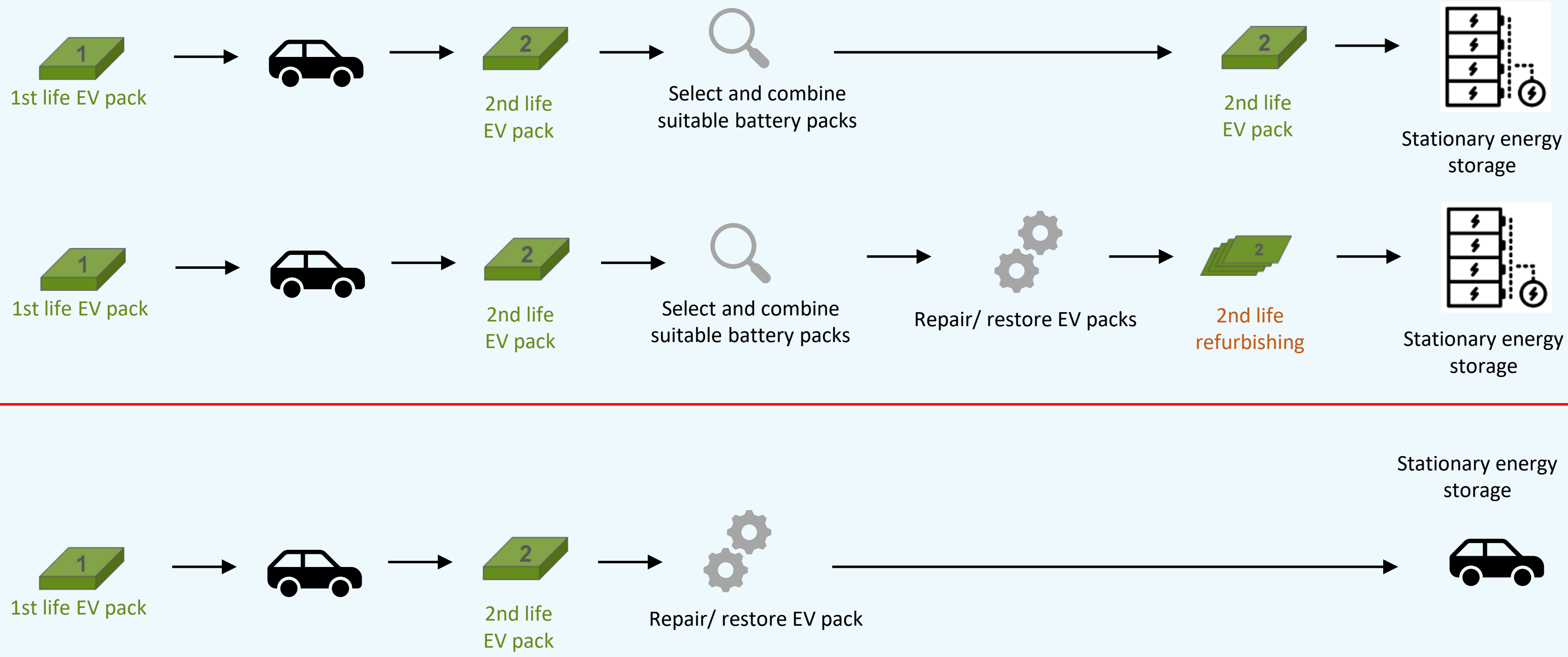
After the “first life”, a couple of main alternative are possible before recycling the electric vehicle battery pack: repurposing, that means “using the pack as it is”, after a process of selection and combination of suitable packs (according to criteria like residual state of health, capacity, etc…), or refurbishing, that means that the packs is first disassembled and single cells are reconditioned and repacked in new modules before being used in stationary applications.

EV packs, if designed with this scope, can be used also directly in stationary applications. On the other side, after their first EV use, EV packs could also being refurbished to be used again in EV applications (instead than on stationary ones), but this option is out of scope.

Repurposing of 2nd life EV battery packs
Collect battery packs, select batteries with sufficient remaining capacity and combine similar EV battery packs

Refurbishing of 2nd life EV battery packs
Open packs, remove modules for possible refurbishment, cell reconditioning or recycling. Repackage modules into new battery packs.

Remanufacturing
Restore an EV pack and to reuse it in a vehicle – *not in focus*



Source: Navigant for Enel

Introduction
Approaches to 2nd life applications: pros and cons

Source: Enel

Refurbishing of EV batteries

- It is necessary to **dismantle packs, collect modules, measure/test, sort, repack and certify** the used EV batteries:
  - an "ad hoc" **supply chain** has to be set up
  - **increase of cost** of batteries re-use
  - A **new module (tray) BMS** has to be realized
- Currently, only few system integrators have **required know-how** to implement this option
- **More time required** to realize and certify repackaged modules
- Once realized the repackaged modules, the assembly and system integration of the stationary BESS system **requires the same needs of common BESS**
- **Warranties on battery performances can be guaranteed** by System Integrator

Repurposing of EV battery packs

- It's a '**ready to use**' approach: **reduced time** and **price** of batteries repurposing (less labor intensive activity, less investment in rebuilding process)
- **Reuse of existing native pack BMS**
- Integration activities can be provided by **several system integrators**
- **A specific Master BMS** (for the whole system) has to be developed
- It is **not possible to connect packs in series but only in parallel**. This requires to **add a DC/DC converters** to elevate the DC voltage to the PCS working level, or to **oversize PCS** due to high currents, increasing system cost.
- Requires **more installation space** with respect to standard stationary BESS based on battery modules.
- **System Integrator doesn't guarantee the battery performances** (life extension, efficiency, C_rate,…). Just expected residual capacity can be guaranteed by battery manufacturer

GSEP Tech Community experience on 2° life projects

Melilla project by Enel

Source: Enel

Need

In **isolated system**, a **relevant f deviation** (for example due to a failure of a generation asset) may cause **load shedding** events and **blackout** due to dynamics of the other gensets.

Solution

The **integration of fast response storage** technologies in the power station to **respond to f deviation** and power unbalances during the initial minutes can decrease or avoid the load shedding events and balckouts, **increasing system reliability**

Project highlights

Site: **Melilla, ≈ 90.000 citizen, island mode fed by** Endesa Genset power plant (60,2MW)

Tested solution: 4MW/1.7MWh battery system **based on direct use (repurposing) of EV battery packs (2MW 2nd life + 2MW new EV packs)**, in parallel to the existing Genset power plant (frequency regulation).

Timing: COD by 2020

GSEP Tech Community experience on 2° life projects

Melilla project by Enel

Source: Enel

Strategic Rationale

Understand possible **investment reduction** in storage installations

Understand the opportunity to use second life batteries as **spare parts** of storage installations to reduce maintenance costs

Develop a sustainable initiative, that improves sustainability impact of battery systems/RES

Develop guidelines on sustainable EV battery reuse for stationary application and sustain a **proactive approach towards regulation and standardization** to foster second life adoption (*)

Establish chain of suppliers and integrators for future energy storage projects

Technical Rationale

Verify performances of the 2nd life batteries declared by manufacturers **(measurement and validation, reference KPIs)**

Internalize skills concerning system integration topics to better tune storage project **design and proposal** phases

Know-how acquisition on 2nd O&M (predict maintenance, identify troubleshooting strategies)

Key findings on **Master Battery Management System (MBMS)** development to effectively operate an uneven pack

(*) **R&D&I**, within international platforms (**EU Battery Alliance, Batteries EU, IPCEI**) is focusing with the growing need of having **design standards** allowing an **easy disassembly** (e.g. use of screws and avoidance of meltings in battery packs), an **effective labeling** (in case of battery pack disassembly and module sorting, it's important to have clear indications of the module chemistry), an **effective and detailed tracking of the single battery use** within the EV operation. On top on this, **standardize the battery Status of Healt definition** is also a relevant ongoing discussion (as of today any battery maker uses it's own proprietary definition).

GSEP Tech Community experience on 2° life projects
Melilla project by Enel

The 2nd life BESS facility during the construction

Factory
Acceptance Tests

Source: Enel

GSEP Tech Community experience on 2° life projects
Melilla project by Enel

Details of the EV battery packs repurposed for stationary application

Source: Enel

GSEP Tech Community experience on 2° life projects

Jiangsu ES with 2LB Case

In 2020, the retired power batteries in Jiangsu Province of China are expected to be about 20.000 tons and by 2025 it will reach about 80.000 tons.

Applied to Telecom Tower

- The Jiangsu Telecom Tower currently maintains about 90.000 base stations. Previously, the base station backup power supply used lead-acid batteries, which had poor high-temperature resistance, low energy density, and low environmental compatibility.
- Last year Jiangsu Tower stopped purchasing lead-acid batteries, and all the backup power sources will be replaced with lithium batteries coming from electric vehicles.
- Jiangsu has now replaced more than 4.000 sets.

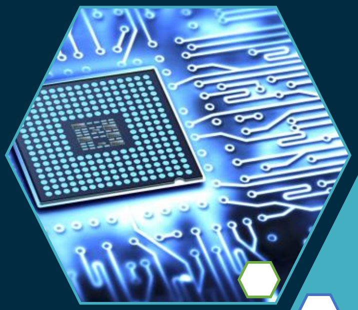
Applied to micro energy storage power station

- Jiangsu Comprehensive Energy Service Company uses retired electric vehicle batteries to provide customized micro-energy storage power stations for enterprises.
- It is equipped with two sets of micro-battery cascade energy storage systems with a total capacity of 204 kWh and a charge and discharge power of 40 kW.
- The project can save a third of the Company's electricity costs.

GSEP Tech Community experience on 2° life projects

Jiangsu ES with 2LB Case

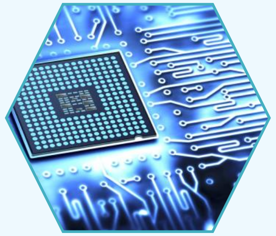
2nd Life Batteries:
Enabling factors and limits



Enabling factors and limits

- Key barriers for 2° life batteries integration
- Technical Challenges and Drivers
- Applications for 2° life batteries

Enabling factors and limits
Key barriers identification from first experiences



During the first 2nd life real-life application (see Mellila Project above), the main key barriers to the wide rollout of 2nd life batteries projects, and related potential solutions, have been identified:

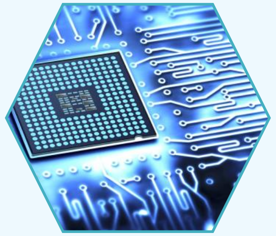
Source: Enel

Key Barriers	Solutions to overcome barriers through Melilla project

Complex and unknown **technical procedures** to better **select, integrate and operate** 2nd life system in safety and economical way	• Development of the **technical standards** to select second-life batteries:
	  ○ Definition of **Test Protocol** for better sorting
	  ○ Definition of **minimum acceptance KPI** values based on classifications and the most promising applications
	• Definition of **guidelines for system integration** to guarantee safety operation (BMS VS master BMS interaction)
	• **EVs standardization for interoperability** of different systems

Lack of data about **battery performance** in both first and 2nd life applications	• Make available **battery log data** during operation Melilla system and definition of a **degradation model** • Implementation of an **open platform** to monitor data from first life use to understand the condition of the batteries and **set the time to move in second use**, in cooperation with car and battery manufacturers
Economic uncertainty about 2nd life battery value	• Identify and promote the **adoption of technical features/standards** suitable for application to 2nd life batteries **already in the phase of EV battery production**

Enabling factors and limits
Technical challenges

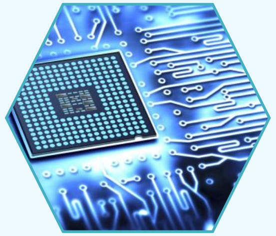


The technical challenges are confirmed also by literature, and can be summarized in: lack of standardization (both technical and regulatory), guaranties, and strong competition from "first life" batteries.

1. **Large number of battery-pack designs** in terms of size, electrode chemistry, and format (cylindrical, prismatic, and pouch). Estimation: up to 250 new EV models will exist by 2025, featuring batteries from more than 15 manufacturers.
2. **Falling costs for new batteries**. As new batteries become cheaper, the cost differential between used and new diminishes. The cost gap needs to remain sufficiently large to warrant the performance limitations of second-life batteries relative to new alternatives.
3. **No guarantees** exist regarding second-life-battery quality or performance, **no common standards** for battery management systems (**BMS**) or state of health (**SoH**) disclosures
4. **There are no market-wide regulatory or policy standards** for manufacturers or end users of EV batteries. Responsibility assignment to players along the 2LB value chain is not clear: it's difficult for the second life industry to maintain a cost-effective strategy across different regions.

Source: elaboration of McKinsey + Guidehouse

Enabling factors and limits
Main drivers to overcome challenges



Nevertheless, various drivers can be identified to valorize 2nd life batteries applications, both from an economical and a sustainability point of view.

1. 2nd life batteries **can reduce the amount of waste** and also **prevent the additional depletion** of Earth's minerals such as cobalt, lithium, and nickel. Lithium extraction can also have negative environmental consequences because the process is water intensive. Wide adoption of 2nd life batteries technology could make it possible to keep up with energy storage demand without mining for battery materials in unsustainable ways.

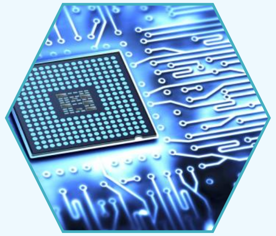
2. Automakers can **design their EVs with second-life applications in mind**.

3. Additionally, EV makers can take advantage of 2nd life batteries technology by **reselling used EV batteries** to companies that will integrate them into new energy storage systems, industrializing and scaling processes to reduce costs, thus maintaining the value gap between new and used batteries. By doing this, carmakers are **increasing the "dollar per kilowatt-hour" value** of their products while also reducing their carbon footprint

4. S**tandards are required**, that would essentially classify batteries based on their performance potential and classify storage applications based on their performance needs in order to create transparency into product supply and market demand.

Source: elaboration of McKinsey + Guidehouse

Enabling factors and limits
Main drivers to overcome challenges



Highlights from EU

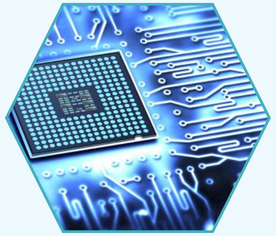
On December 2020, European Commission proposed a new Battery Regulation that aims to ensure that batteries placed in the EU market are sustainable and safe throughout their entire life cycle. In particular, there’s specific article related to Second Life Batteries, that contains following key points:

- *Battery Management Systems to store the information needed. Independent operators have access to this information.*
- *Used industrial or EV batteries are no longer considered waste if the battery holder proves that*
  - *State of health checks confirm the capability to deliver the specified performance relevant for its use,*
  - *It will be used (by means of an invoice or sale contract),*
  - *It will be appropriately protected against damage during transport.*
- *The repurposer is considered as the manufacturer of the repurposed battery. Therefore he has to comply with all appliable product, environemntal and other requirements, including to carry out conformity assessment procedures etc., with the exception of certain sustainability rules.*

The draft is under discussion\review.

https://ec.europa.eu/environment/waste/batteries/pdf/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf

Enabling factors and limits
Applications for 2nd life batteries



The technical economic feasibility of 2nd life application, and the competitiveness versus 1st life batteries, shall be evaluated case by case. Anyway, some general considerations can be done:

Power-Intensive applications

Examples:

- Frequency regulation
- EV Charging Support:

In these applications, the use of 2nd life batteries originally designed for EV can take advantage of their typical capability to work at higher c-rates, thus being potentially more competitive versus 1st life batteries. On the other side, such applications can apply to the batteries a relatively higher stress, thus reducing the lifetime

Energy-Intensive applications

Examples:

- Behind the meter for C&I and residential
- Distribution Upgrade Deferral
- Energy shifting

In these cases the competiveness of 2nd life batteries versus 1st life is harder, because of the lower performances required that reduce the capital costs for a business-as-usual solution. On the other side, these applications are typically less stressful, thus the expected lifetime of 2nd life batteries can be significantly higher if compared to power intensive use cases

Source: elaboration of Guidehouse

2nd Life Batteries: Economics

Economics

- Expected volumes of 2° life batteries from EV
- Cost comparison: 1° vs 2° life

Economics

Expected volume of 2nd life batteries from EV

Continued global growth of EVs and technology advances in increasing the capacity per unit of batteries, raise the expected volume of the 2LB market.

Stationary Storage powered volumes' predictions from different sources by 2030:

- **136 GWh globally** (Guidehouse) with annual growth rates:
    - **61,3%** for Plug-in Hybrid EV (PHEV)
    - **75,7%** for Battery EV (BEV)
- **200 GWh** from (McKinsey & Company*)* regarding stationary storage powered by 2LB.

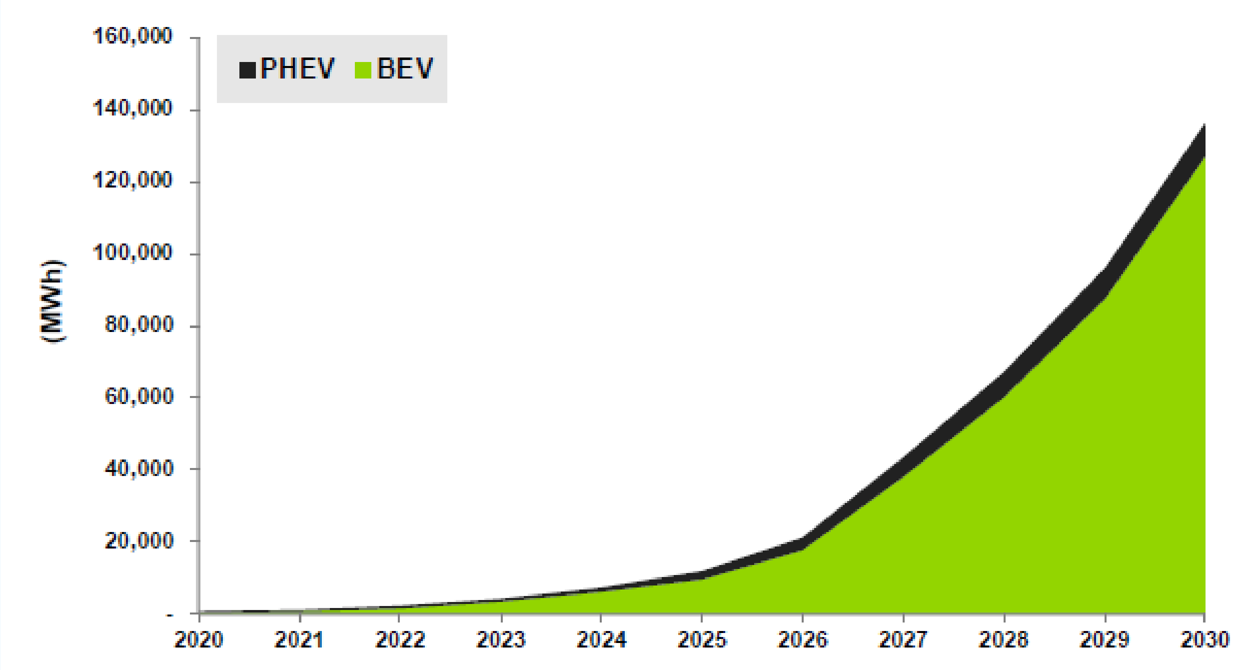


Figure: Annually available 2LB Energy capacity by Powertrain, Base Scenario, World Markets: 2020-2030

Nb: The substantial growth of BEV versus PHEV observed on the figure is due to the larger portion of BEV sales in the EV market, as well as the larger batteries contained in BEV powertrains.

Source: Guidehouse + McKinsey

Economics

Costs comparison 1^{st} vs 2^{nd} life

The accuracy of comparing the costs between 1LB and 2LB is correlated with the **multiple characteristics** of the battery itself. Therefore, due to the **lack of standardization** and **data amongst** the batteries, as well as other factors mentioned previously, an important portion of the costs can remain unknown until the evaluation of said batteries is performed. However here are some facts that can be found in the literature:

- **Repurposing** EV batteries is **more cost-effective** than **refurbishing** EV batteries.
  - Repair, replacement and extraction of individual cells within modules is **unlikely to be economically feasible.**

- Both technologies will stay **more cost effective than 1LB** : 30-70% less expensive than 1LB.
  - Predictions for 2030 are of:
    - **$80/kWh** for 1LB
    - **$53/kWh** for Repurposing EV batteries (2LB Direct Reuse)
    - **$77/kWh** for Refurbishing EV Batteries (2LB Reworked)

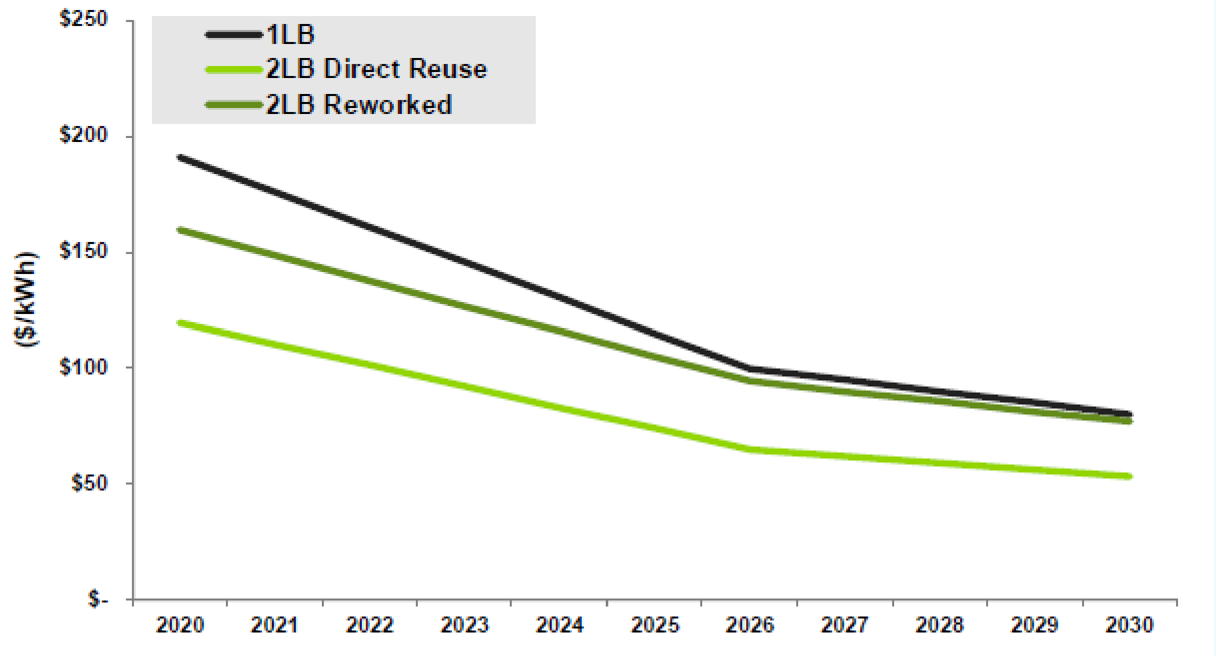


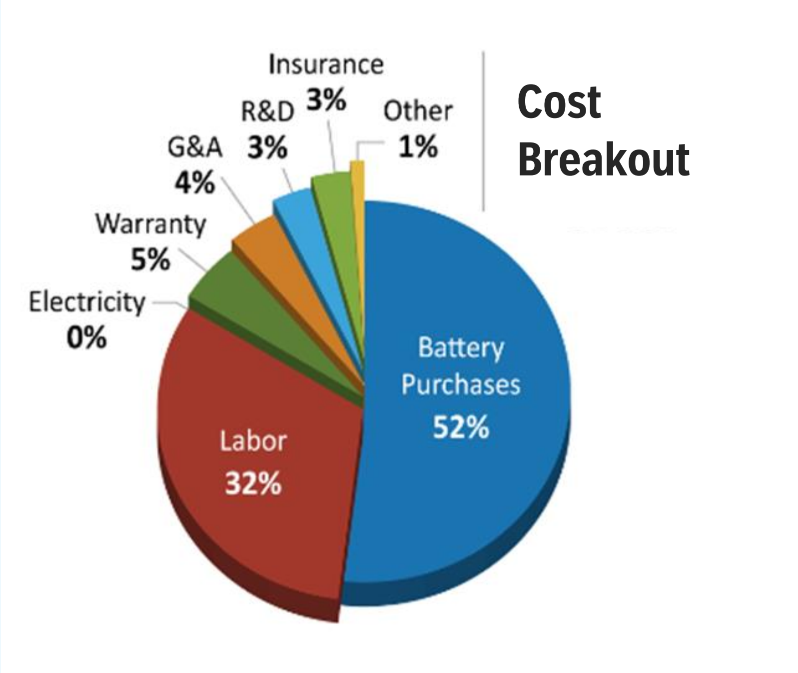
Figure: BEV Battery pack pricing by Technology, World Markets : 2020-2030

Source: Guidehouse + NREL + McKinsey

Economics
Costs comparison 1st vs 2nd life

A 2LB strategy corresponds the design and development of a storage technology to serve two purposes. The first one is the initial use in the vehicle and the second the use in another vehicle or for stationary application.

- 2LB Repurposing Cost Calculator developed by the NREL reveals that **2LBU is both viable and valuable**
  - Can help determine repurposed-battery selling price to identify used-battery buying price paid to battery owner.
  - Costs can be shared between the primary and secondary users.
  - **Repurposing only battery modules** and not the cells, decreases the costs for technician labor (around 32%).
  - Possibility to use vehicle diagnostics data to confirm the state of health and absence of cells in modules prior to purchase.
  - Repurposing costs can be as low as **$20/kWh-nameplate**.



Source: Guidehouse + NREL + McKinsey

2nd Life Batteries: Sustainability and Circularity

Sustainability and Circularity

- Drivers and Challenges for recycling batteries
- Recycling options
- Policy implications

Sustainability and Circularity
Economic and Environmental Drivers for recycling

a) To reduce carbon footprint of LIBs manufacturing
b) To reduce LIBs manufacturing cost
c) To reduce reliance on mineral extraction
d) To reduce reliance on specific suppliers or goods importation
e) To generate local economic activity (circular economy)

Source: Hydro-Québec : "Progress and Status of Hydrometallurgical and Direct Recycling of Li-Ion Batteries and Beyond", December 2019
Source: Hydro-Québec : "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials », July 2020

Highlights from EU

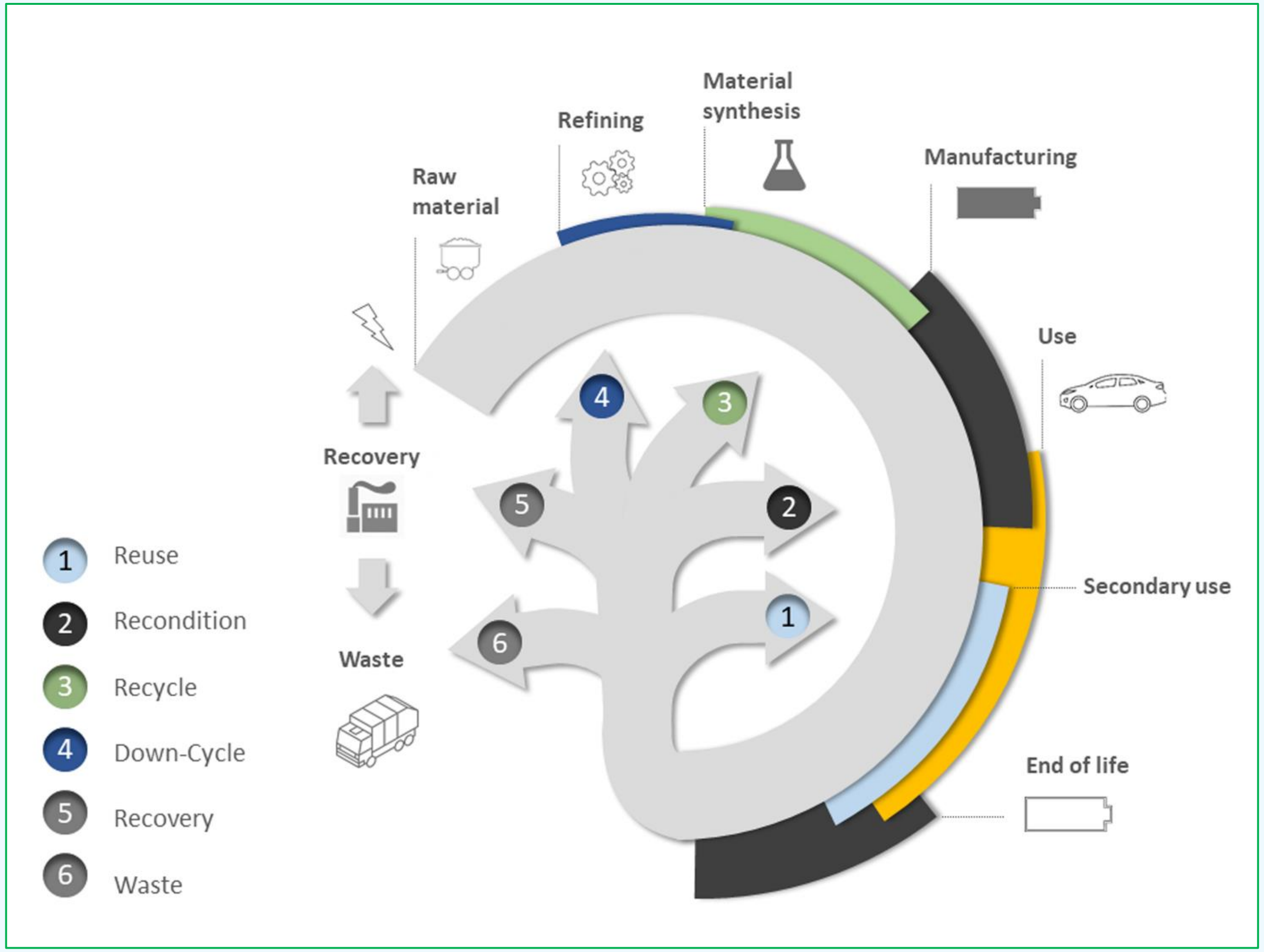
On December 2020, European Commission proposed a new Battery Regulation that aims to ensure that batteries placed in the EU market are sustainable and safe throughout their entire life cycle. In particular, there's a strong focus on circularity with targets on:

a. Increasing resilience and closing the materials loop
b. Reducing the EU's dependence on imports of strategic materials
c. Ensuring appropriate collection and recycling of all waste batteries

The draft is under discussion\review.

https://ec.europa.eu/environment/waste/batteries/pdf/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf

Sustainability and Circularity
Technical and financial challenges



Challenges

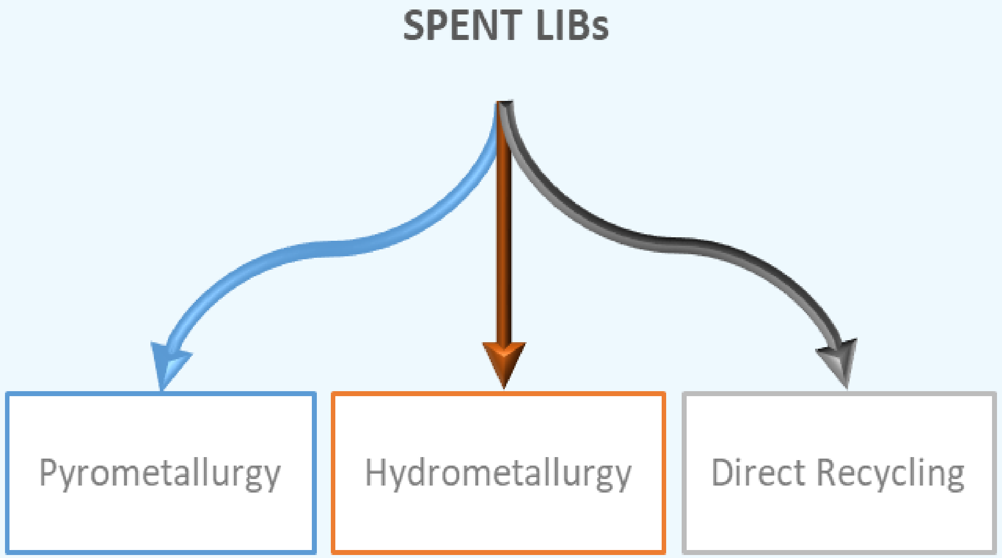
- *High product quality and supplier reliability*
- *Competitive collection and recycling costs*
- *Low environmenental footprint*

Recycling processes should offer a reasonable balance of **affordability**, **energy efficiency**, **environmental-friendliness**, and **safety**; their output must also be comparable (or superior) to raw materials in terms of price, quality, and reliability of supplies.

Source: Hydro-Québec : "Progress and Status of Hydrometallurgical and Direct Recycling of Li-Ion Batteries and Beyond", December 2019

Source: Hydro-Québec : "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials », July 2020

Sustainability and Circularity
Current recycling options



- Pyrometallurgy : Smelting of spent batteries
- Hydrometallurgy : Complete or selective dissolution of spent batteries
- Direct: Recover and restore cathodic material for direct use in new batteries

Source: Hydro-Québec : "Progress and Status of Hydrometallurgical and Direct Recycling of Li-Ion Batteries and Beyond", December 2019
Source: Hydro-Québec : "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials », July 2020

Sustainability and Circularity
Current recycling options

Recycling method	Advantages	Disadvantages
Pyrometallurgy	• Flexible; applicable to any battery chemistry and configuration • No sorting or other mechanical pre-treatment necessary • High recovery of metals (e.g., Co, Ni, and Cu) • Proven technology; can be implemented using existing pyrometallurgical facilities	• Cannot recycle Li, Al, or organics • Cannot treat LFP batteries • Expensive gas clean-up is required to avoid toxic air emissions • Energy intensive • Capital intensive • Further refinement is necessary to produce elemental metals from metal alloys produced in smelting process
Hydrometallurgy	• Applicable to any battery chemistry and configuration • Flexible in separation and recovery processes to target specific metals • High recovery rates (e.g., for lithium) • High purity of products (suitable for cathode precursors, etc.) • Energy efficient • No air emissions	• Battery cells must be crushed (causing safety concerns) • Acid breaks down cathode structure • High volume of process effluents to be treated and recycled or disposed • Not economical for lithium iron phosphate (LFP) batteries • Anode materials (e.g., graphite and conductive additives) are not recovered • High operating cost
Direct recycling	• Retains valuable cathode structure • Practically all battery materials can be recovered, including anode, electrolyte, and foils • Suitable for LFP batteries • Energy efficient • Convenient for recycling manufacturing scraps	• Complex mechanical pre-treatment and separations are required • Recovered material may not perform as well as virgin material or becomes obsolete by the time it is introduced to market • Mixing cathode materials could reduce the value of recycled product • Regeneration processes yet to be developed • Not scaled up to industrial level

Source: Hydro-Québec : "Progress and Status of Hydrometallurgical and Direct Recycling of Li-Ion Batteries and Beyond", December 2019

Source: Hydro-Québec : "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials », July 2020

Sustainability and Circularity
Policy implications

Market Creation

The lack of regulatory incentives is one of the most important barriers to LIB recycling

We shall consider:

- Applying the Extended Producer Responsibility (EPR) regulation
- Setting cost and performance goals with rewards and penalties
- Increasing “gate fees” for landfilling
- Establishing a deposit at the purchase
- Facilitating international transportation of spent LIBs

R&D priorities

- Consider the entire recycling value chain in R&D

  The cost of safely transporting spent batteries alone represents 40%–50% of the overall recycling cost
- Aim to recycle all types of LIBs and every components

  Graphite anode is one of the most neglected components in R&D
- Design the battery pack for recycling
- Better understanding of failure mechanisms
- Establish minimum quality specification for recycled battery material and standard procedure for their determination

Source: Hydro-Québec : “Progress and Status of Hydrometallurgical and Direct Recycling of Li-Ion Batteries and Beyond”, December 2019

Source: Hydro-Québec : “Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials », July 2020

Sustainability and Circularity
Policy implications

Piloting & Process Scale-up

Policy priorities should:

- Support pilot projects that seek to demonstrate the technical and financial viabilities of proposed solutions.
- Promote all stakeholders to participate in large-scale recycling efforts
- Promote cooperation and collaboration along the value chain
- Secure spent battery supplies to developers and recyclers
- Assess the energy use and lifecycle emission of recycling processes

Source: Hydro-Québec : "Progress and Status of Hydrometallurgical and Direct Recycling of Li-Ion Batteries and Beyond", December 2019

Source: Hydro-Québec : "Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials », July 2020

Highlights from EU

New EU Battery Regulation proposal targets:

- ❖ **Mandatory declaration on the amount of recycled content in industrial**, EV and automotive **batteries in 2025** and mandatory levels of recycled content, in [2030, 2035] for Pb [85%, 85%], Co [12%, 20%], Ni [4%, 12%], Li [4%, 10%]
- ❖ **New targets for batteries' recycling efficiencies** in [2025,2030]: Li-ion [65%, 70%] and Pb-acid [75%, 80%]
- ❖ **Increased key materials recovery rates** (from waste batteries and separated for reuse) in [2025,2030] for Pb [90%, 95%], Co[90%, 95%], Ni[90%, 95%], Li[35%, 70%], Cu[90%, 95%]
- ❖ **Obligation for batteries' producers to report** on performance and durability for EV and industrial batteries, from 1 January 2023 and minimum performance requirements shall be meet from 1 January 2026

The draft is under discussion\review.

https://ec.europa.eu/environment/waste/batteries/pdf/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf

2nd Life Batteries: Cross-Sectors Synergies

Cross-sectors synergies

Potential collaborations with Electric Vehicles Associations

Cross-Sectors Synergies

Potential collaborations with EV Associations

EDTA
Electric Drive Transportation Association

World Wide

A «dialogue» between utility-world and EV-world is to be favored to develop synergies between two sectors strongly connected in 2nd life batteries.

- *What's EV OEM view on end-of-life management of batteries?*
- *Are they considering EoL batteries a cost? Or a residual value? How will this view change in 5, 10 years?*
- *What's going on in terms of circularity by design, standardization, and open access to info?*

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