



ANALYSIS OF THE  
REMAINING USEFUL  
LIFE OF ELECTRIC  
VEHICLE BATTERIES  
AND DEVELOPMENT  
OF SECOND-LIFE  
SOLUTIONS

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# → Second-life EV batteries



## First-life conditions

Extreme operating temperatures, hundreds of partial cycles a year, and changing discharge rates



## Battery disposal

By 2040, 3.4 million kg of LiBs that were previously used in EVs will end up in landfills

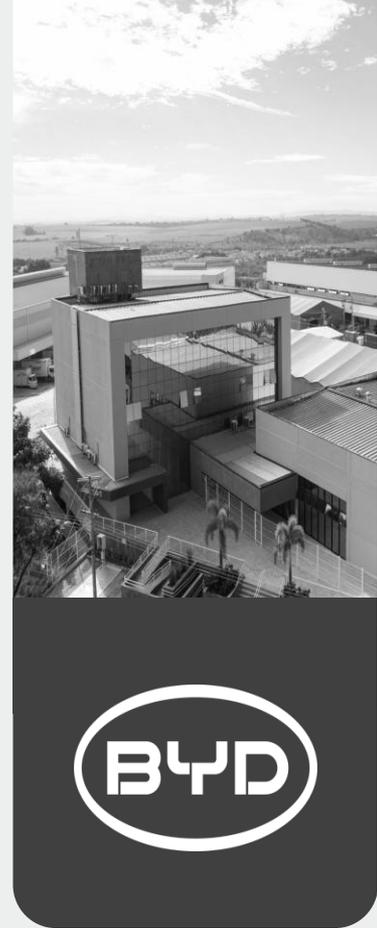
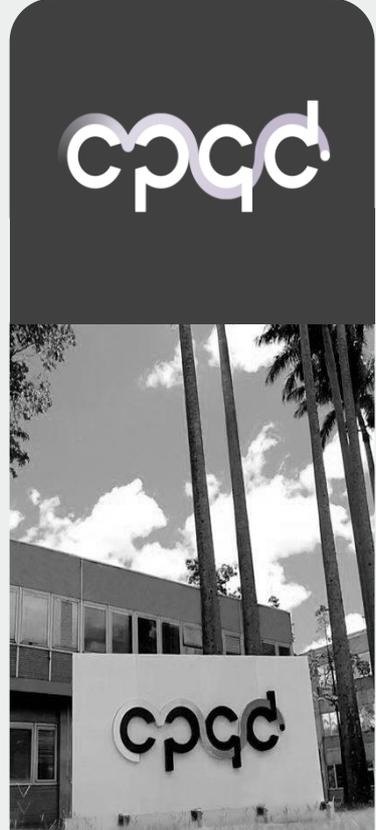


## Second-life batteries

Batteries are expected to retain between 70 and 80 percent of their available capacity after being removed from electric vehicles

# R&D Project CPFL “Second-life”

The objective is to develop energy storage solutions using second-life batteries that have already been degraded during use in EVs



# Topics to be discussed

As an overview of the methodologies conceived and the main achieved results during the realization of this project, the following topics will be presented today:



Cell characterization



Cell selection methodology



Cycling tests results



Algorithm development



# UL 1974

STANDARD FOR  
EVALUATION OF REUSE OF  
BATTERIES

Specifies that a series of tests must be performed to ensure that the second-life lithium-ion cells are all in appropriate safety and performance conditions for reuse in a new application

# 500

Second-life cells

# LFP

Lithium iron  
phosphate

# 270 Ah

Nominal capacity

2% below 60%

3% above 80%

12% between 70% to 79%

83% between 60% to 69%

# Electrochemical Impedance Spectroscopy (EIS)

A well-established technique that is widely used in laboratories to study the degradation of lithium-ion batteries. The application of low amplitude sinusoidal currents in a wide frequency range distinguishes several degradation processes.

Resistance or Impedance

Considering that a lithium cell is a complex structure, it is questionable if a single measurement would be able to give us enough information about the degradation of a lithium-ion battery

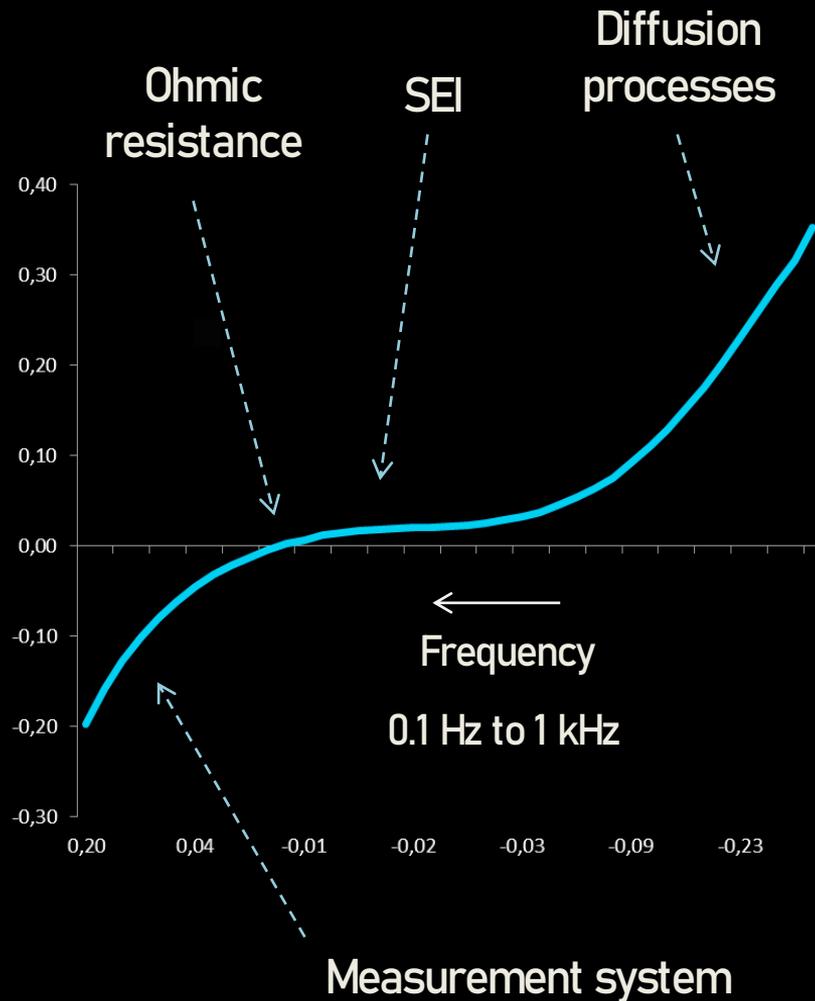
EIS

The EIS is able to provide more accurate results than those obtained only with measurements at a specific frequency, such as resistance or impedance measurements



# Nyquist diagram

Finding quantitative features of individual cell deterioration while working with this volume of data may be difficult. This motivated the development of methods for analyzing the entire frequency spectrum.



Cell Selection  
Algorithm



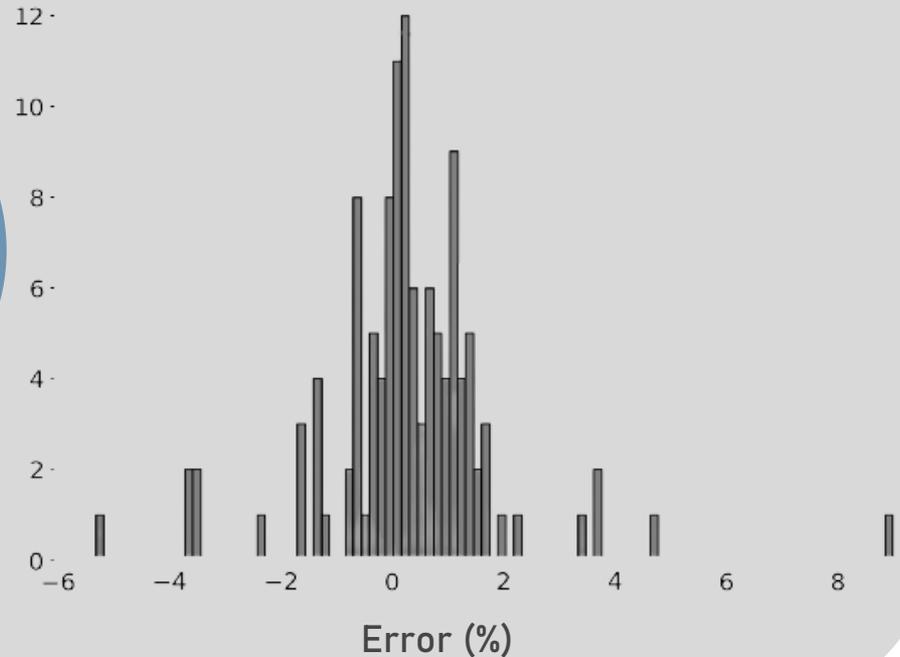
Inference system  
based on **Fuzzy logic**

Resistance  
0,4 Hz  
Corr = 0,5

Reactance  
50 Hz  
Corr = 0,7

70%

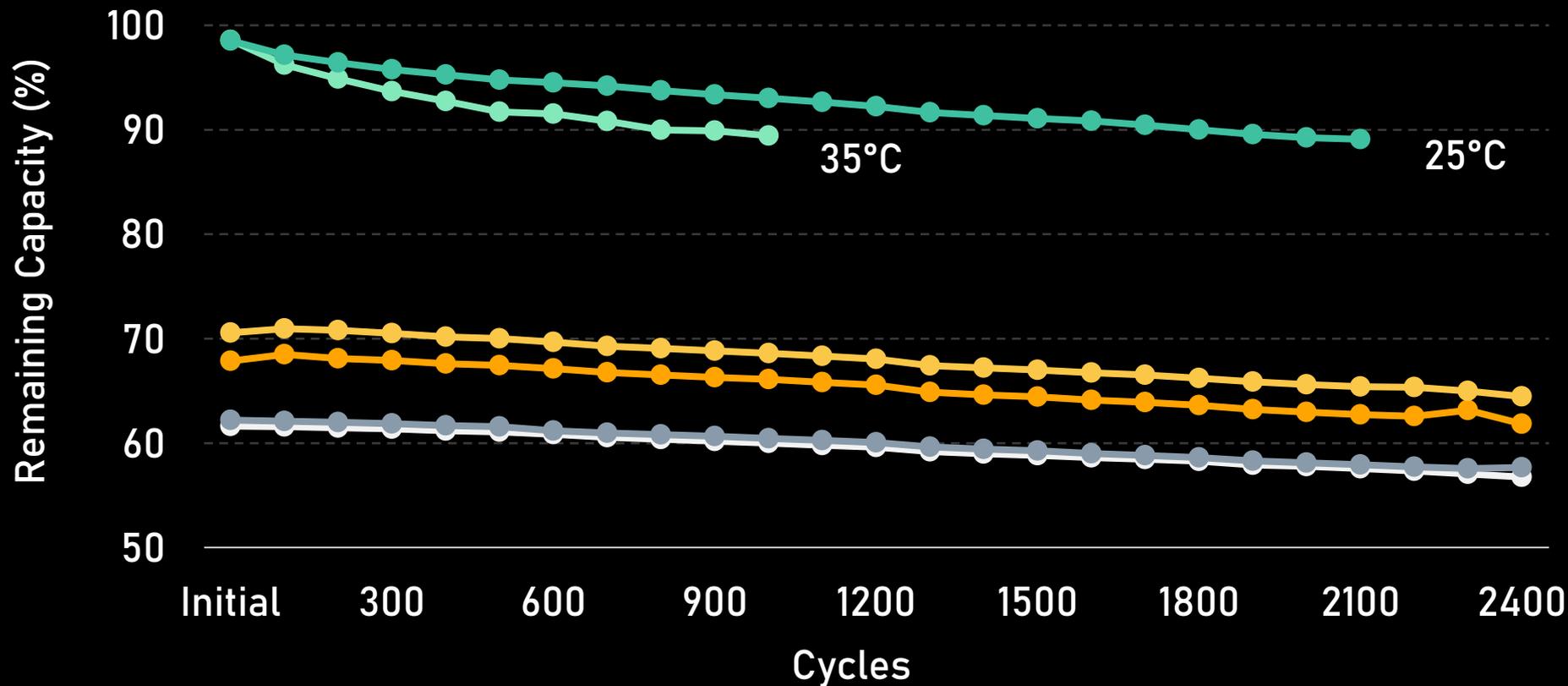
Training data





# Cycling Results

Performed according to the procedures described in IEC 62620 - Stationary Application



# 48 Vdc

Energy storage  
device

using second-life  
cells

# RUL

Remaining Useful Life  
algorithms

are integrated  
into the BMS

1

Unscented Kalman Filter (UKF) associated with a generic model capable of reproducing the behavior of the battery aging curve

2

The algorithm checks the battery's SoH and configures the initial states of the filter

3

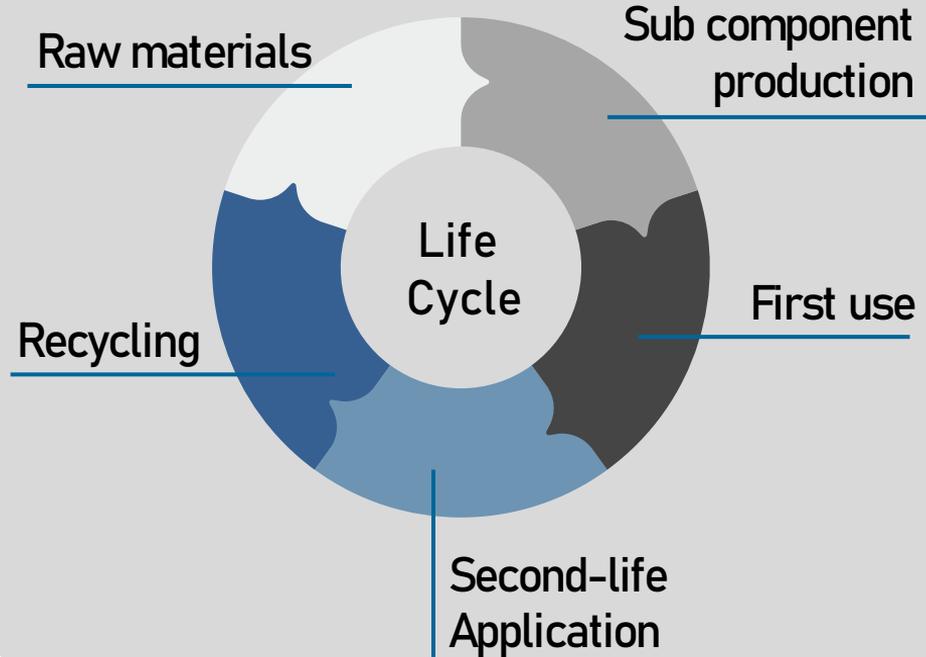
The UKF estimates the parameters of the generic model in every iteration

4

The algorithm anticipates the battery's aging behavior cycle by cycle up till the end of its usable life for a specific application

# Project results

➔ The development of an energy storage solution from second-life cells will promote the technological advancement of the national industry





# Challenges to be addressed



Not all EV battery cells degrade uniformly



One way to address this problem is to analyze the data stored in the BMS



Data-based algorithms to estimate the remaining capacity and lifespan of second-life batteries



# Let's get in touch

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