DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

UNIVERSITÀ DEGLI STUDI DI PADOVA

Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria dell'energia

Second life of lithium-ion batteries: degradation methods, selection of batteries, applications and environmental benefits

Tutor universitario: Prof. Massimo Guarnieri
Co-tutor: Dott. Nicolò Zatta

Laureando: *Martina Rettore*

Padova, 16/07/2024

INTRODUCTION

EV batteries are usually retired when they reach about 70-80% of their original SOH.

- **Why does this happen?**
  Due to degradation mechanisms the battery can no longer meet the vehicle requirement.

- **What happens then?**
  The battery pack is removed from the car and analysed.

- **What options are available?**
  If possible, the battery can be used in a less demanding application (second life).

Various mechanisms contribute to the unavoidable process of battery ageing:

➡ INTERNAL MECHANISMS:

1. *Loss of lithium inventory*: parasitic reactions, such as SEI (solid electrolyte interface) growth and lithium plating consume lithium ions

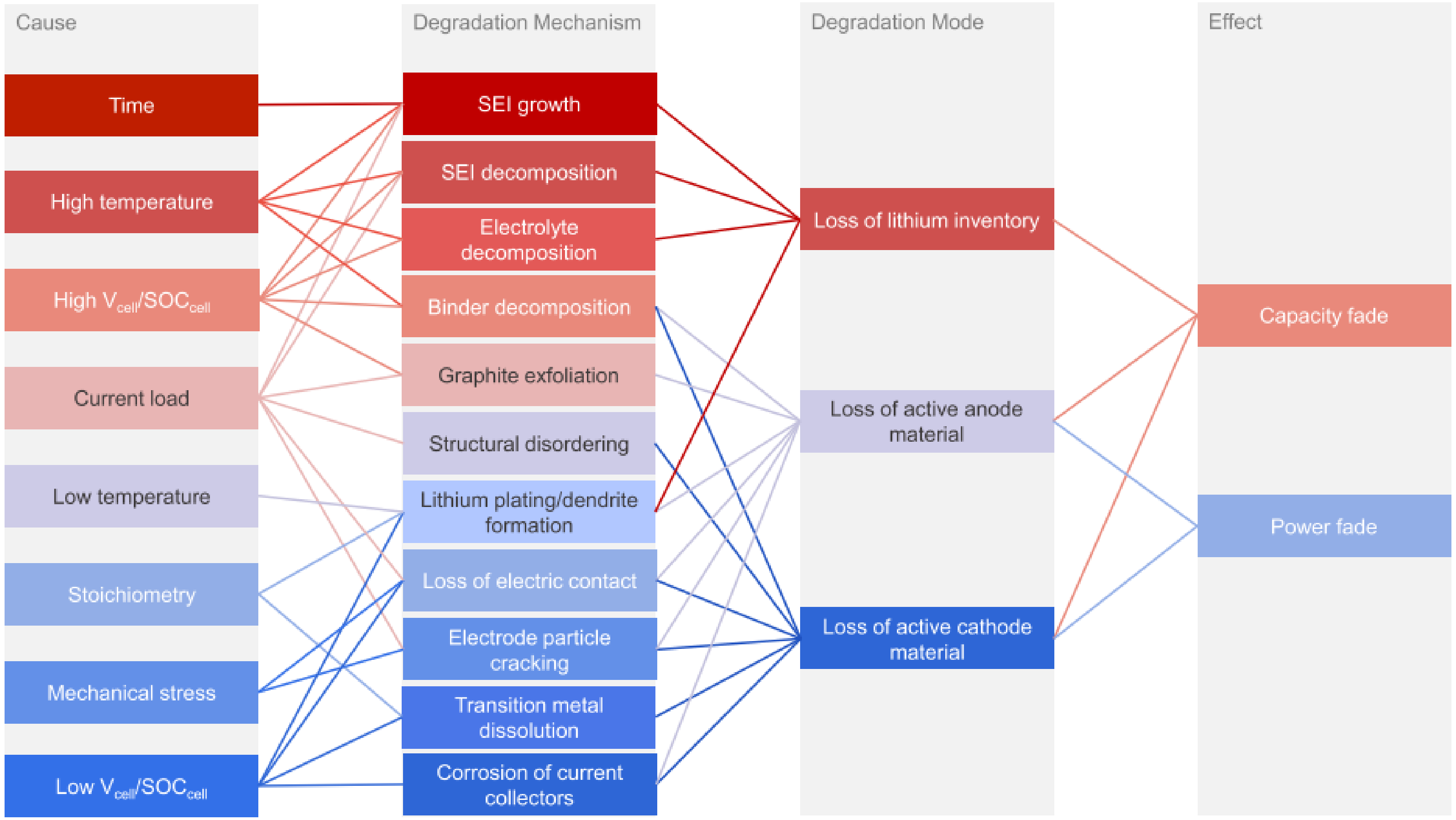
2. *Loss of active material of the negative electrode*: active mass of the negative electrode is no longer available for the insertion of lithium

3. *Loss of active material of the positive electrode*: similar process to the previous one on the cathode

LITHIUM-ION BATTERIES AGEING

EXTERNAL FACTORS

1. *Temperature*
2. *Storage SOC*
3. *Mechanical stress*
4. *Stand-by time*
5. *Operating time*



Main degradation mechanisms

CONSEQUENCES

INTERNAL RESISTANCE GROWTH

- Reduced ability to accelerate and drive uphill
- Limited maximum charging power (increased charging time)
- More heat generation (more losses, if not properly cooled, safety issues)

CAPACITY FADE

Reduced driving range

Criterion first introduced in 1996 (USABC): the battery pack should be replaced when it loses 20% of its original capacity.

SOH AND RUL

Widley used parameters to understand the state of a battery

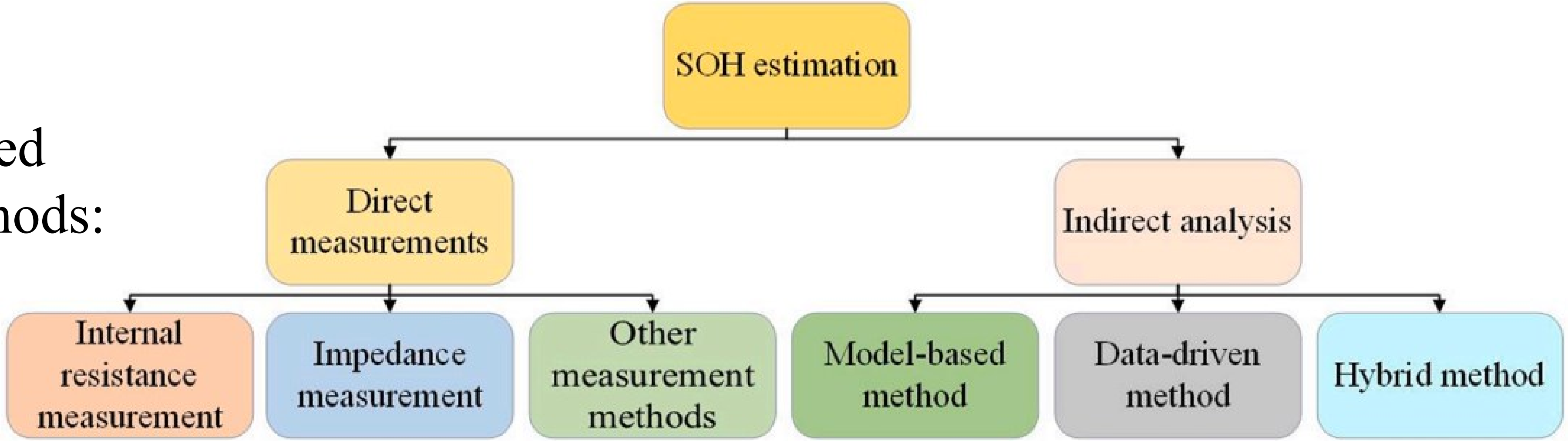
State of health SOH

$$SOH = \frac{Cc}{Cnom} x100 \text{ or } SOH = \frac{Reol - Rc}{Reol - Rnom} x100$$

Remaining useful life RUL

$$RUL_{\alpha} = \beta - \alpha$$

They can be estimated through similar methods:



SOH ESTIMATION METHODS

DIRECT METHODS:

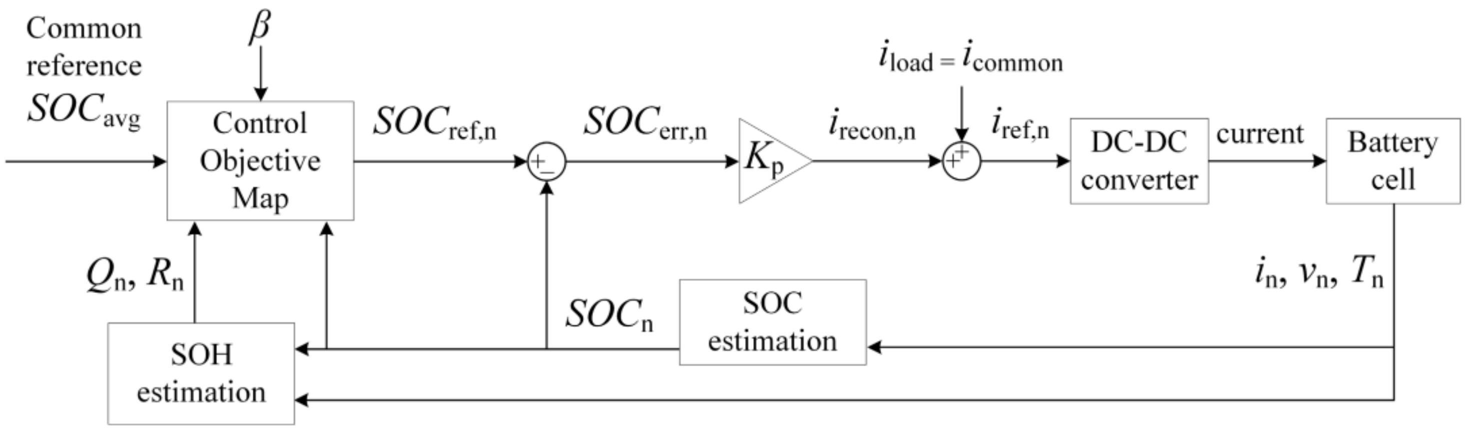
- *Internal resistance measurements* with current pulse methodology
- *Impedance measurement* with EIS (electrochemical impedance spectroscopy)
- *Other measurement methods*: amper hour counting, cycle number counting, destructive test

INDIRECT ANALYSIS:

- *Model based methods*: the characterisation model for the LIB is selected and the corresponding algorithm is initialized to identify model parameters
- *Data driven methods*: measured parameters are combined with the data mining algorithm
- *Hybrid methods*: e.g. direct measurements and model-based methods

The procedure of selecting and commissioning SL LIBs includes five steps:

1) Assessment of the retired battery system based on historical information
2) Disassembly of retired battery (cell/module/pack)
3) Mechanical-electrochemical performance evaluation
4) Sorting and regrouping:

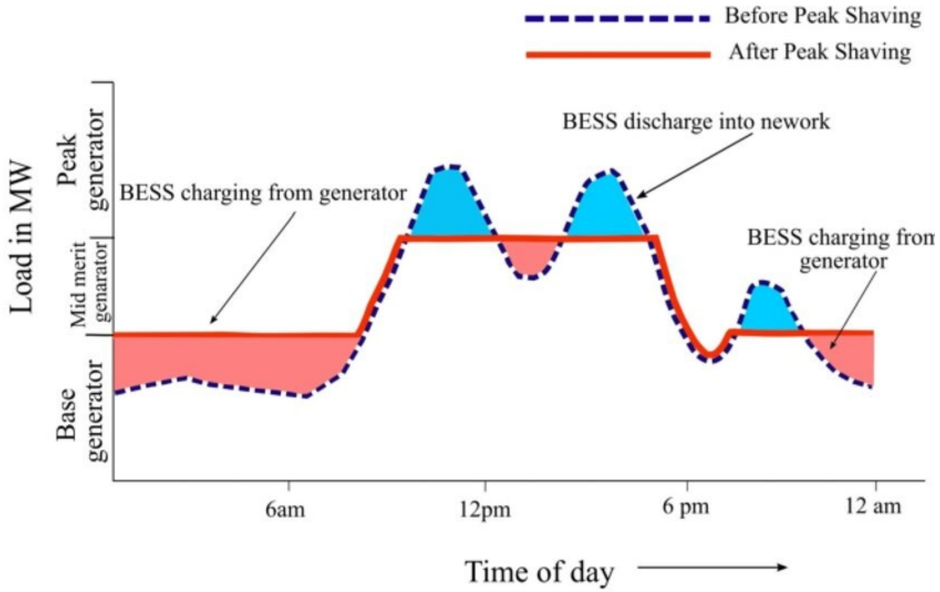


Reconditioning controller to charge and discharge differently cells with a significant variation in cell capacity and obtain a uniform capacity pack. *"Active Reconditioning of Retired Lithium-Ion Battery Packs From Electric Vehicles for Second-Life Applications", Rasheed et al.*

5) Developing control and management strategies for SL

SECOND LIFE APPLICATIONS

- Energy storage systems and grid services
- Microgrids and smart grids
- Low speed EVs
- EV charge stations

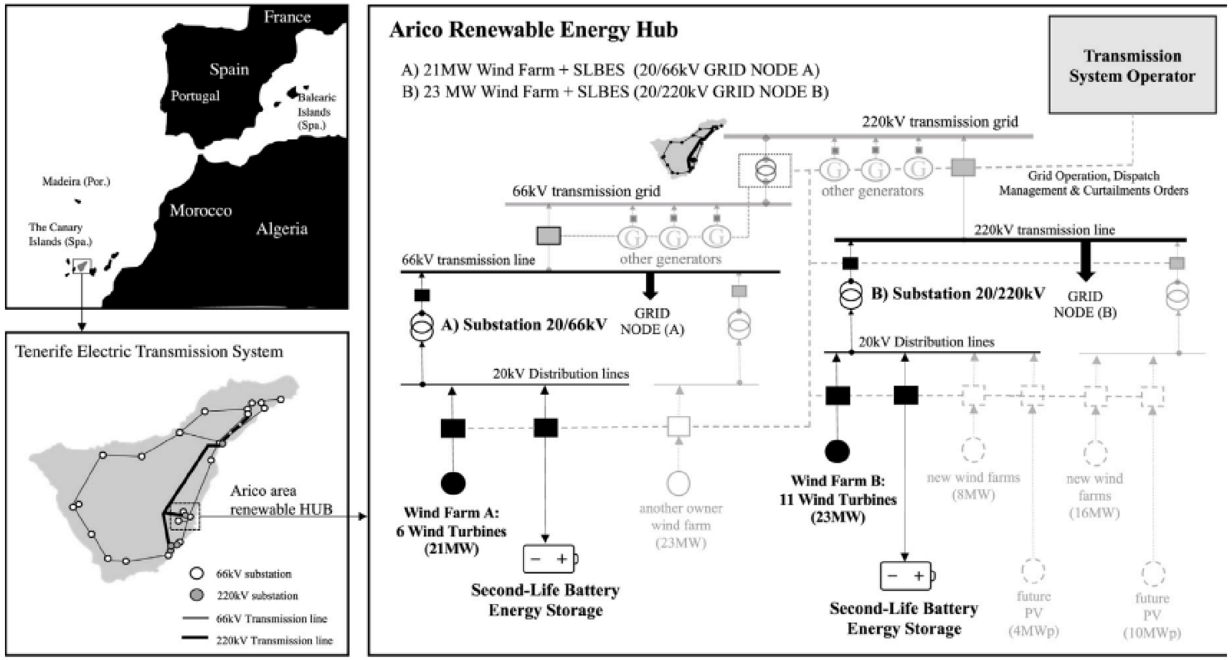


Peak shaving

Smart grid representation

WIND FARM ENERGY STORAGE IN TENERIFE

"Wind farm energy surplus storage solution with second-life vehicle batteries in isolated grids" Lopez et al.



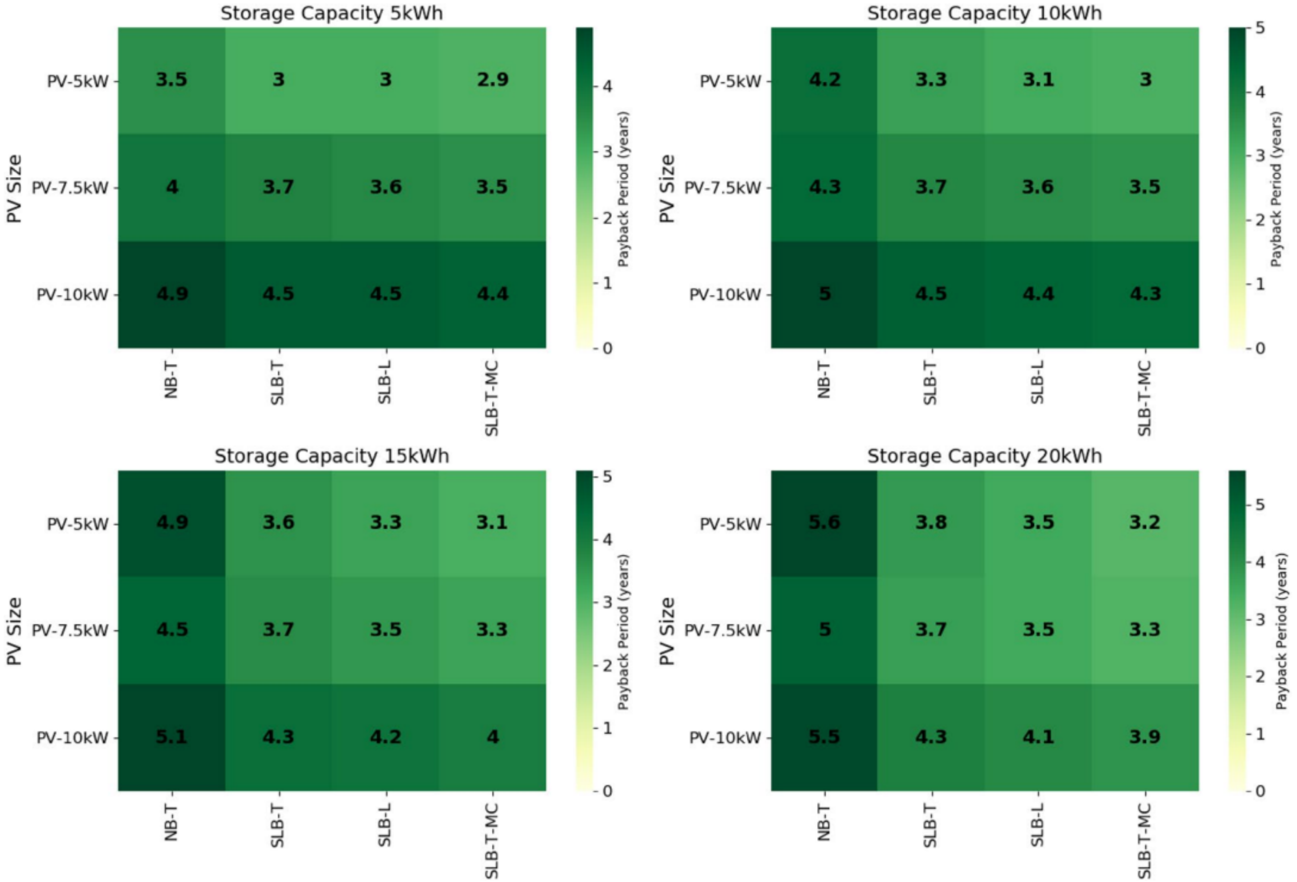
Connection scheme of the wind turbines studied

- ESS with SL batteries to storage the energy from two wind turbines
- Different scenarios considered
- The payback time is always under the lifespan of the installation
- A potential of **28-90 kilotons of CO_2** and 0.7-1.2 kilotons of waste is saved

AFFORDABLE ENERGY ACCESS IN KENYAN SCHOOLS

“Second-life battery systems for affordable energy access in Kenyan primary schools”, Kebir et al.

- In Kenya only 76% (2017) of schools have access to electricity
- SL batteries and solar photovoltaics to provide affordable energy access to primary schools
- Schools will be able to pay back hybrid system costs in a shorter period when SLBs are employed compared to first life ones



Payback period for different scenarios

PIONEER

Stores excess power produced by a **30MW** solar photovoltaic plant powering the Leonardo da Vinci airport in Fiumicino (Rome).

MELILLA BESS

78 spent battery packs provided by Nissan are employed for the storage system of the thermal power plant in Melilla, Spain. The size is **7 MWh** and the expected lifetime is around 6 years.

Melilla power plant and energy storage equipment

PV ELECTRIC VEHICLE CHARGING STATION

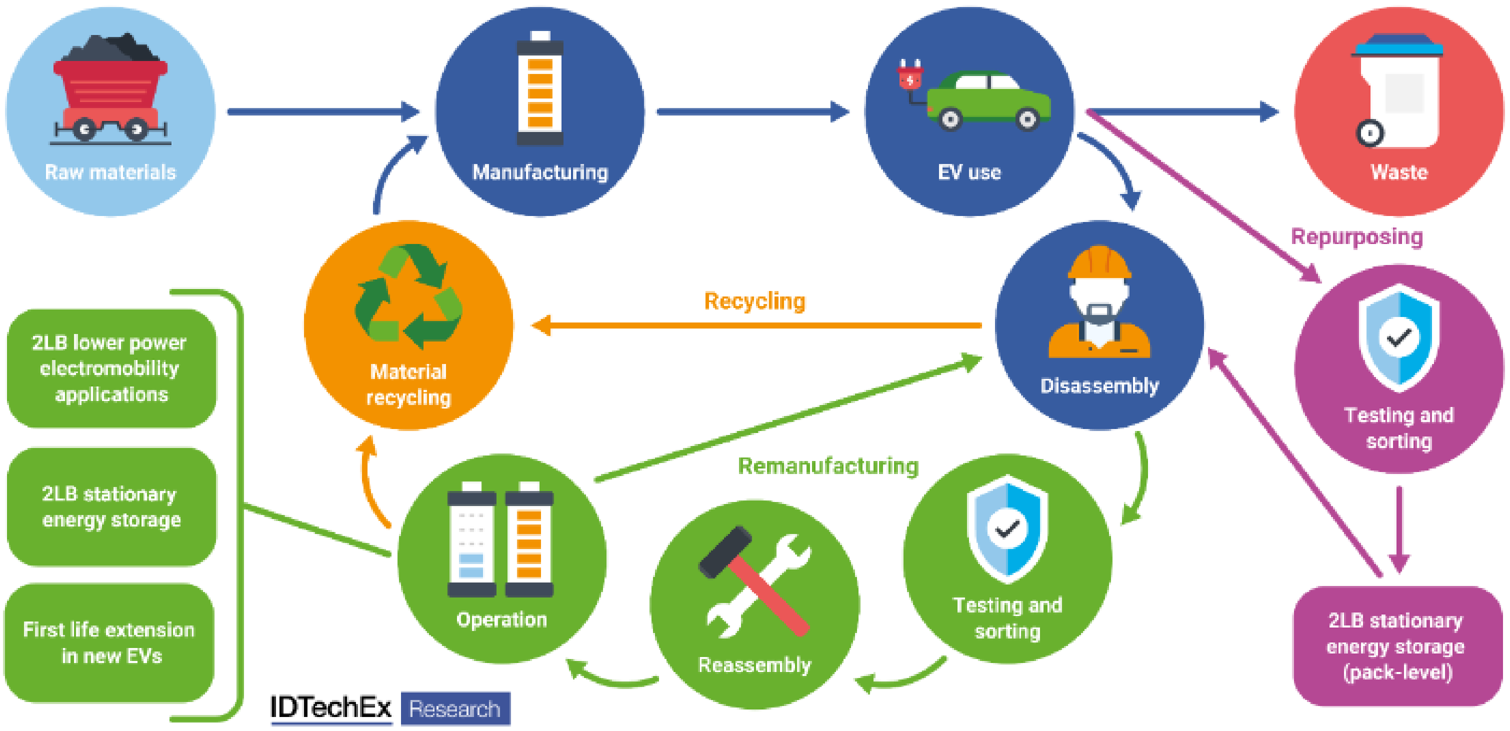
Study on the feasibility of a charging station for EVs in the ENEA Research Center "la Casaccia" in Rome. The station is powered by photovoltaic panels integrated with a SL energy storage system. "*PV assisted electric vehicle charging station considering the integration of stationary first- or second-life battery storage*", *Bartolucci et al.*

Landafors hydropower plant storage system

LANDAFORS HYDROPOWER PLANT

The Swedish energy company Fortum modernised the Landafords hydropower plant with a SL BESS using batteries from Volvo Cars.

Second-life LIBs embrace circular economy, which is a model of producing and consumption, involving sharing, leasing, reusing, repairing, refurbishing and recycling existing products as long as possible to extend their lifespan and reduce waste.



SECOND LIFE LIBs BENEFITS

ENVIROMENTAL

- Reduced greenhouse gas emissions thanks to:
  - Renewable energy storage
  - Minimized energy spills
  - Delayed mining and manufacturing process
- More safeguard of habitats threaten by mining
- Waste saving

ECONOMIC

- Saving
- Affordable BESS

SOCIAL

- Working conditions in some mining region

POLITICAL

- Reduced geopolitical risk linked to mineral extraction

The estimated capability of **100-300 GWh** each year coming from retired EVs batteries represent an enormous potential.

Thank you for the attention