

Automotive Second-Life Batteries: Challenges and Opportunities

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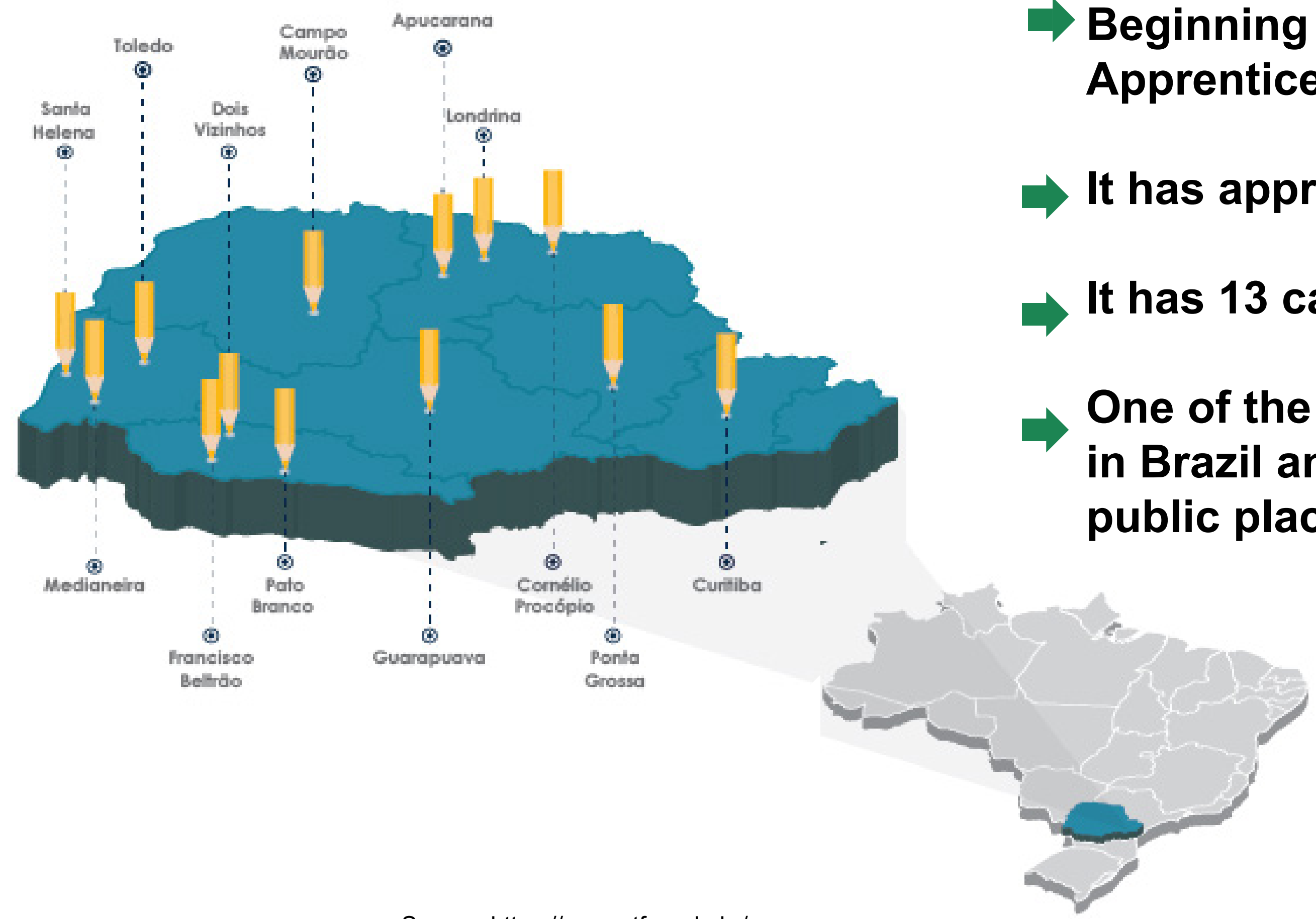
Federal University of Technology - Paraná

Presentation at the Webinar 2026 - SOBRAEP / PELS



April 30th, 2026

➔ About UTFPR



- ➔ **Beginning its work in 1909 as the 'School of Apprentice Artisans';**
- ➔ **It has approximately 35,000 students;**
- ➔ **It has 13 campuses across Paraná State;**
- ➔ **One of the largest multi-campus universities in Brazil and has the largest offering of public places in engineering courses in the.**



UTFPR - Câmpus Ponta Grossa

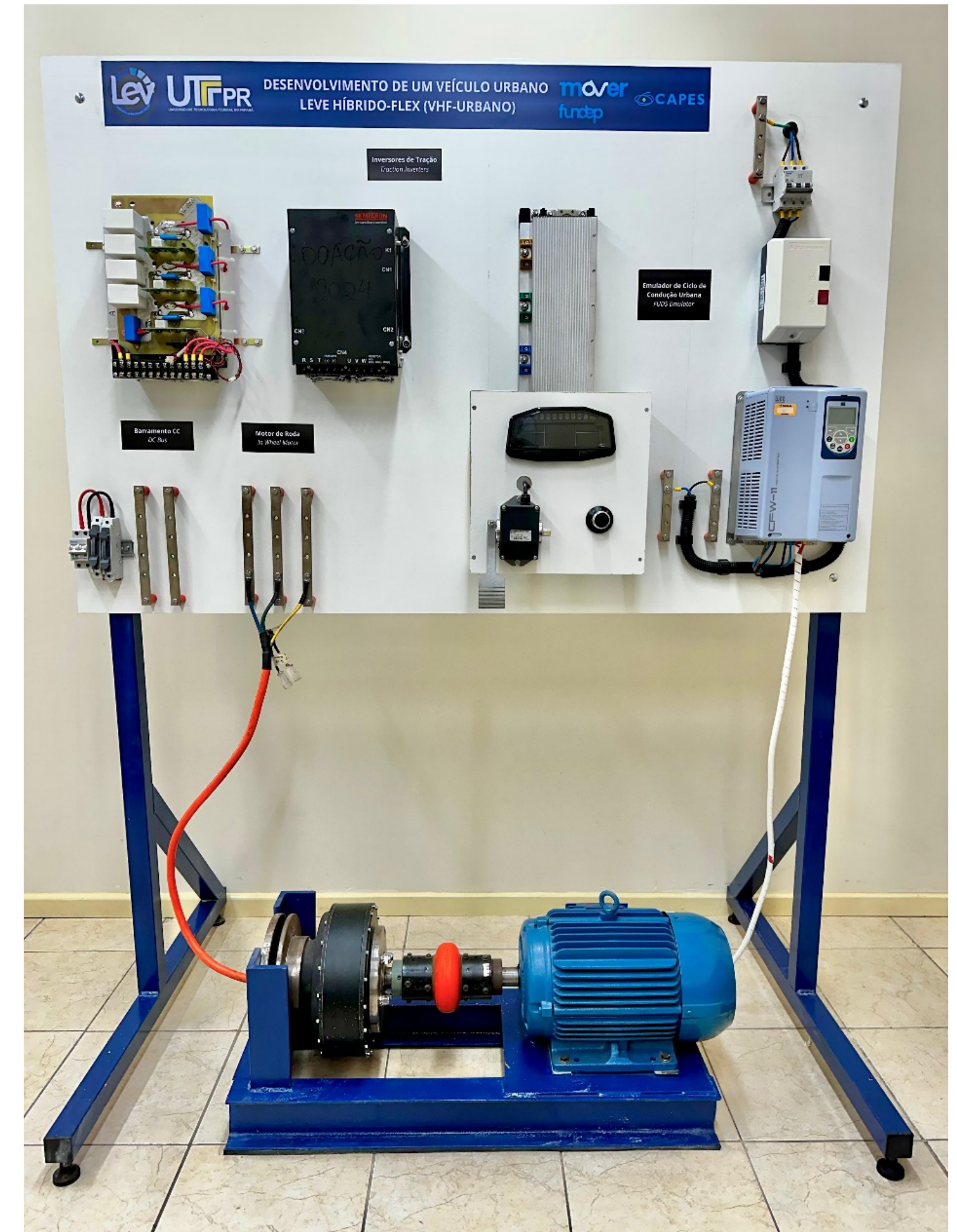
About UTFPR Campus Ponta Grossa

- ➔ It has 11 under graduation courses;
- ➔ It has 8 graduate programs with 8 Master Degree courses and 2 Doctorate Degree courses;
- ➔ The Department of Electrical Engineering offers:
 - Bachelor of Electrical Engineering;
 - Bachelor of Mechatronics Engineering;
 - Industrial Automation Technology Degree;
 - Master in Electrical Engineering.



Source: <https://www.utfpr.edu.br/>

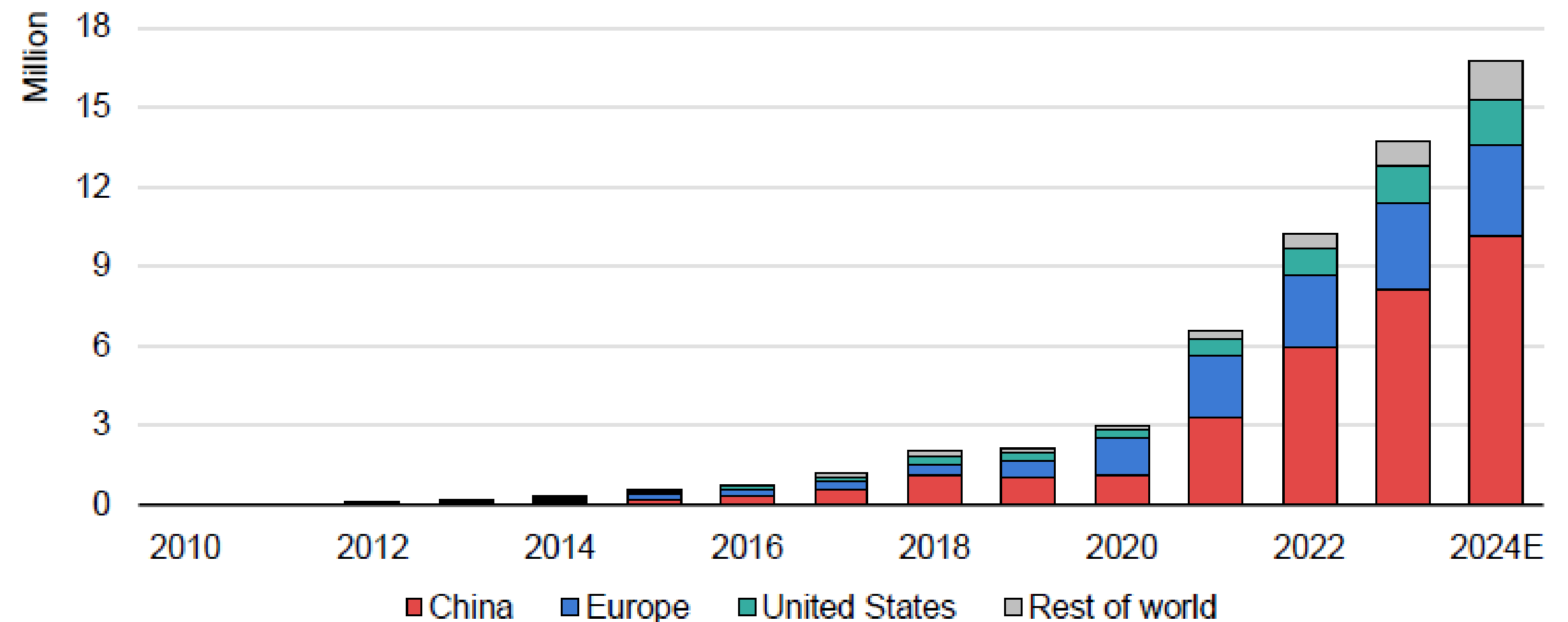
- ➔ **Vehicle Electrification Laboratory:**
- Automotive Batteries;
 - Automotive Power Electronics;
 - EV Charging Infrastructure.



• The Age of Electrification and Its Challenges - World

- ➔ Exponential growth of the Electric Vehicle (EV) market
- ➔ Increase in the volume of batteries reaching end of primary life
- ➔ Significant residual capacity (70–80%) in EV batteries
- ➔ Environmental impact of disposal and the need for sustainable solutions

Electric car sales, 2010-2024



IEA. CC BY 4.0.

Note: 2024 sales ("2024E") are estimated based on market trends through the first quarter of 2024.

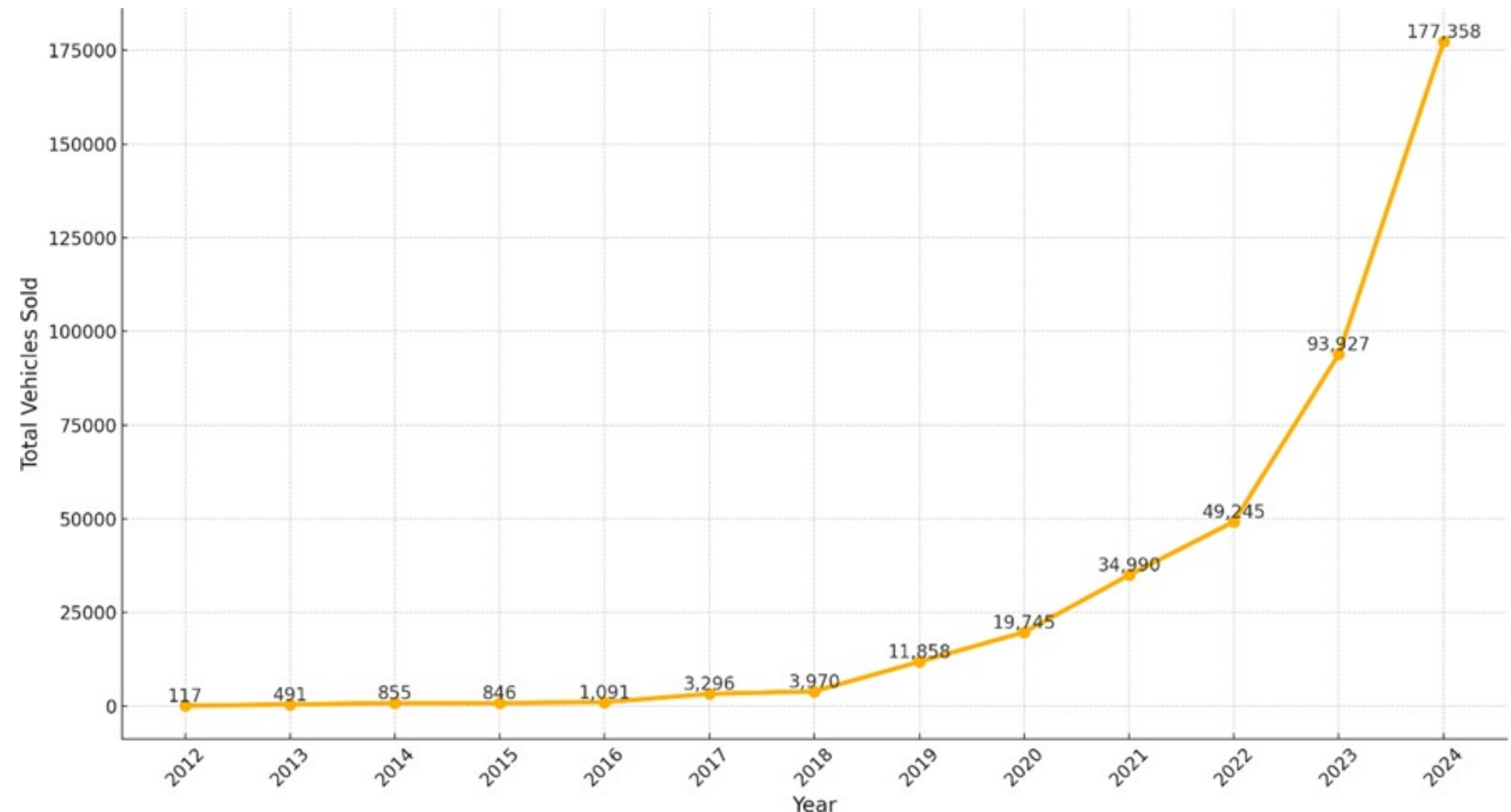
Source: IEA analysis based on data from EV Volumes (2024) and the China Passenger Car Association (2024).

Source: <https://www.iea.org/reports/global-ev-outlook-2025>

• The Age of Electrification and Its Challenges - Brazil

➔ Annual Growth Of Electrified Light Vehicles Sales in Brazil (2012 - 2024)

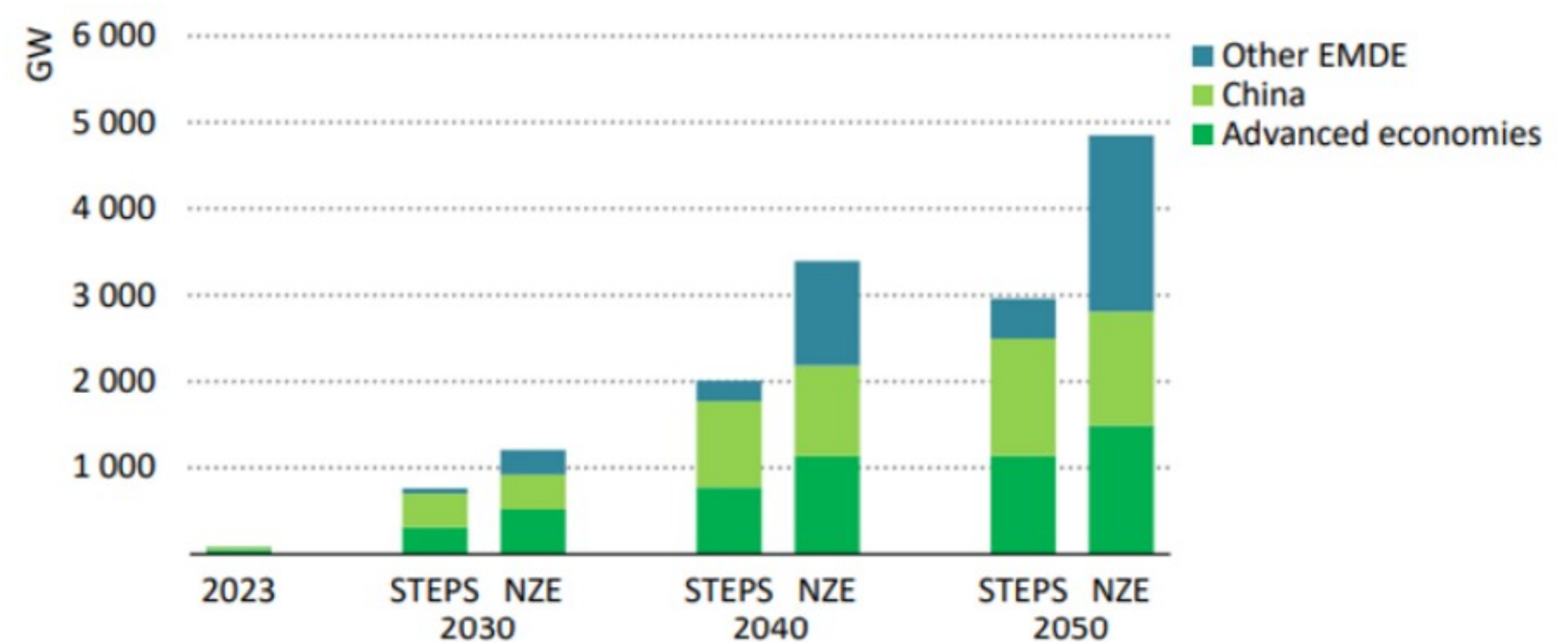
➔ There is strong market attractiveness in the sale of hybrid EVs driven by the successful national strategy of FLEX-FUEL hybrid vehicles



Source: <https://abve.org.br/abve-data/eletrificadosmhev/>

• Battery Energy Storage System (BESS) – Growing Market

- ➔ Growth in battery energy storage system capacity
- ➔ Increase in new solutions
- ➔ Rising demand for renewable energy
- ➔ Application potential



Source: <https://www.iea.org/commentaries/scenarios-in-the-world-energy-outlook-2025>

- **Second-life BESS – A New Solution**

- ➔ **Economic: Most of the manufacturing cost has already been “paid” during the battery’s first life in a vehicle.**
- ➔ **Environmental: Lower demand for raw materials, reduced carbon footprint, and waste reduction.**
- ➔ **Technical: Modular and scalable architecture and lower performance requirements outside EVs.**

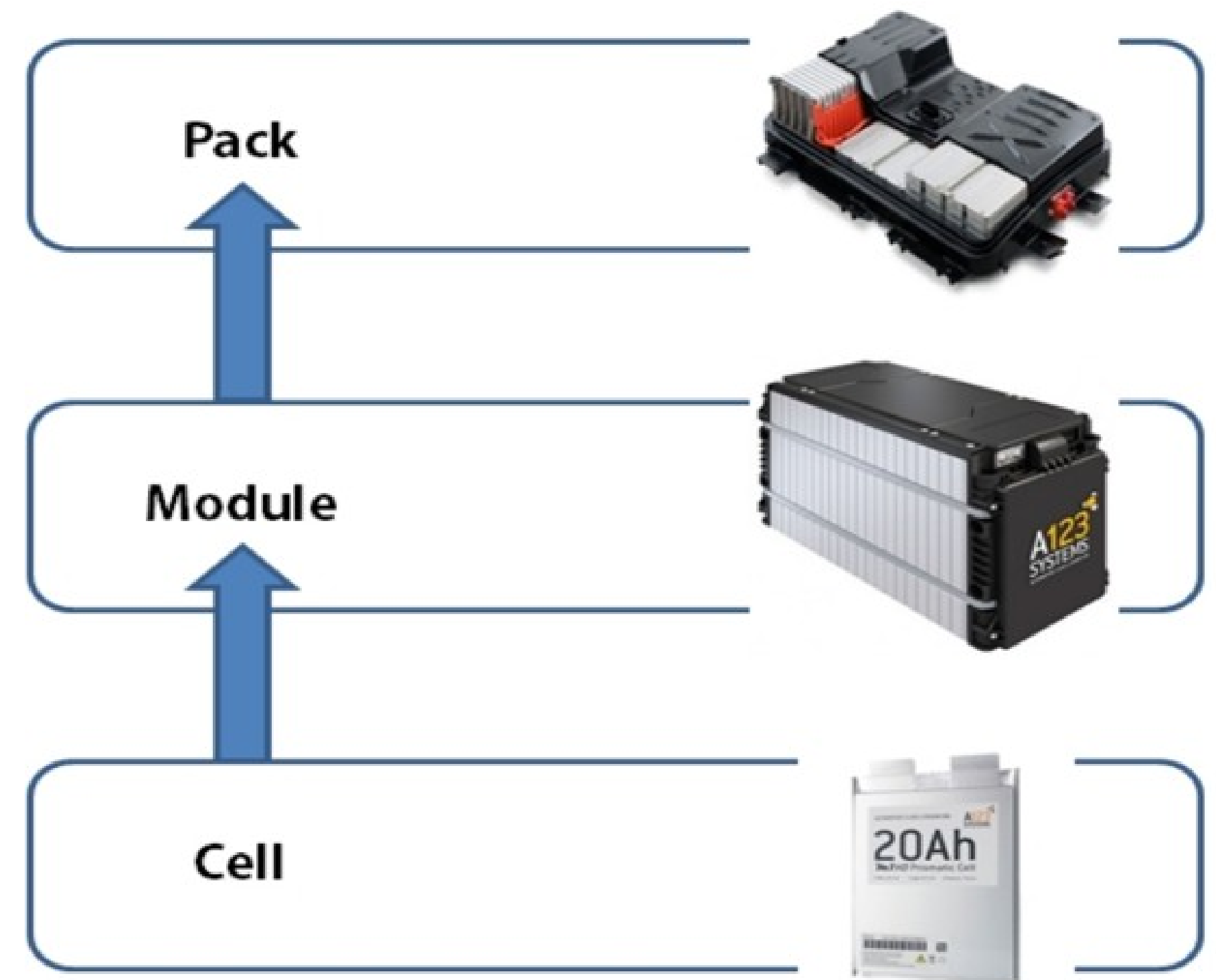
- EV Battery Assembly

- ➔ Cell-Module-Pack Structure.

- ➔ Cells can have different formats.

- ➔ Modules help simplify manufacturing, improve serviceability and manage thermal behavior.

- ➔ Wide variety of arrangements.



Source: Amir Khajepour, M. Saber Fallah, and Avesta Goodarzi, Electric and Hybrid Vehicles: Technologies, Modeling and Control—A Mechatronic Approach (New York: John Wiley & Sons, 2014)

- EV Battery Assembly

- ➔ Types of Cell Packaging

Cylindric Cell



Prismatic Cell

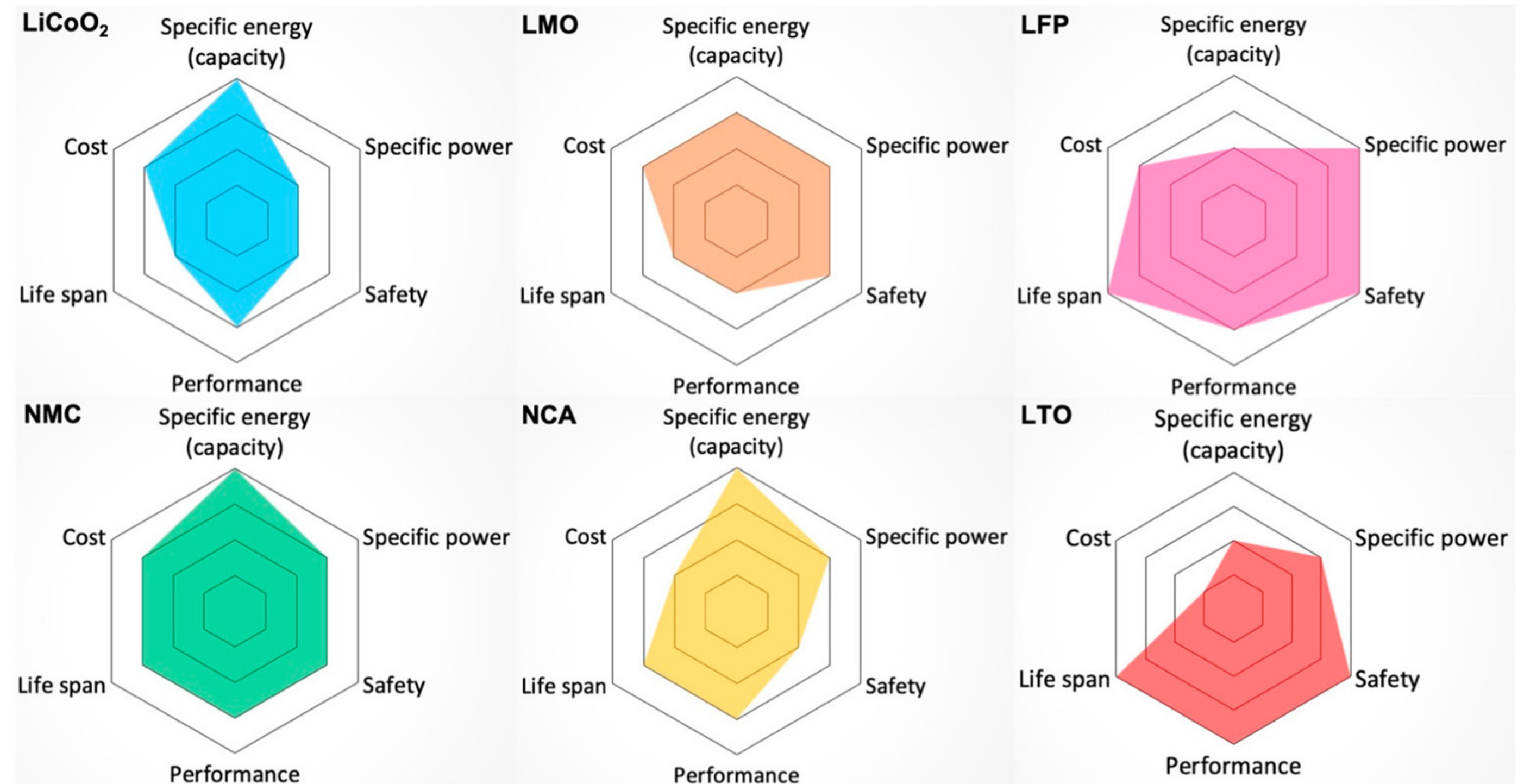


Pouch Cell



• EV Battery Assembly

➔ **Types of Cell Chemistry**
- NMC, LFP, and NCA
are the most commonly
used chemistries in
electric vehicle batteries.

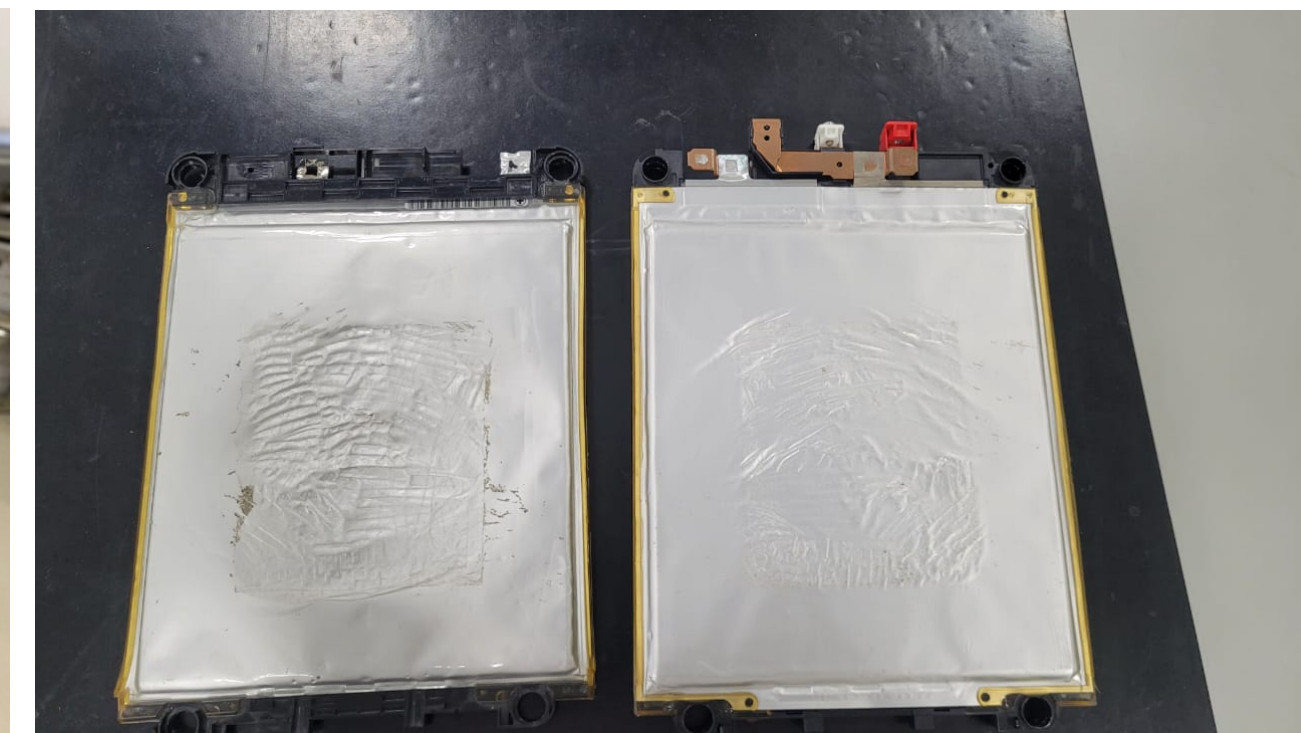
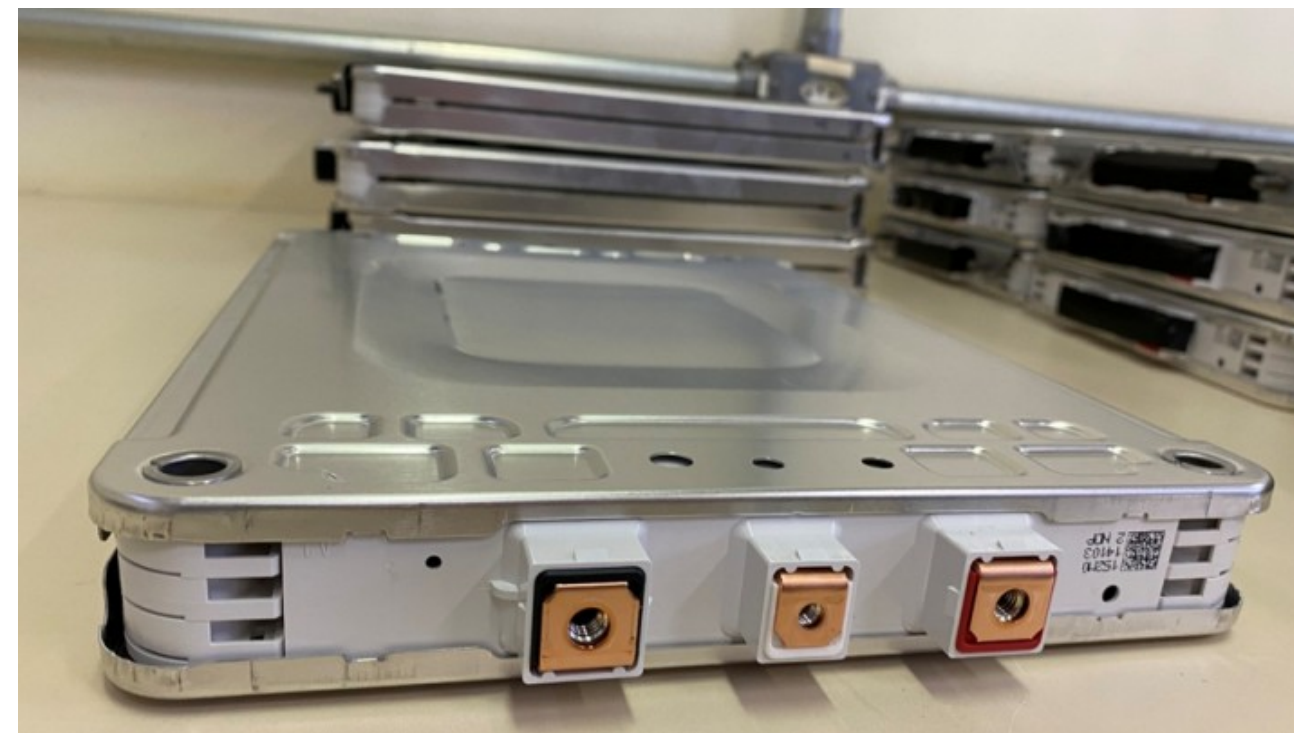


➔ Automotive Batteries

- EV Battery Assembly

- ➔ Renault Kangoo Z.E.

- Battery pack: 48 modules;
- Module: 4 cells (2S2P).

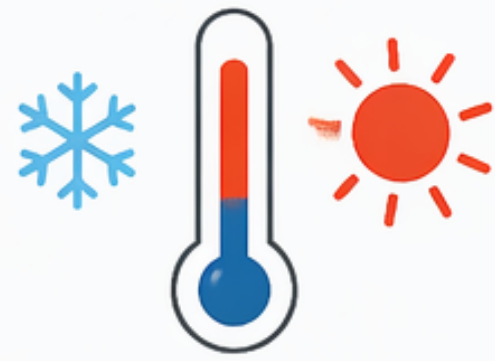


• Operating Conditions of Batteries in Electric Vehicles



MORE THAN 1,000 CHARGE CYCLES

They support more than 1,000 charge cycles.



WIDE TEMPERATURE VARIATION

They are exposed to a wide range of temperature variations.



HIGH DEPTH OF DISCHARGE (DOD)

They undergo high depth of discharge.



FAST CHARGING

They are subjected to fast charging.



AS A RESULT,

manufacturers recommend replacing the batteries when their capacity reaches **70% to 80%**, as this represents a loss of vehicle range (it is estimated that this occurs after 12–15 years of vehicle use).

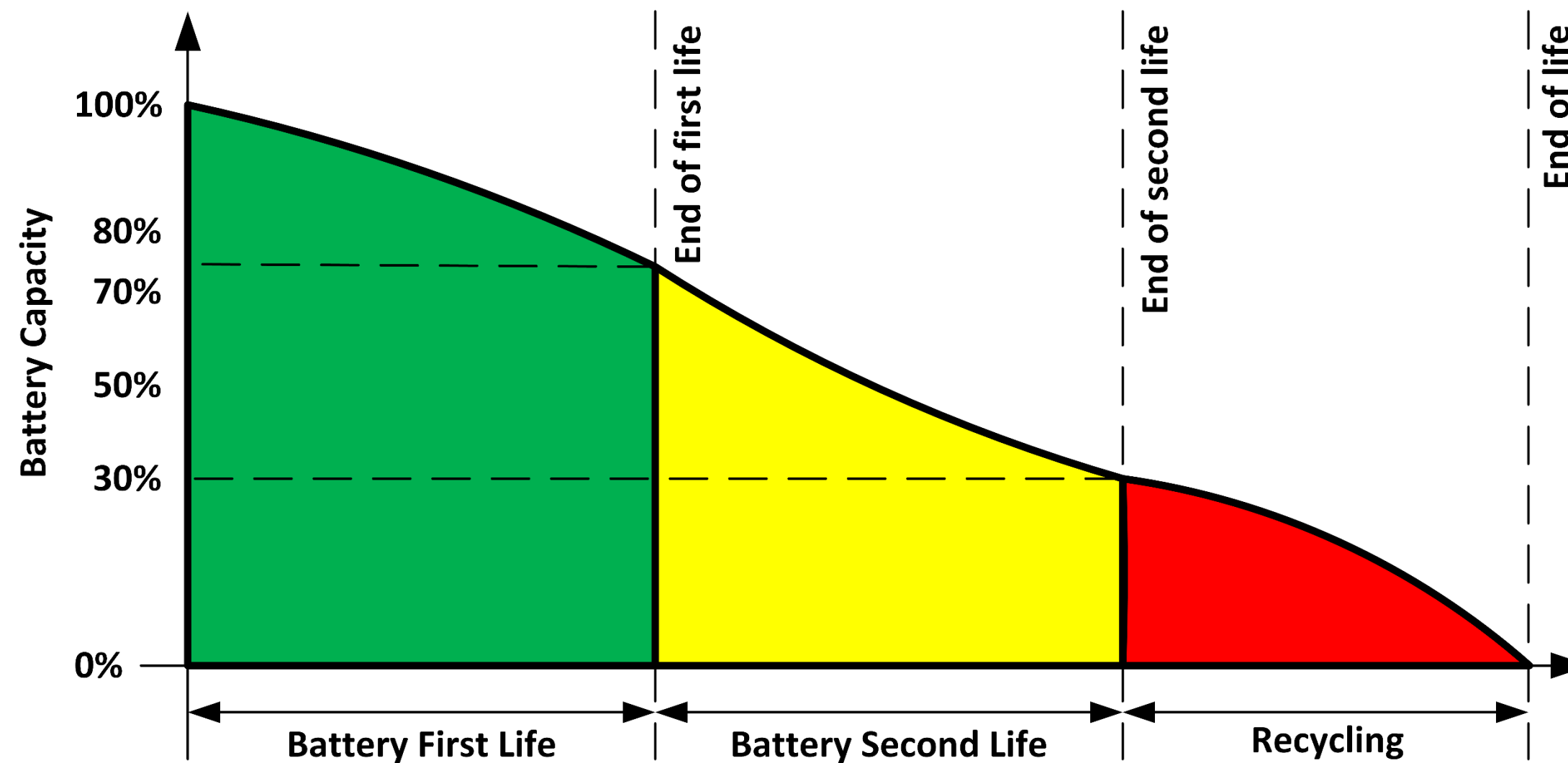
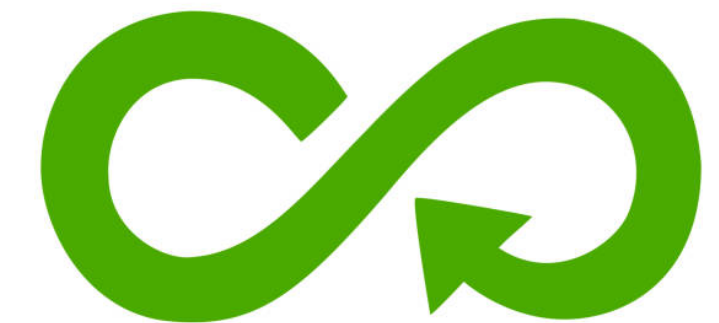
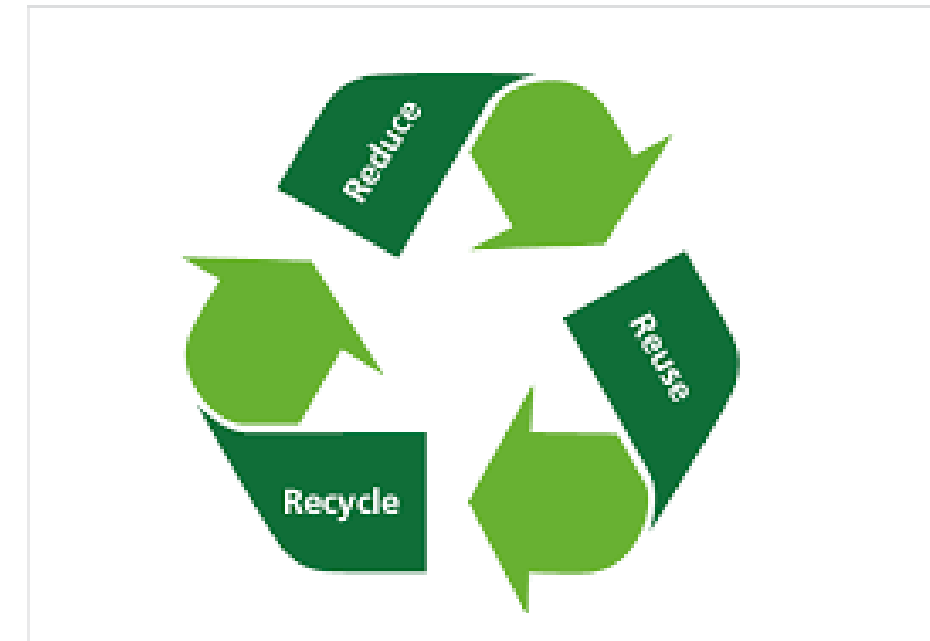


OF VEHICLE USE

➔ Second-life Batteries

- **Definition**

➔ It is the use of the remaining capacity of a vehicle battery in other applications, preferably stationary applications.



➔ Second-life Batteries

• How to deal with it?

➔ A three-step approach:

- First step: battery pack disassembling;



- Second step: classification (estimating SoH);



- Third step: BESS designing.



➔ Second-life Batteries

- **First Step: Why not use electric vehicle battery packs directly, without disassembly?**

- ➔ **The vehicle's Battery Management System (BMS) is proprietary (OEM-specific)**

- It is designed for communication with the vehicle (CAN, ECU, etc.);
- Related problems: fail to start , enter protection mode, operate unsafely, etc.

- ➔ **Performance can be limited by the weakest module/cell**

- Modules exhibit uneven degradation (heterogeneity)

- ➔ **Safety Concerns**

- Increased risk of localized failures;
- Increased risk of thermal runaway.

- ➔ **Lack of Design Flexibility**

- Voltage and capacity levels can not be changed, not matching BESS requirements.



➔ Second-life Batteries

• First Step: Battery Pack Disassembling

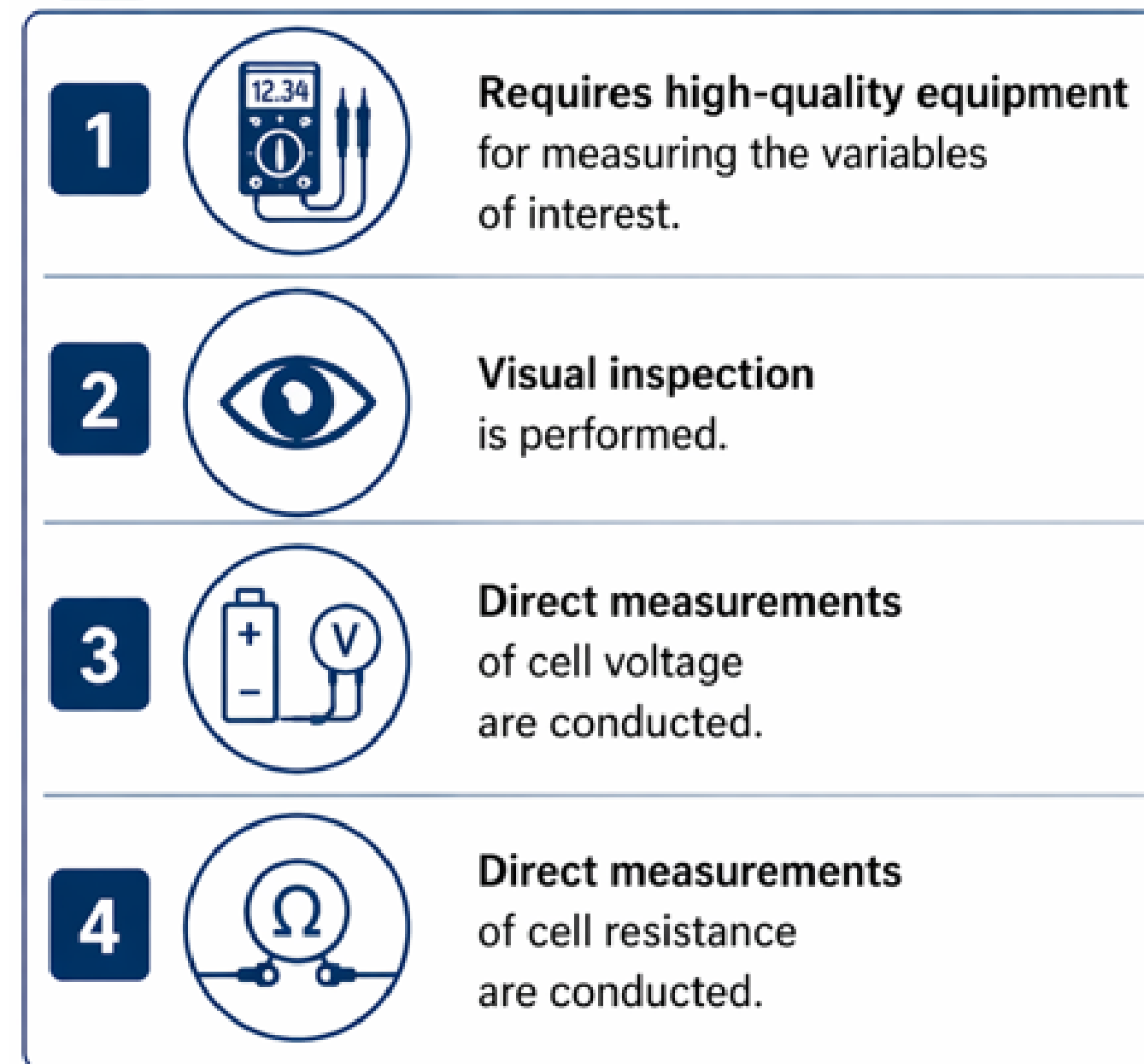
➔ Stage dedicated to the safe and controlled disassembly of battery packs, ensuring the integrity of components and compliance with technical and safety requirements.




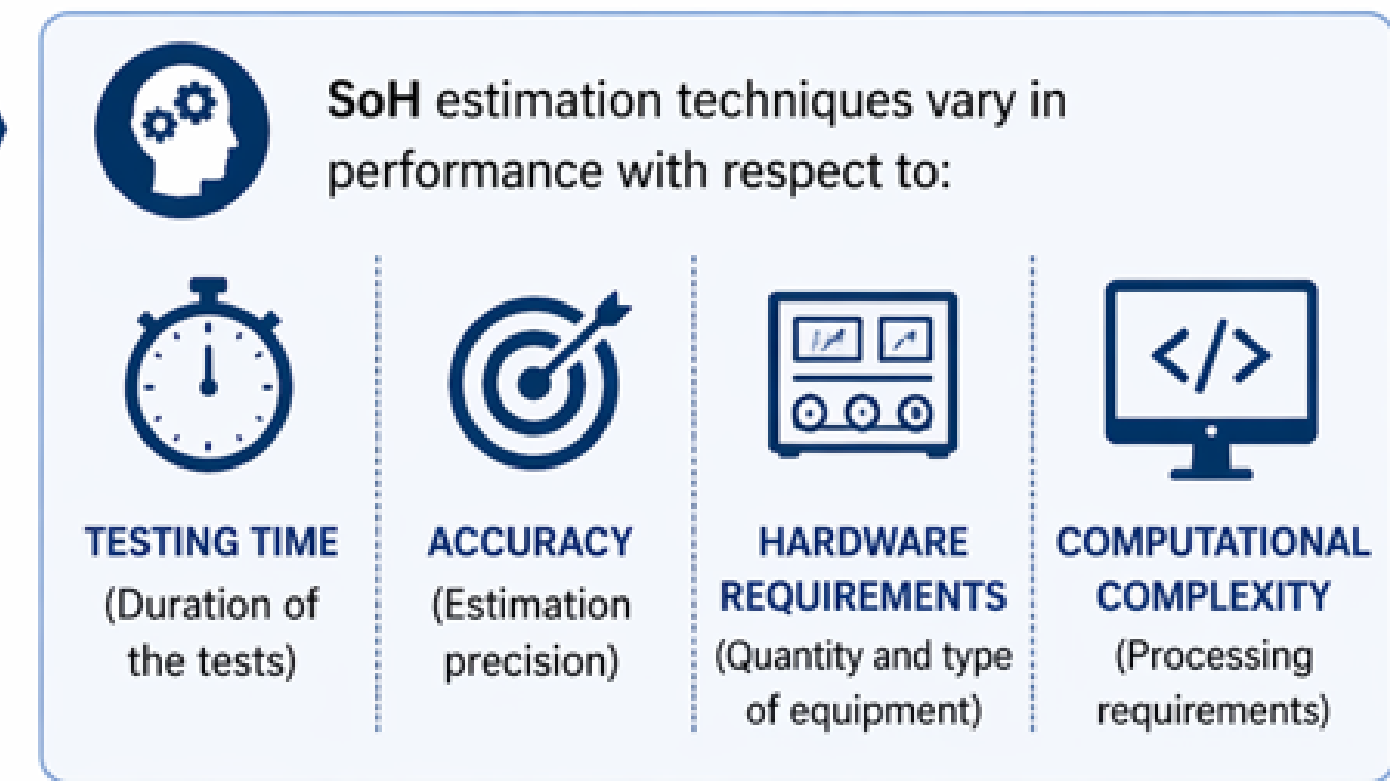
	1	Lithium batteries are classified as hazardous materials and require specialized transportation.
	2	Adequate facilities are required to support the disassembly process.
	3	The use of insulated tools and equipment is mandatory.
	4	Personnel involved in disassembly operations must receive appropriate training.
	5	The use of personal protective equipment (PPE) and collective protection measures (CPE) is required.
	6	The process is predominantly manual, with significant limitations to automation.

• Second Step: Classification (Estimating SoH)

➔ Stage dedicated to assessing the aging level of the modules. The extracted modules are evaluated and classified based on electrical, thermal, and state-of-health (SoH) criteria, aiming to determine their suitability for second-life applications.

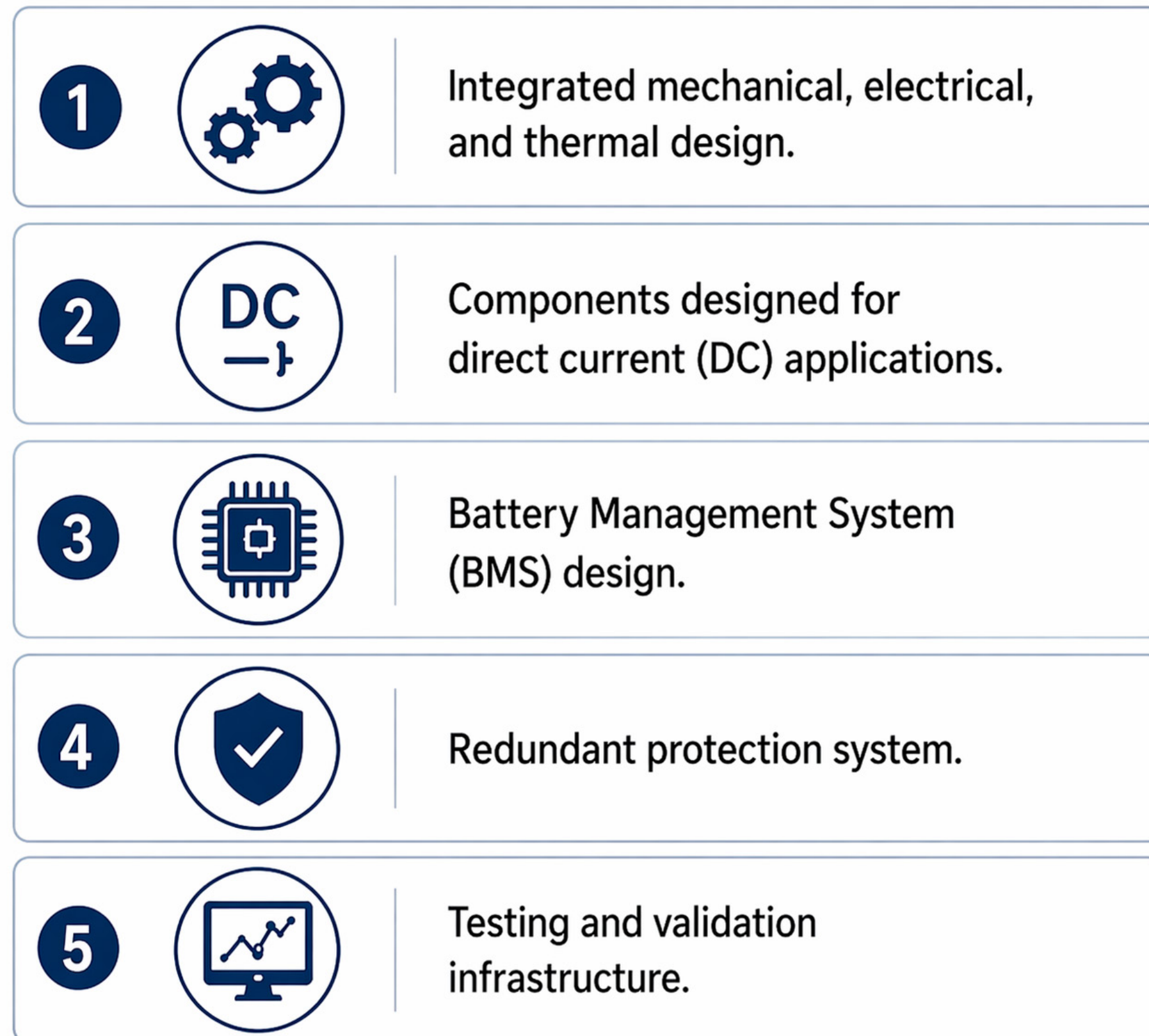


 However, the most important parameter for determining the cell aging level, the state of health (SoH), cannot be measured directly and must be estimated.



• Third Step: BESS Designing

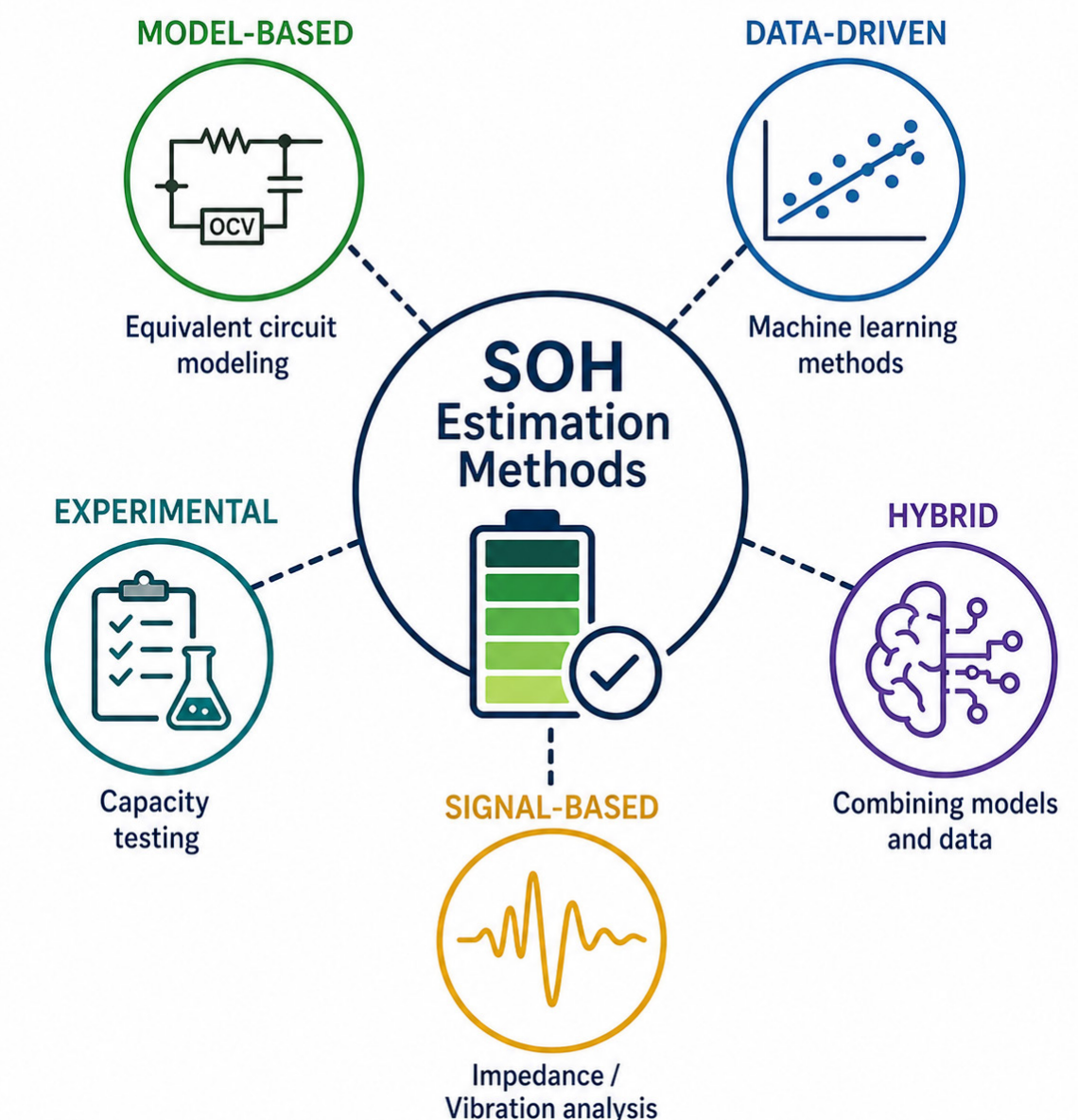
➔ At this stage, the qualified modules are integrated into a prototype battery energy storage system (BESS), enabling the technical, operational, and economic validation of the proposed solution.



- **State-of-Health (SoH) Estimation**

➔ SoH estimation methods can be categorized into the following main groups:

- **Direct Methods (Measurement-Based)**
 - E.g.: Internal Resistance, Coulomb Counting
- **Model-Based Methods**
 - E.g.: Equivalent Circuit Model (ECM), Kalman Filter
- **Data-Driven Methods**
 - Artificial Neural Networks (ANN), Machine Learning
- **Hybrid Methods**
 - ECM + ANN
- **Advanced Diagnostic Methods**
 - Electrochemical Impedance Spectroscopy (EIS)



- **State-of-Health (SoH) Estimation**

- ➔ **Internal Resistance Method**

- **Offline method;**
- **Requires precision equipment to measure internal resistance;**
- **It is based on an empirical expression and may present significant error for a given cell type;**
- **Depends on the knowledge of the internal resistance of a new battery, which can be a limiting factor for second-life applications;**
- **Fast to execute, but with low accuracy.**

$$SoH_{\%} = \frac{R_{EOL} - R_{CELL}}{R_{EOL} - R_{NEW}} \cdot 100\%$$

$$R_{EOL} = 160\% \cdot R_{NEW}$$

- **State-of-Health (SoH) Estimation**

- ➔ **Coulomb Counting Method**

- **Offline method;**
- **It is based on counting the charge delivered (during the charging process) or withdrawn (during the discharging process) from the cell;**
- **The implementation algorithm of this method does not require high computational effort;**
- **Slow to execute, but with high accuracy.**

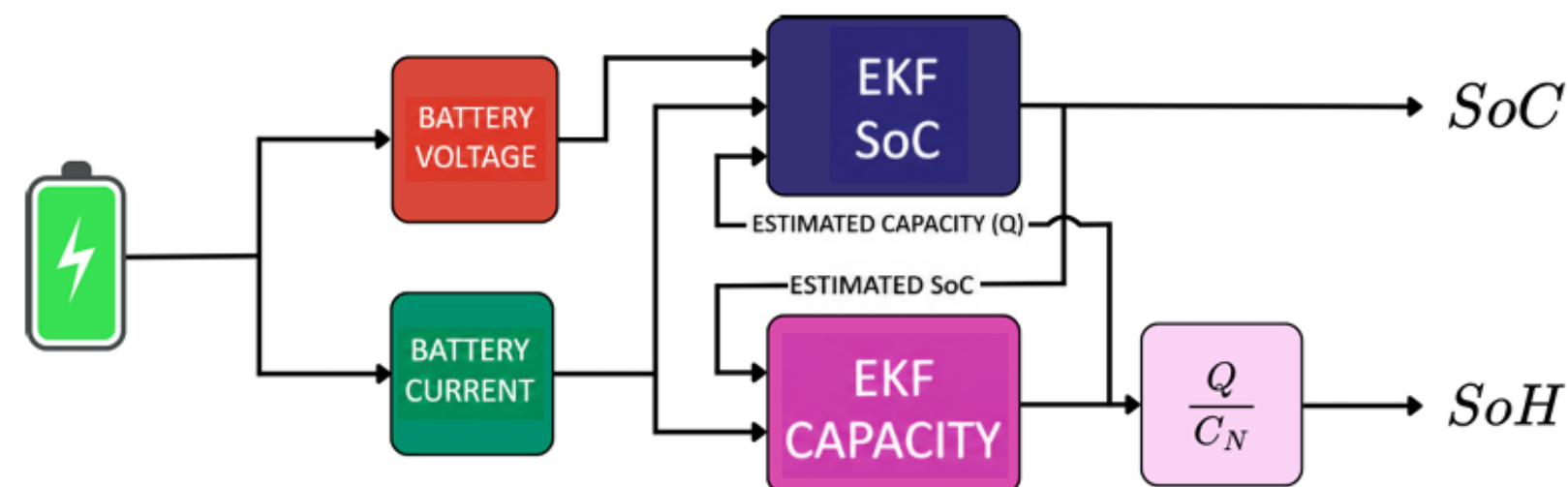
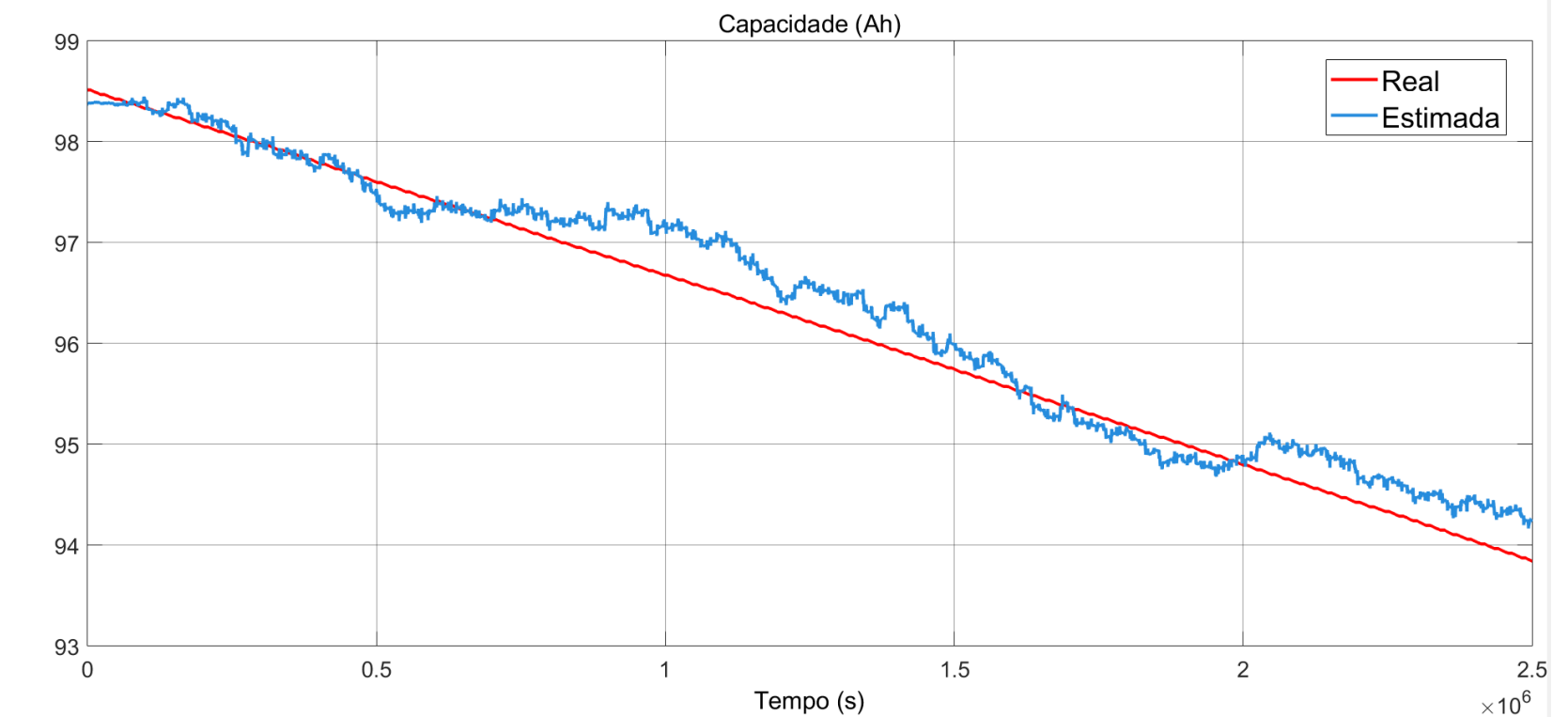
$$SoC(t) = SoC(t_0) + \frac{1}{C_N} \int_{t_0}^t i(\tau) \cdot d\tau$$

$$SoH_{\%} = \frac{C_A}{C_N} \cdot 100\%$$

• State-of-Health (SoH) Estimation

➔ Kalman Filter Method (EKF/UKF)

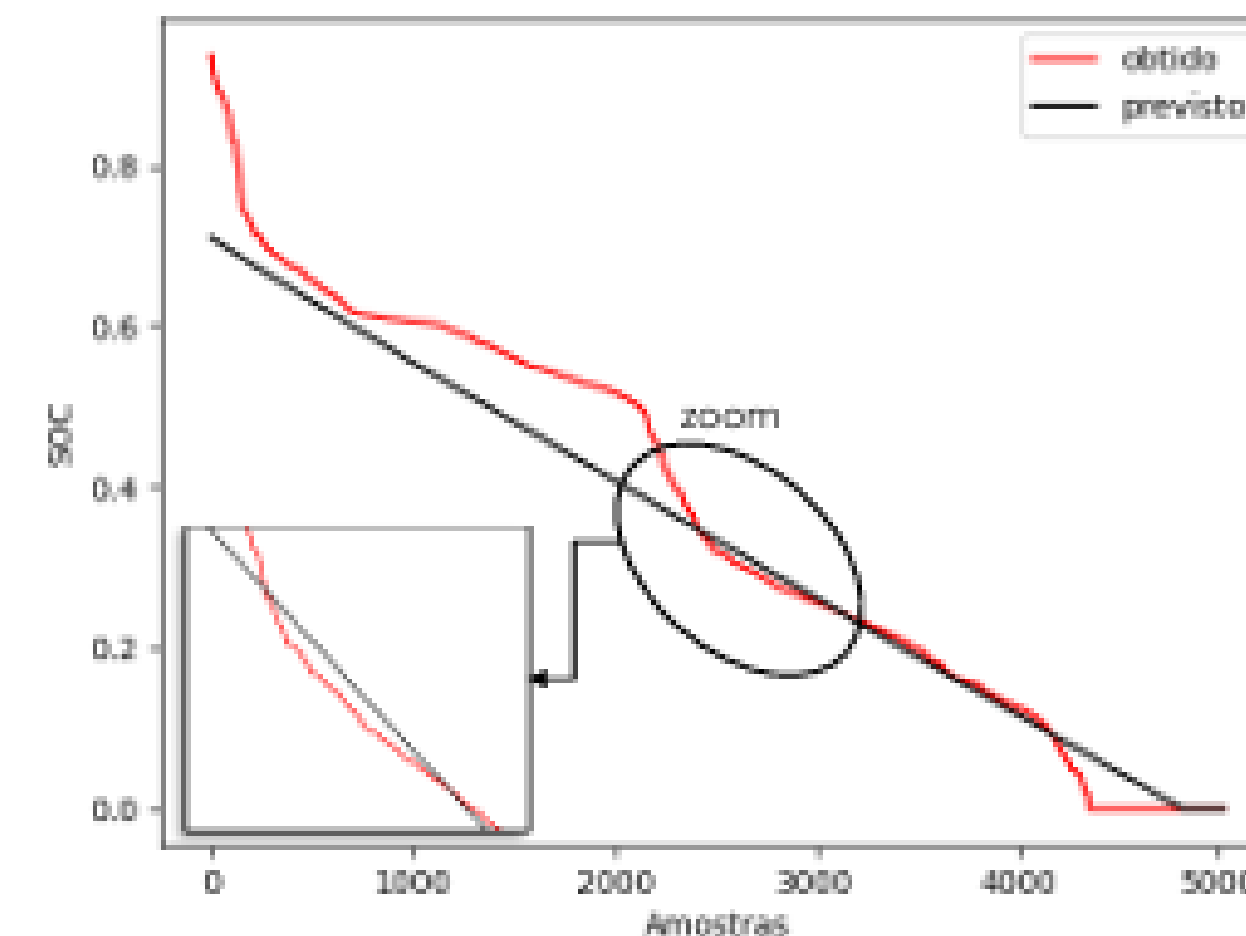
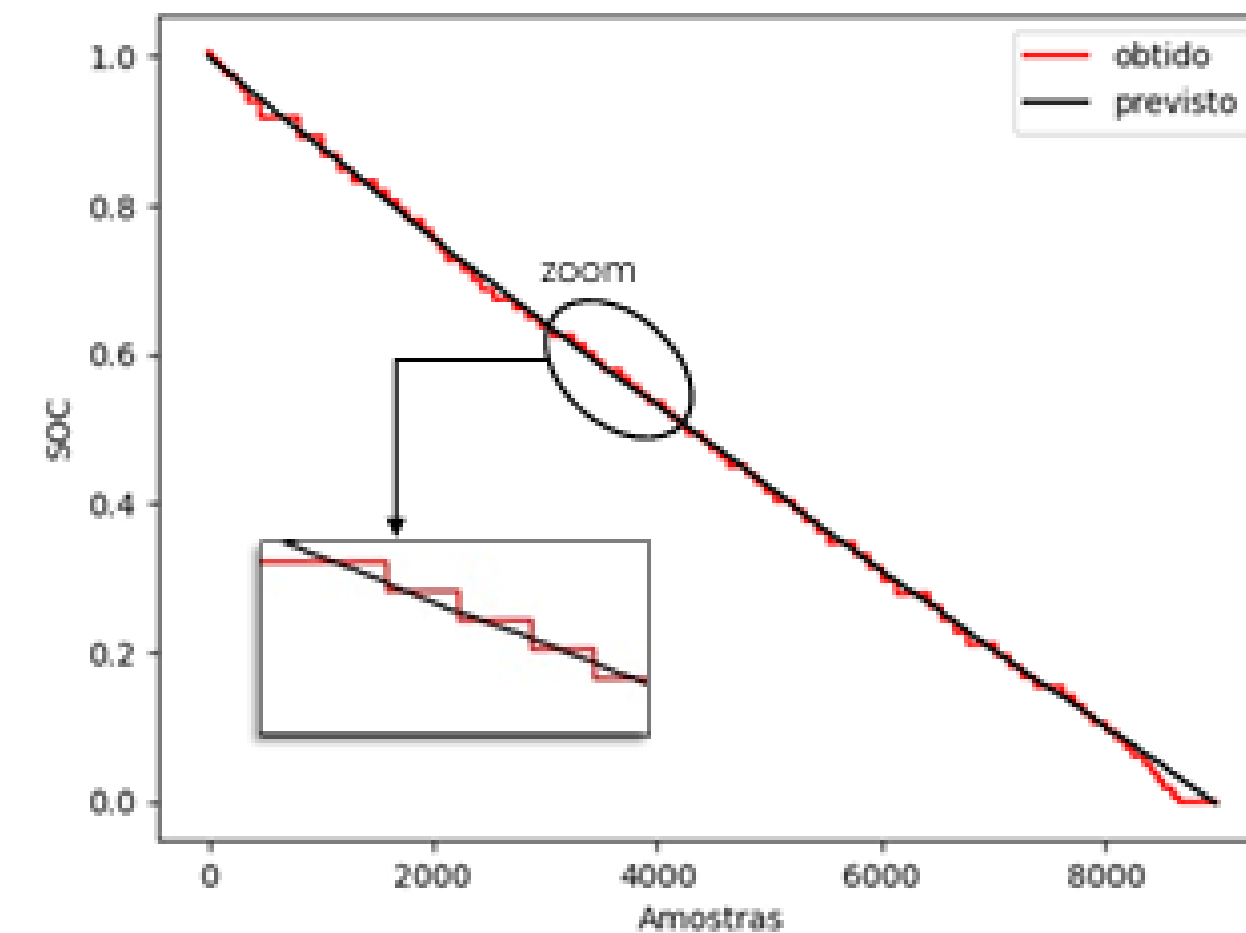
- Online method;
- It requires accurate model (model-based);
- It is robust to noise;
- It presents medium-high computational cost;
- It has high accuracy.



- **State-of-Health (SoH) Estimation**

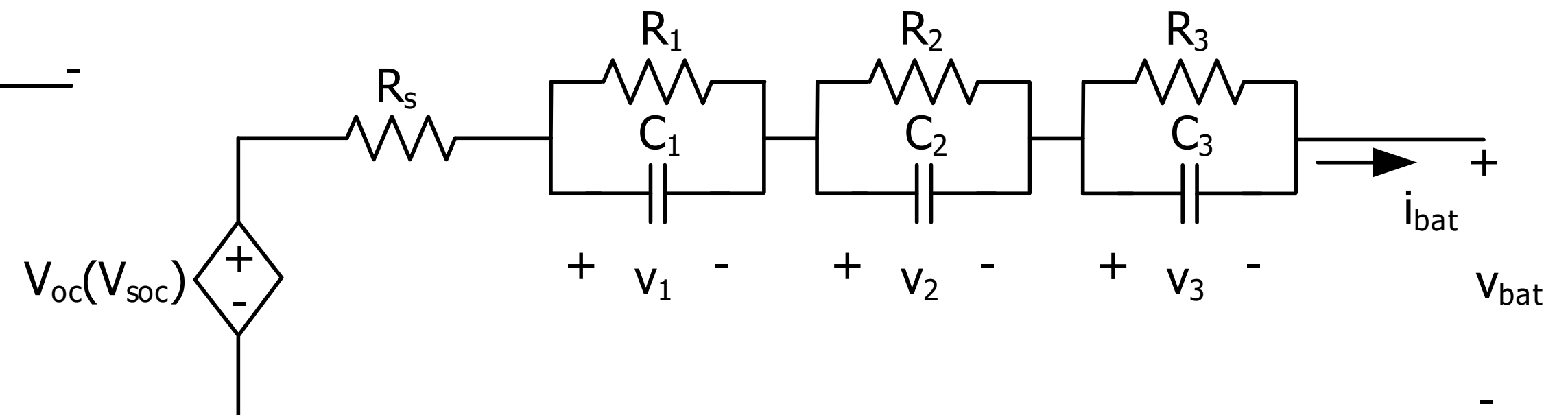
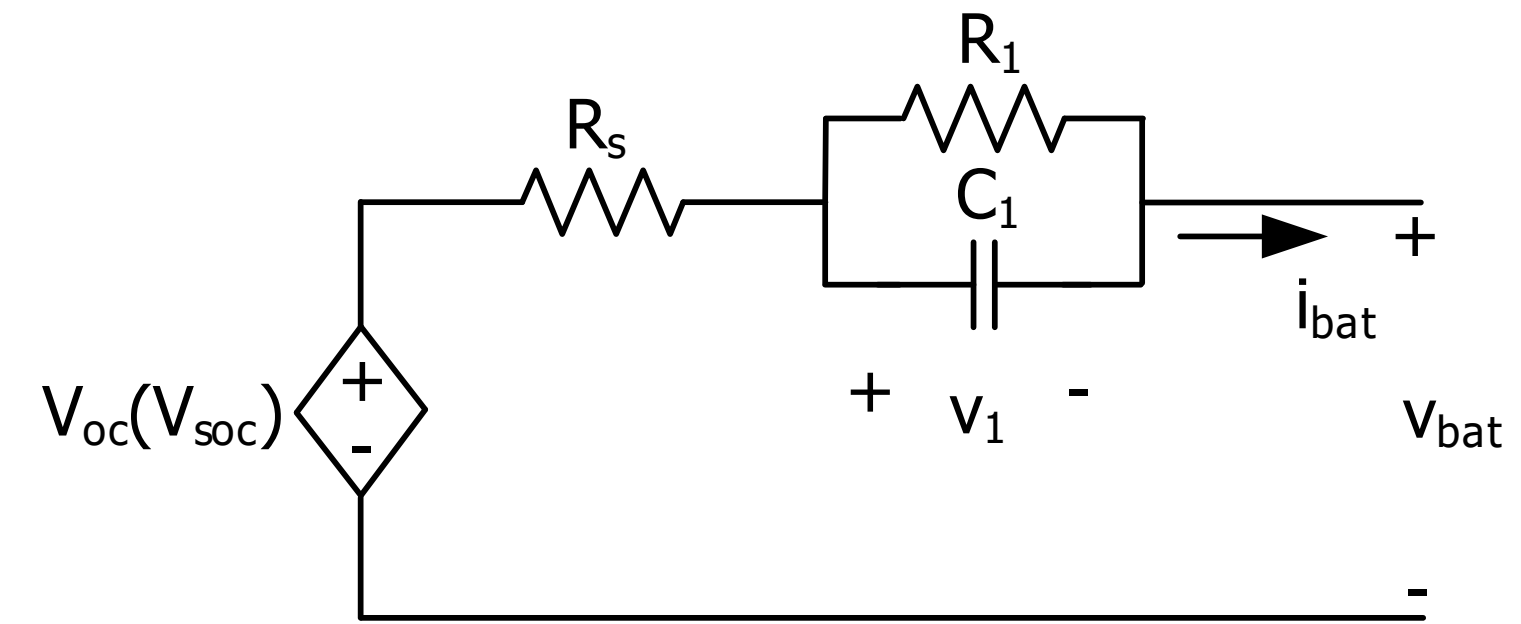
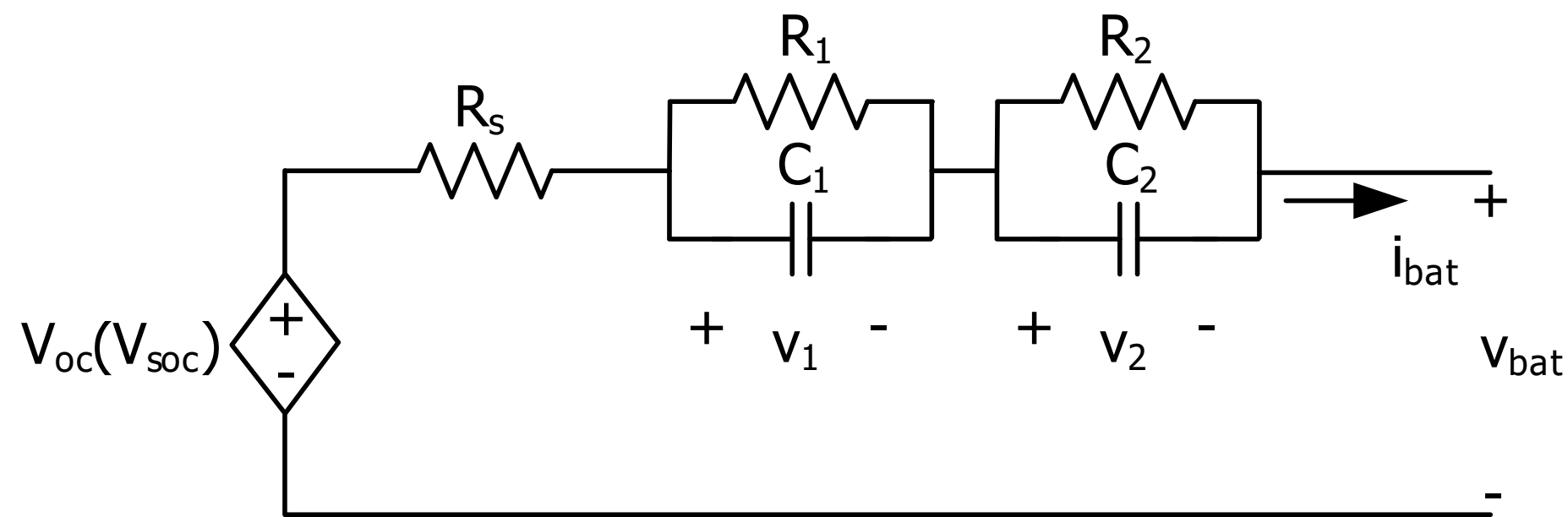
- ➔ **Artificial Neural Network Method**

- Online/offline method;
- It requires large dataset;
- It presents high computational cost;
- It has high accuracy.



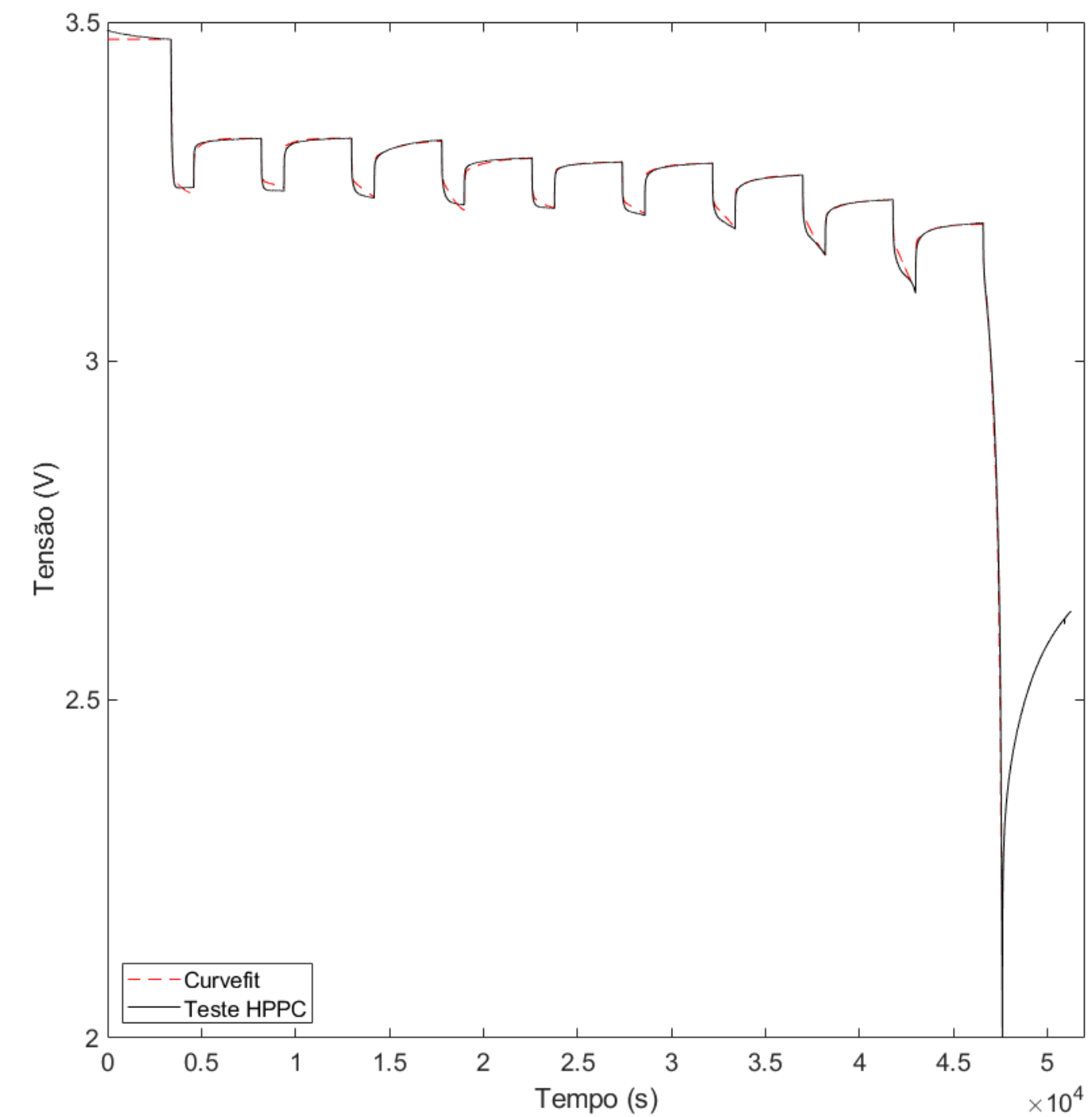
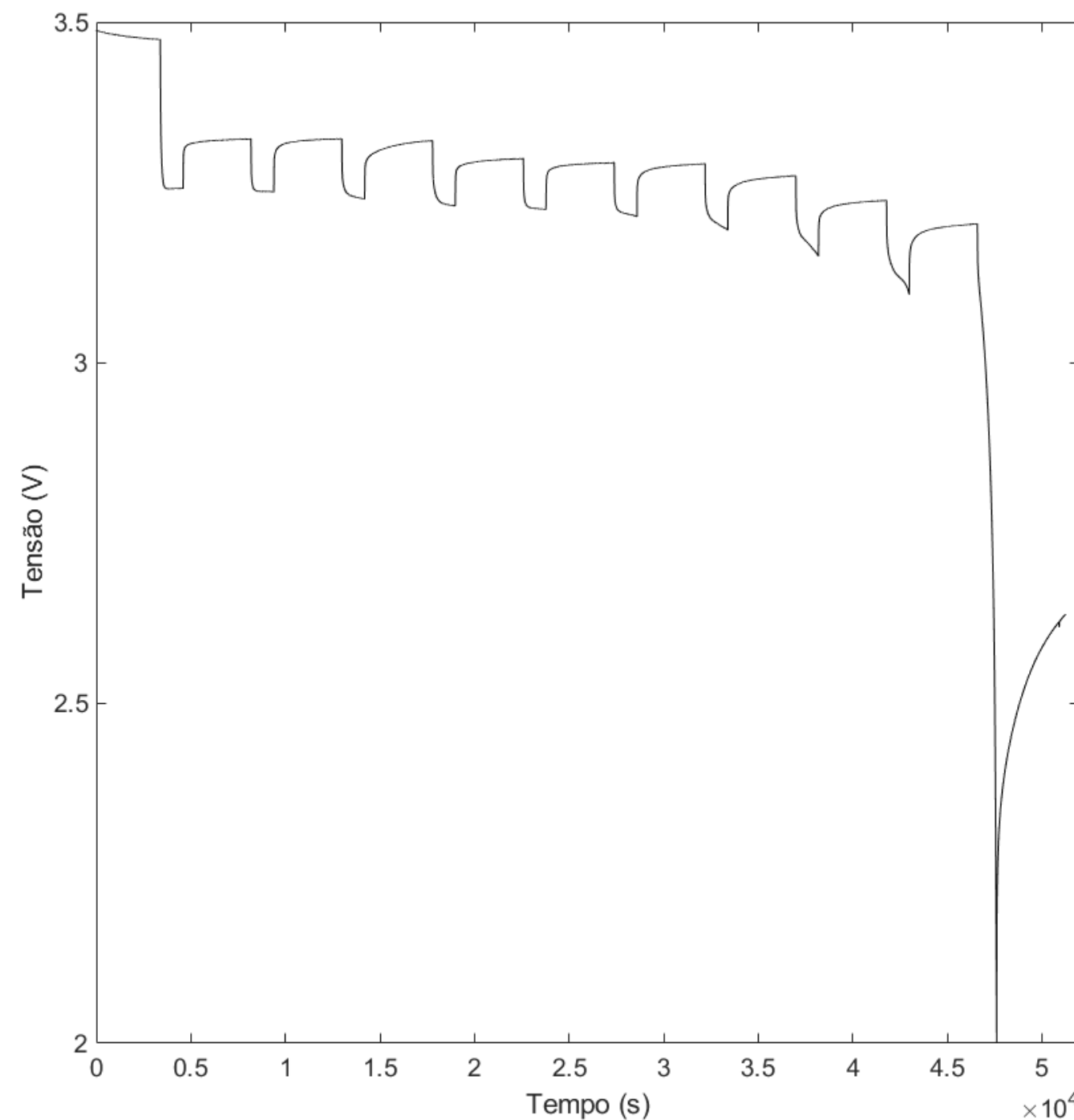
- Equivalent Circuit Model (ECM)

➔ Different approaches



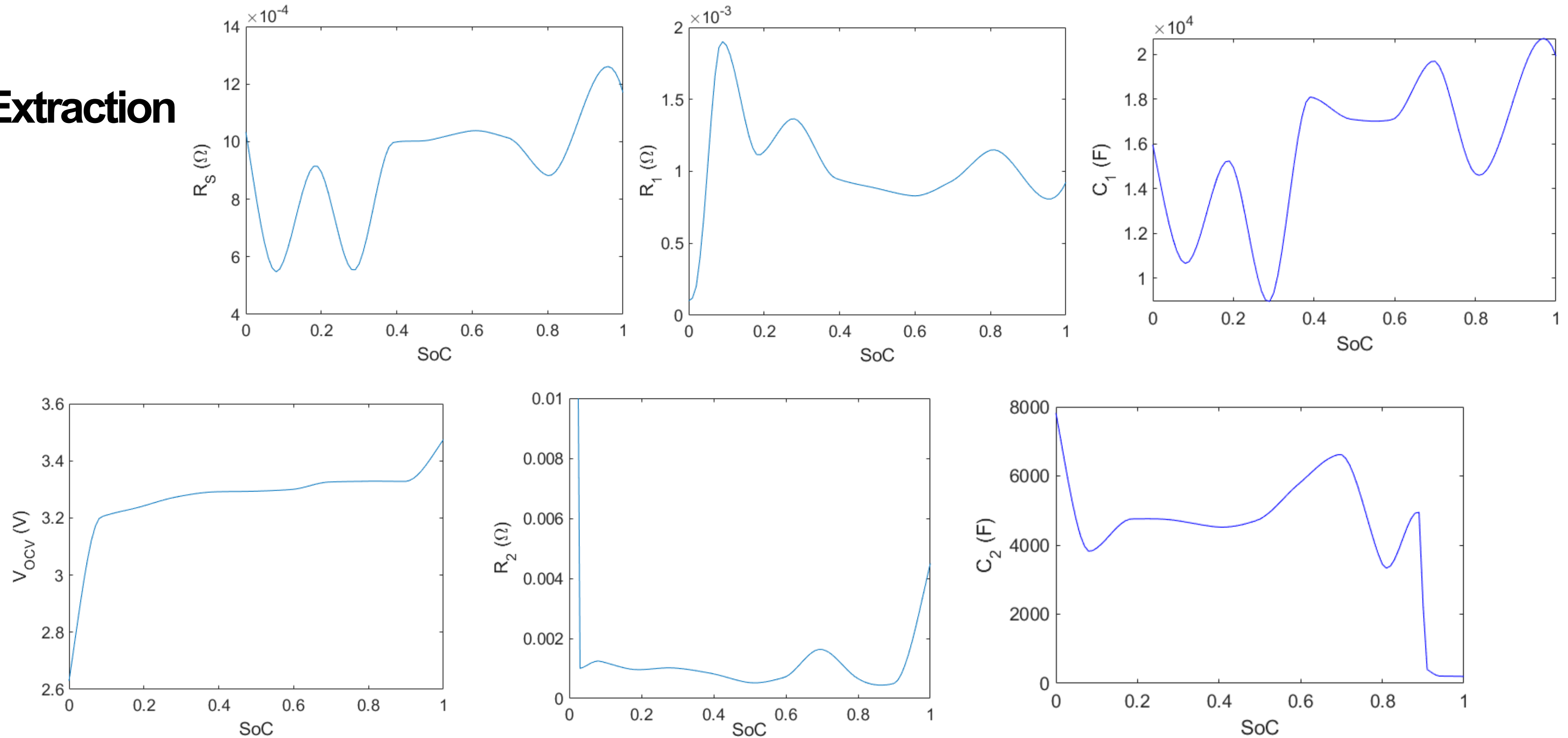
- Equivalent Circuit Model (ECM)

➔ HPPC Test



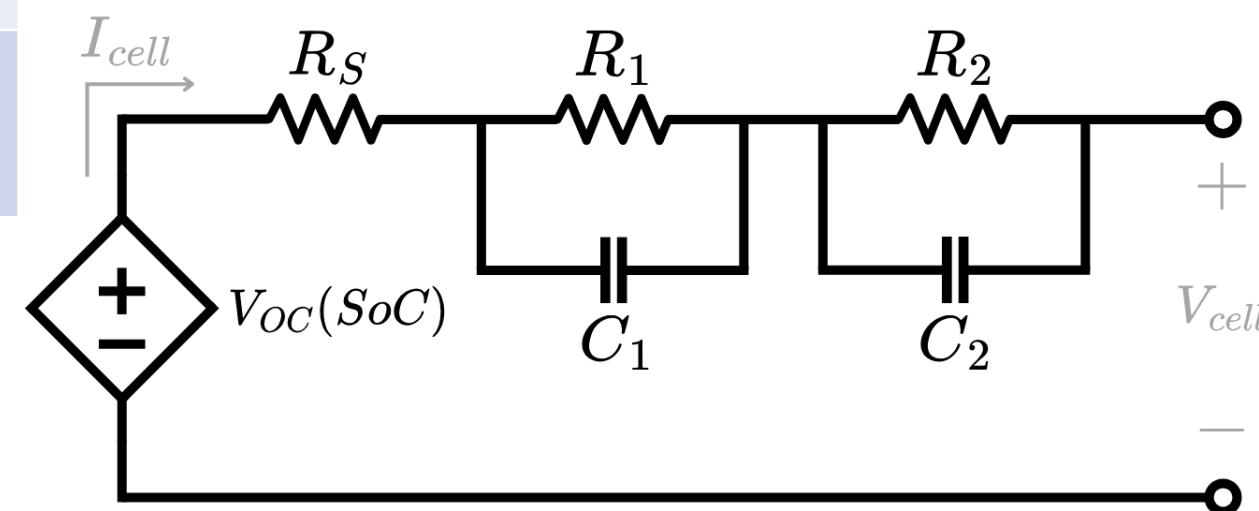
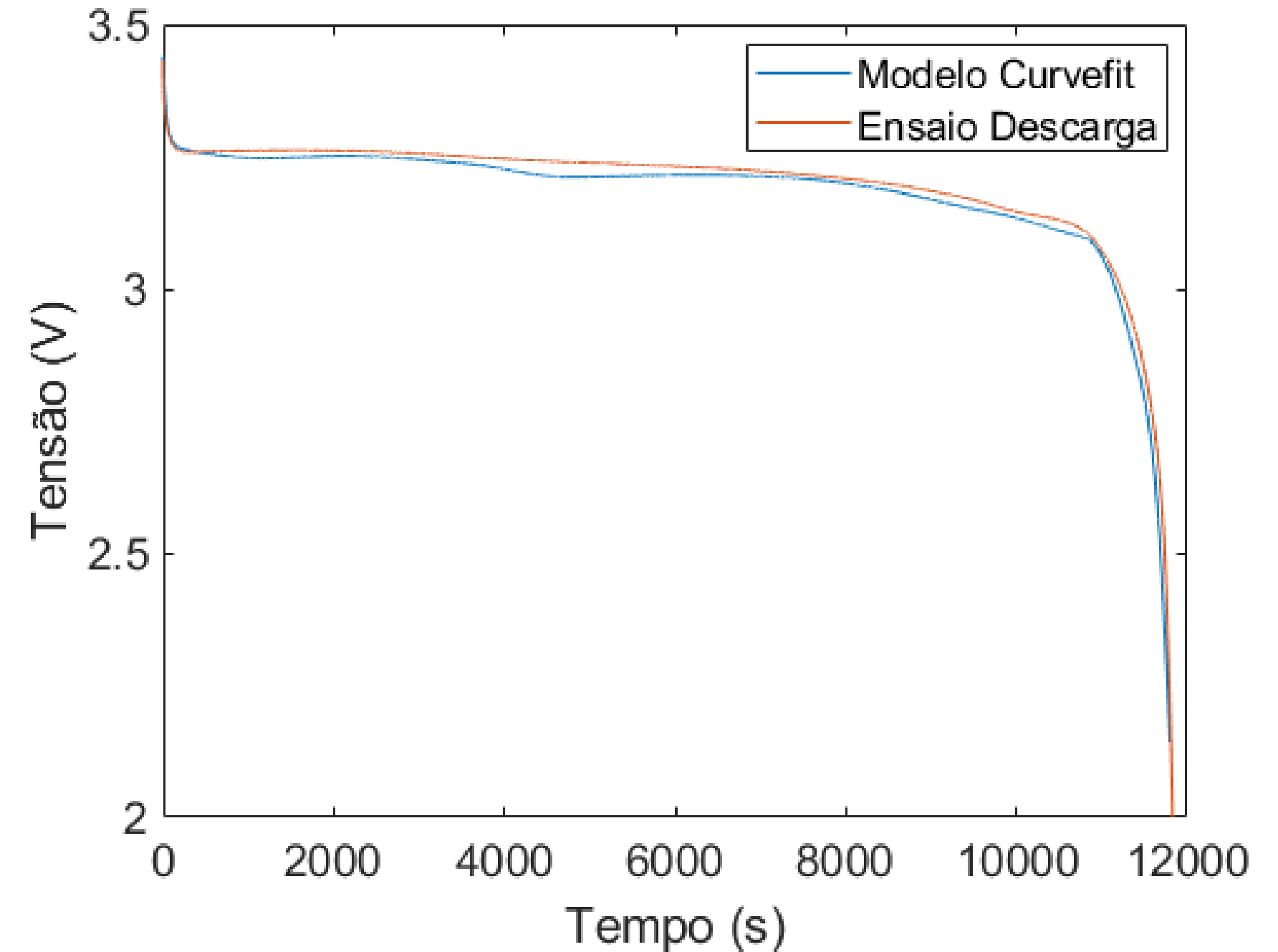
• Equivalent Circuit Model (ECM)

➔ Parameters Extraction



• Equivalent Circuit Model (ECM)

➔ Validation

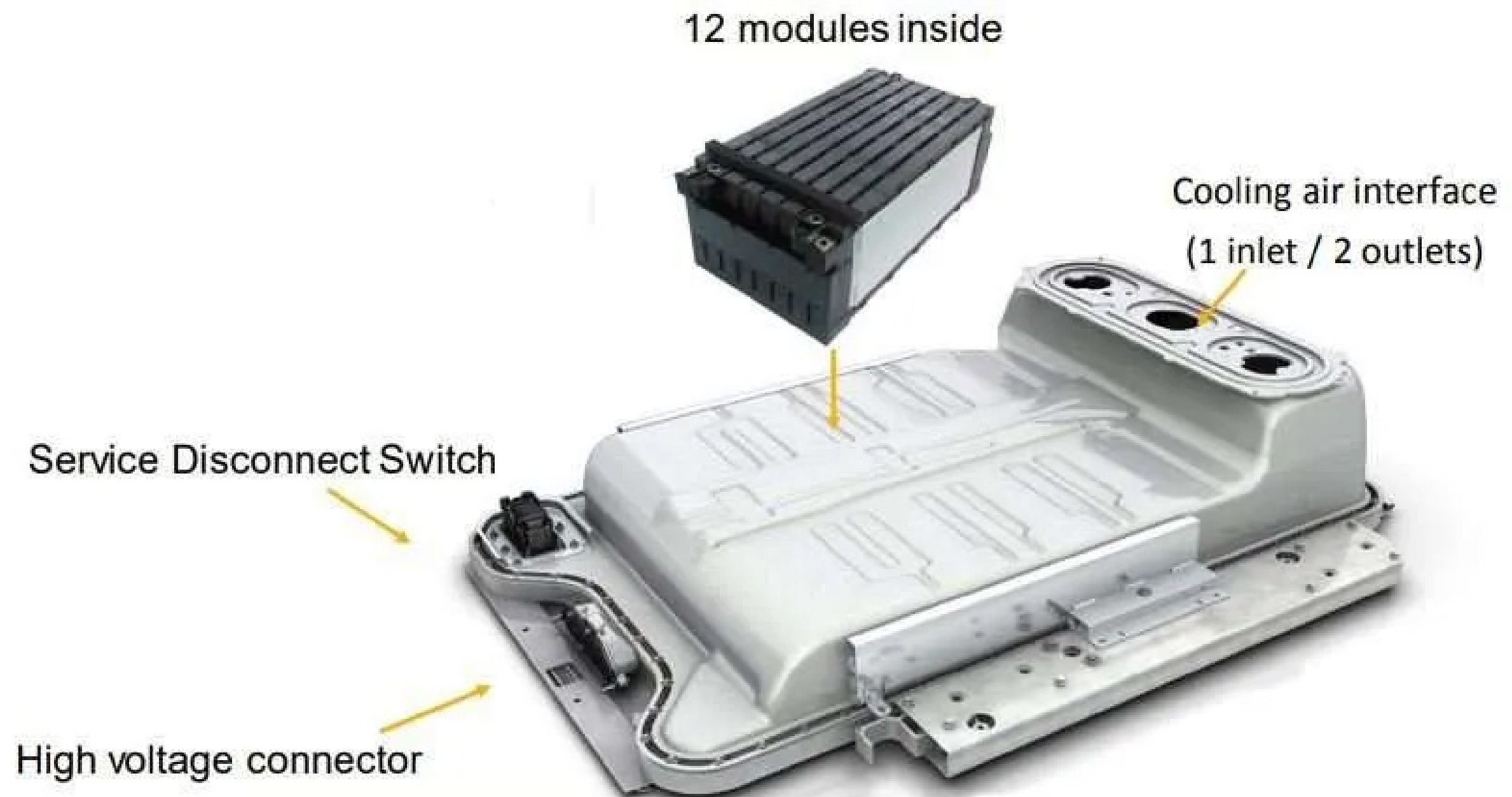


- **Equivalent Circuit Model (ECM)**

- ➔ **Modules with Many Cells in Series**

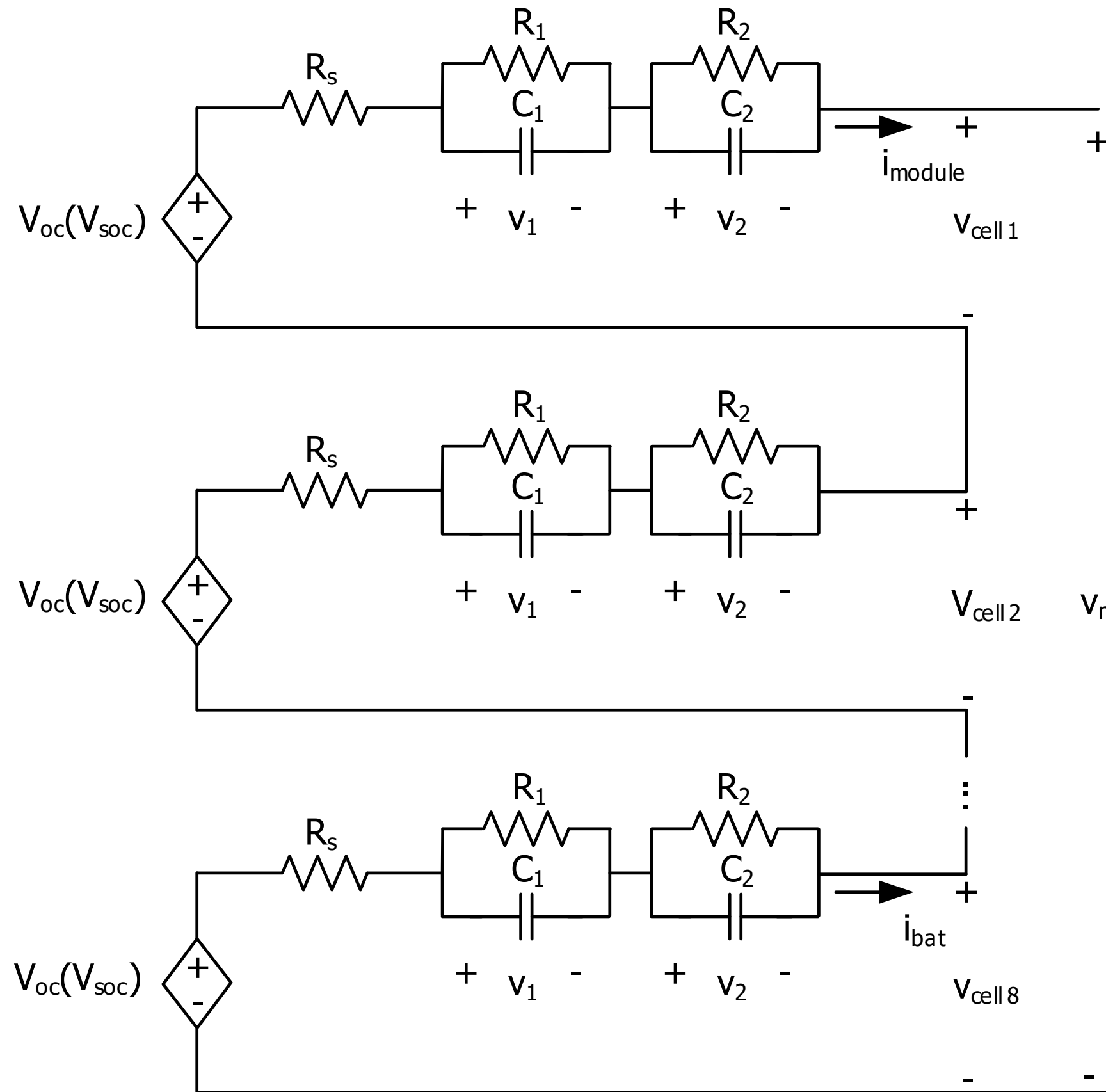
- **Renault Zoe:**

- **Battery pack: 12 modules;**
 - **Module: 16 cells (8S2P).**

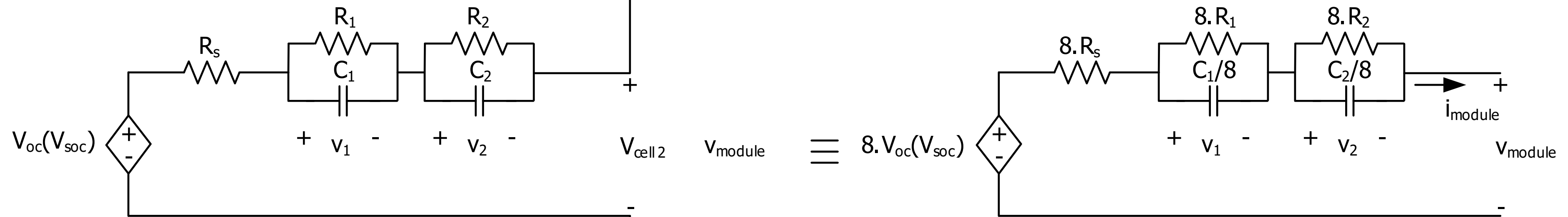


Source: <https://www.batterydesign.net/2016-renault-zoe-ze-40/>

• Equivalent Circuit Model (ECM)



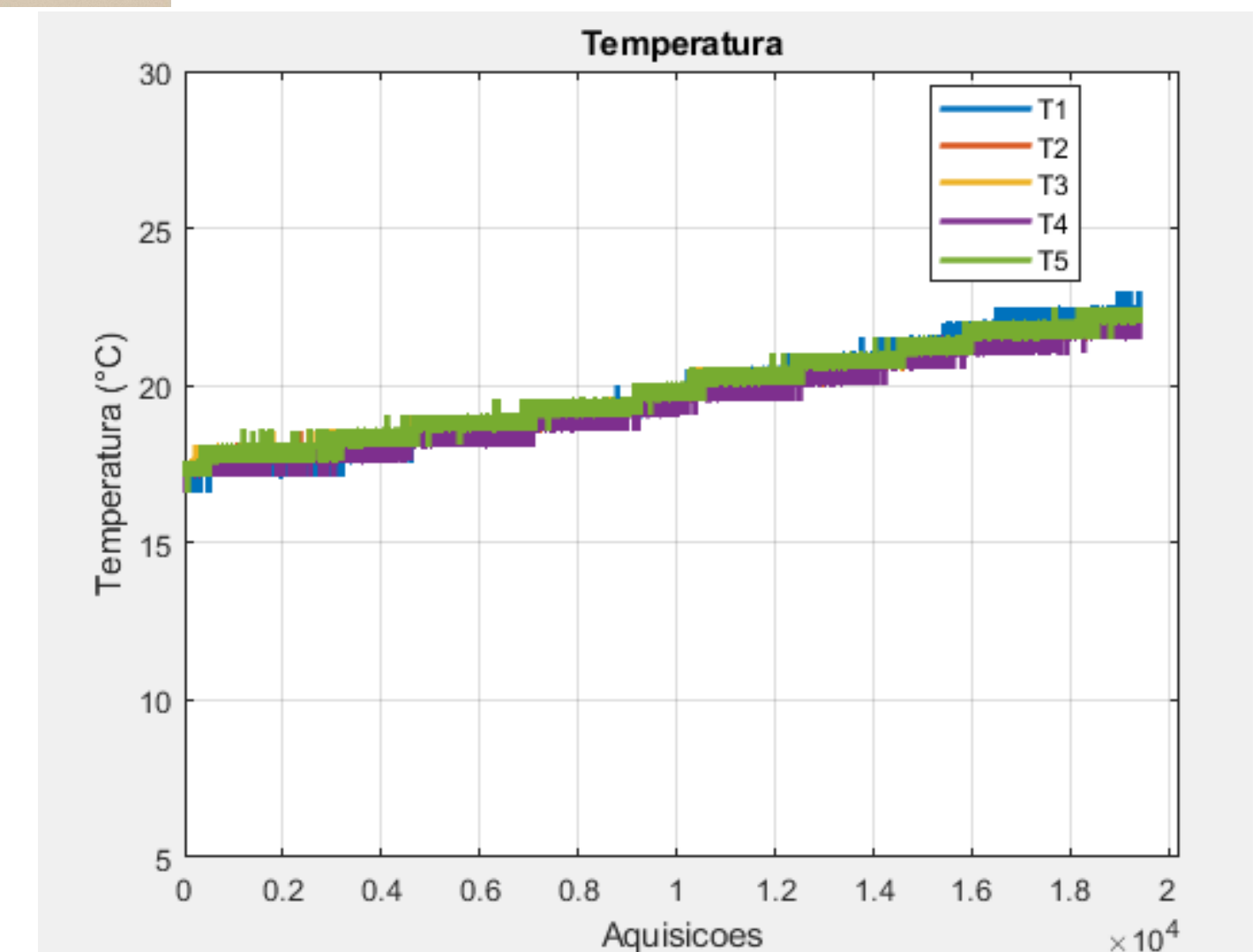
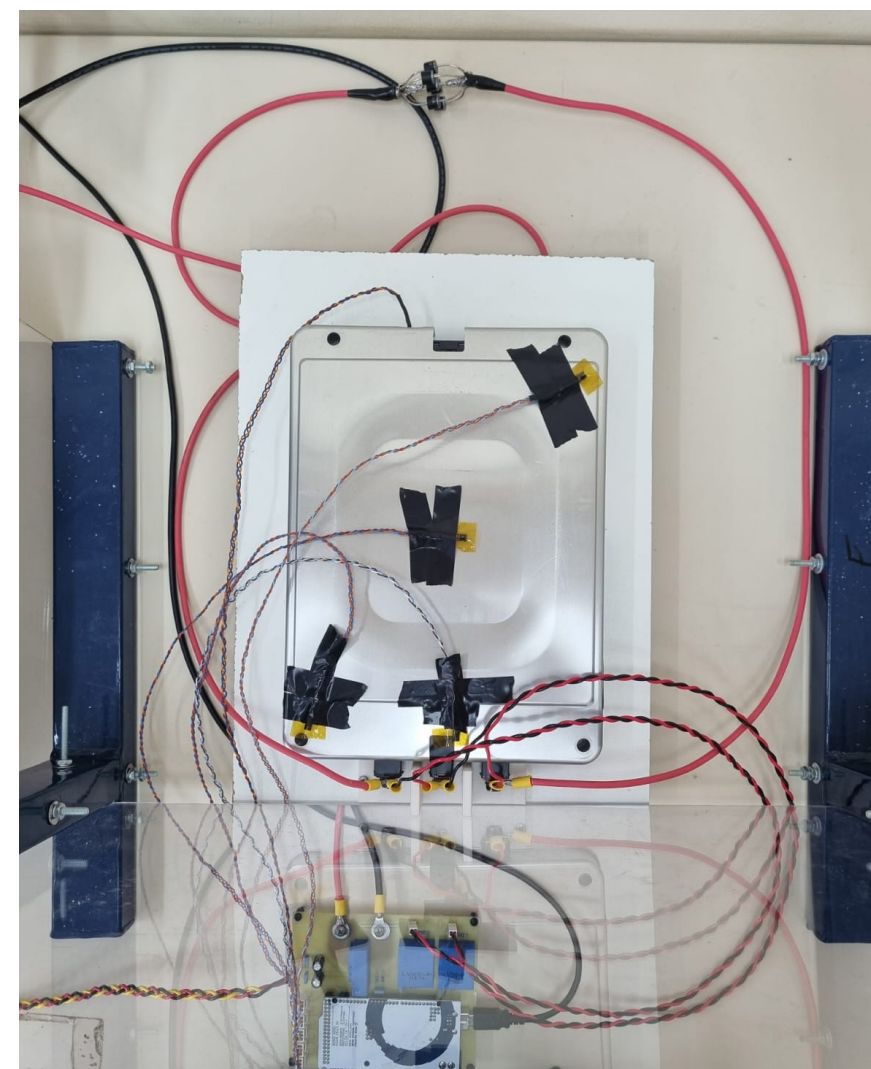
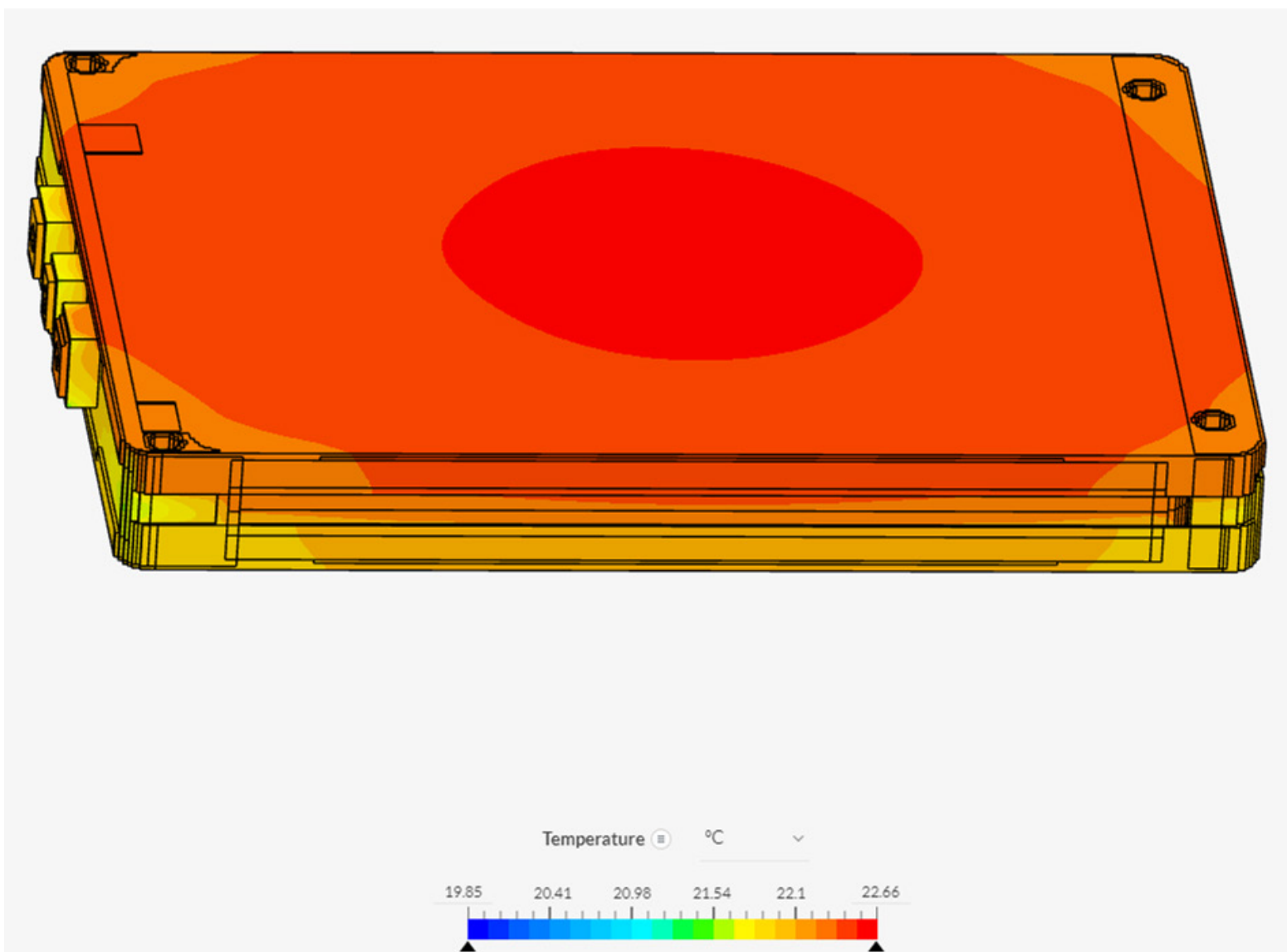
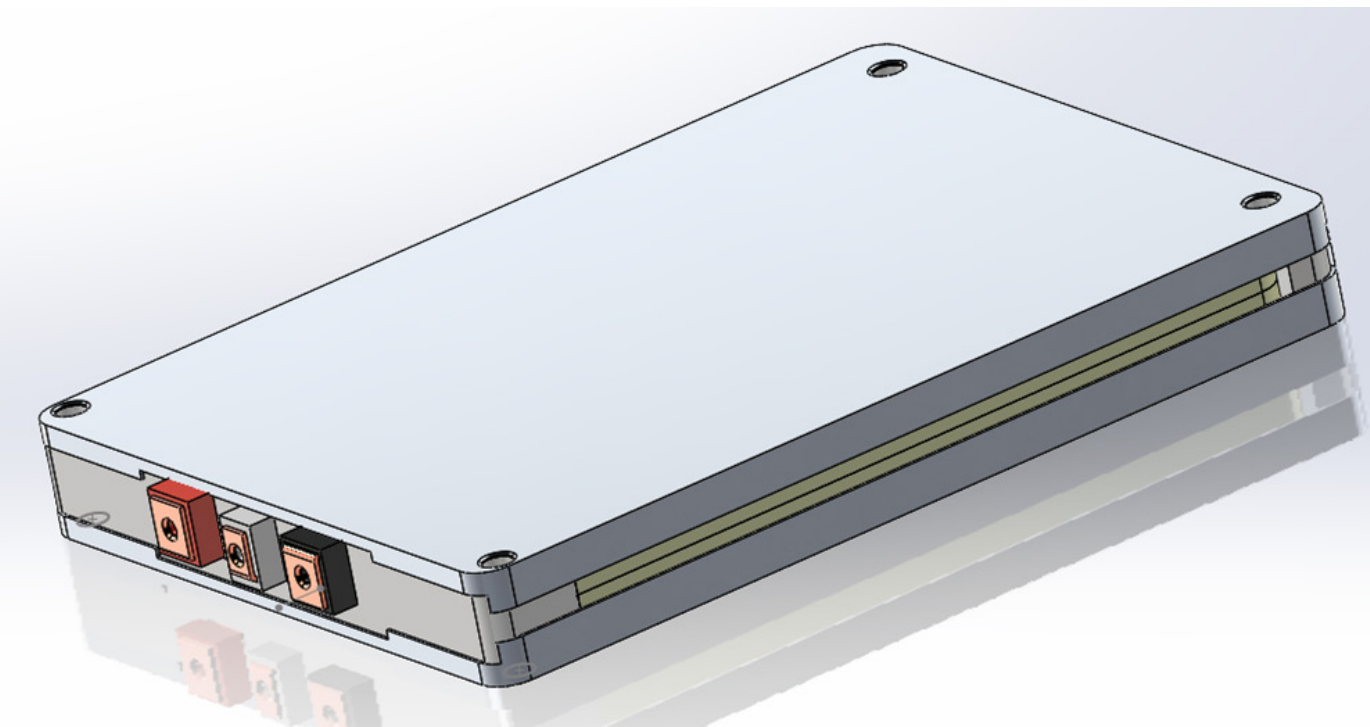
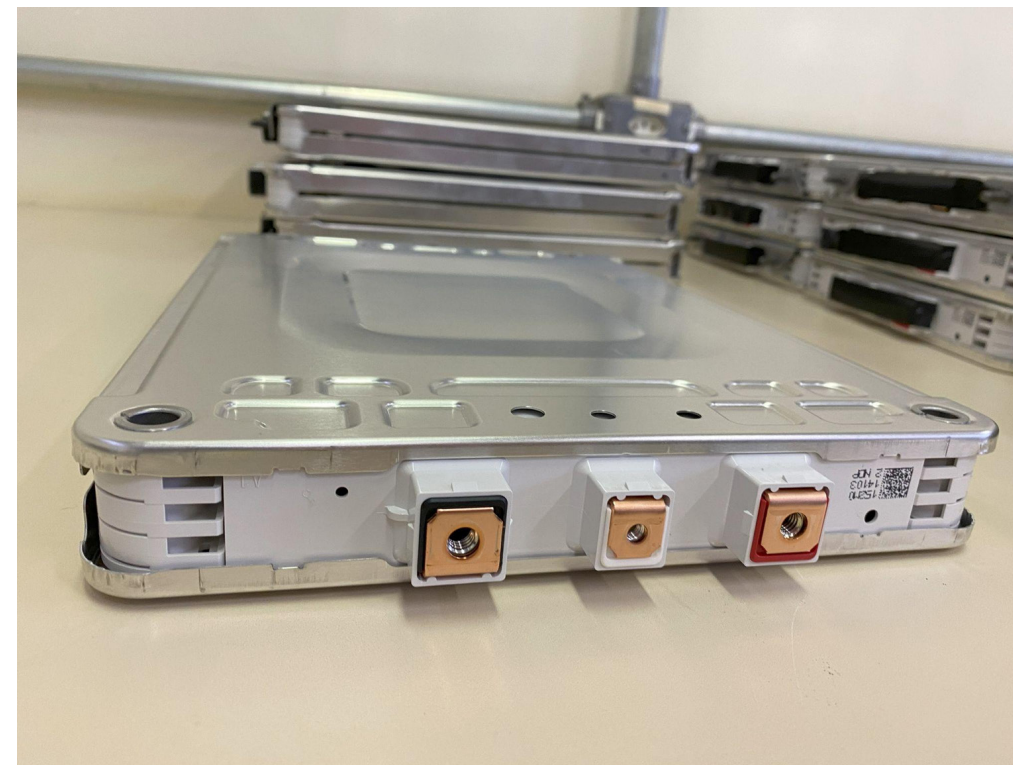
➔ **Modules with Many Cells in Series**
- Thevenin Equivalent Circuit.



➔ Second-life Batteries

- Thermal Model (TM)

➔ CFD (Computational Fluid Dynamics)



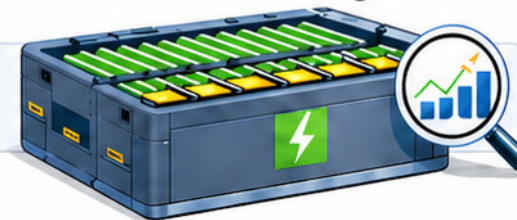
• A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry

➔ Design Specifications

Design and Operational Specifications of the 60V-SLBESS System

System Configuration

Number of Modules	8
Module Configuration (Cell level)	2S2P
System Configuration	8S (Modules in Series)



Electrical Limits

Nominal System Voltage	60.0 V
Maximum System Voltage	67.2 V
Cutoff System Voltage	40.0 V
Maximum Cell Voltage	4.2 V
Cutoff Cell Voltage (Operational)	2.5 V

Capacity and Energy

Rated Capacity (Nominal)	40 Ah
Nominal Energy	2.4 kWh
Maximum Energy	2.5 kWh
Minimum Energy	1.6 kWh
Mass	25.568 kg



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

- ➔ **Modular Design**

- 60 V modules: enable manufacturing, testing, and validation with lower safety requirements;
- Versatility, customization, and scalability;
- Reduced investment and development costs;
- Flexibility to meet demand;
- Ease of maintenance, repair, and recycling;
- Uncertainty management;
- Requires a control and management unit.



➔ Second-life Batteries

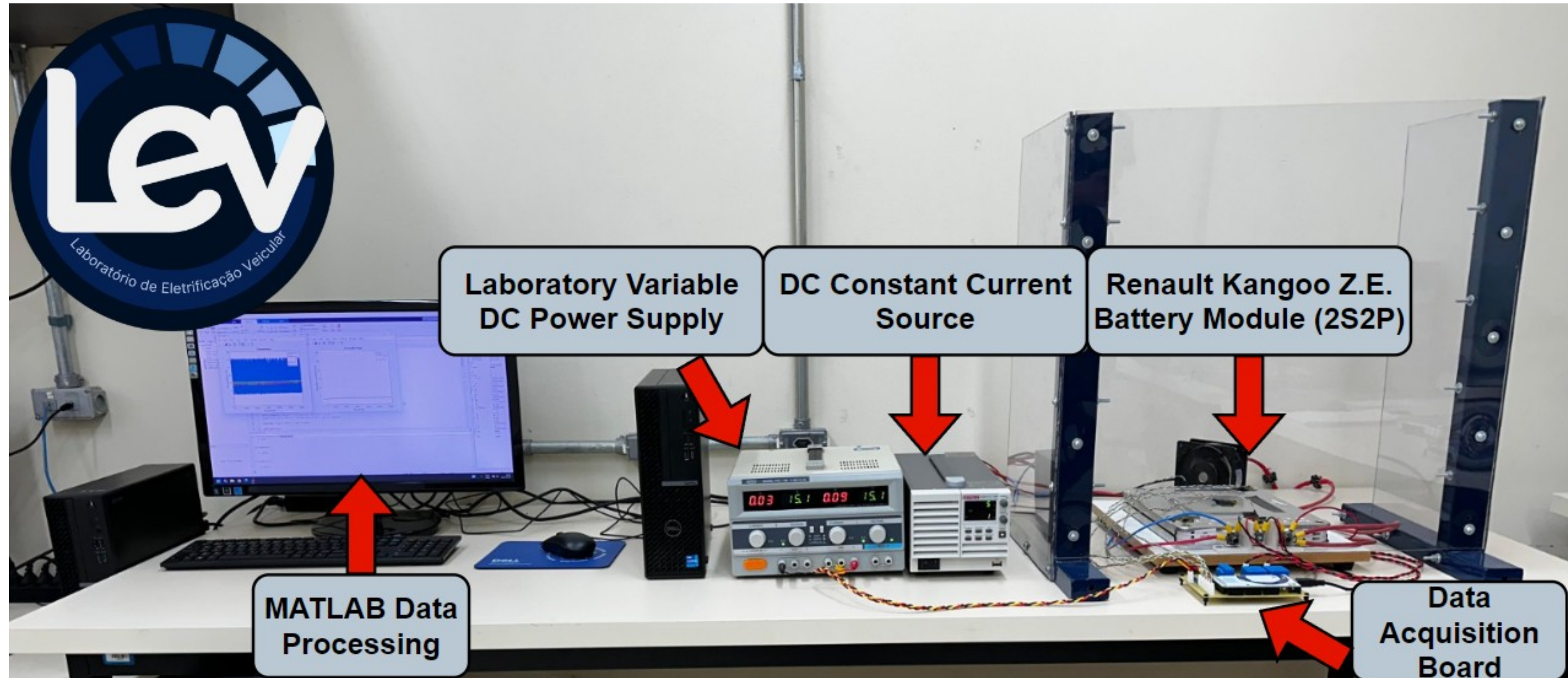
- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

➔ Disassembling Process



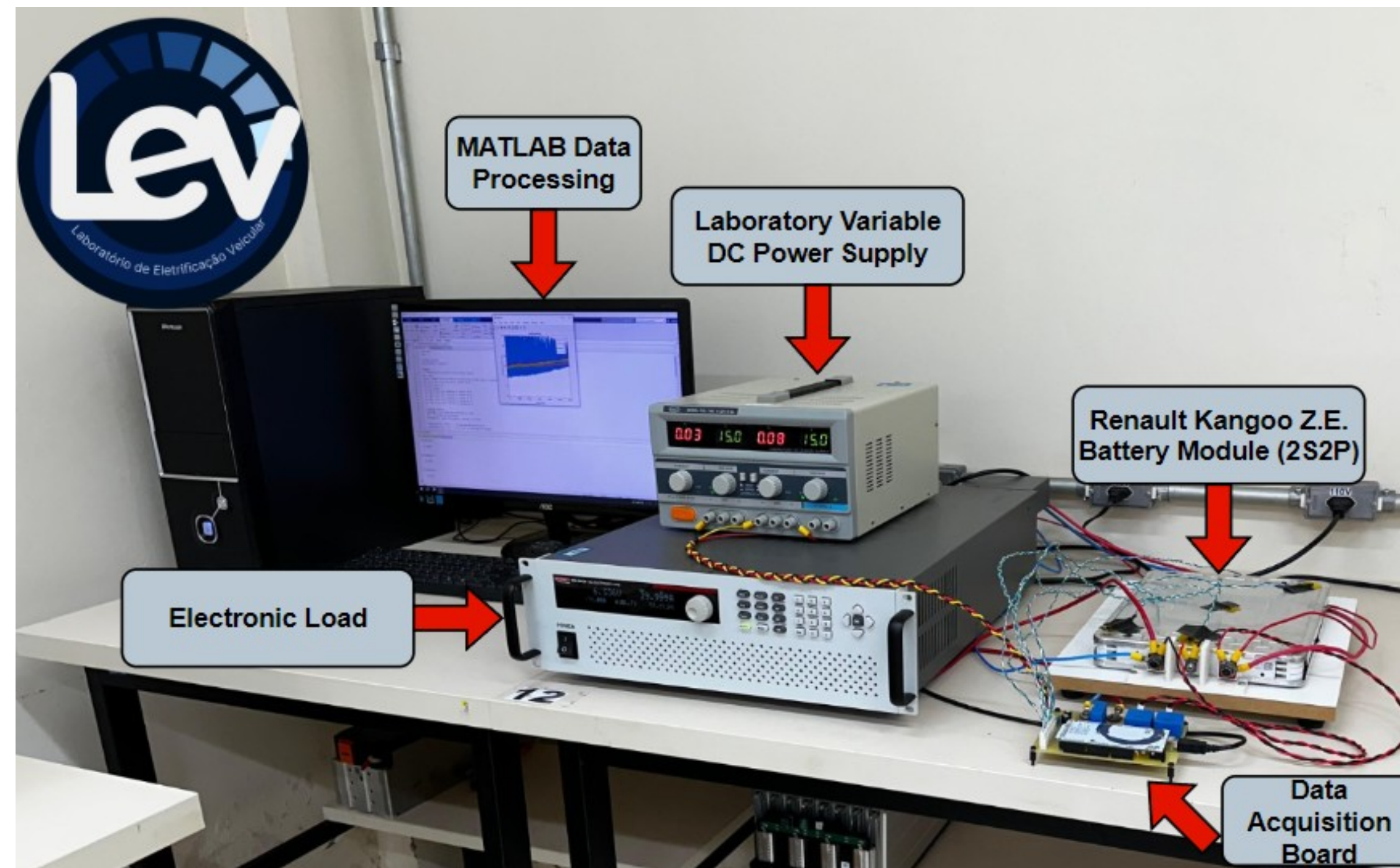
- A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry

➔ Data Acquisition and SoH Estimation



- A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry

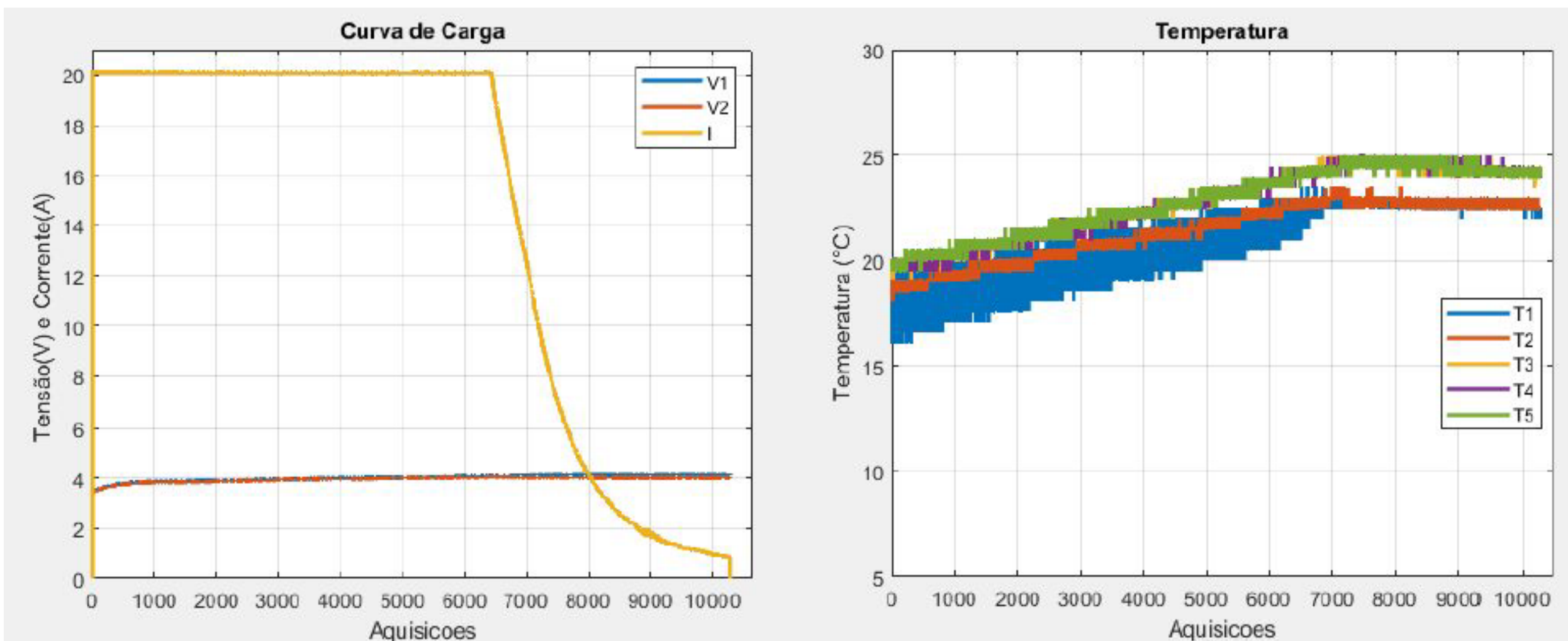
➔ Data Acquisition and SoH Estimation



➔ Second-life Batteries

- A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry

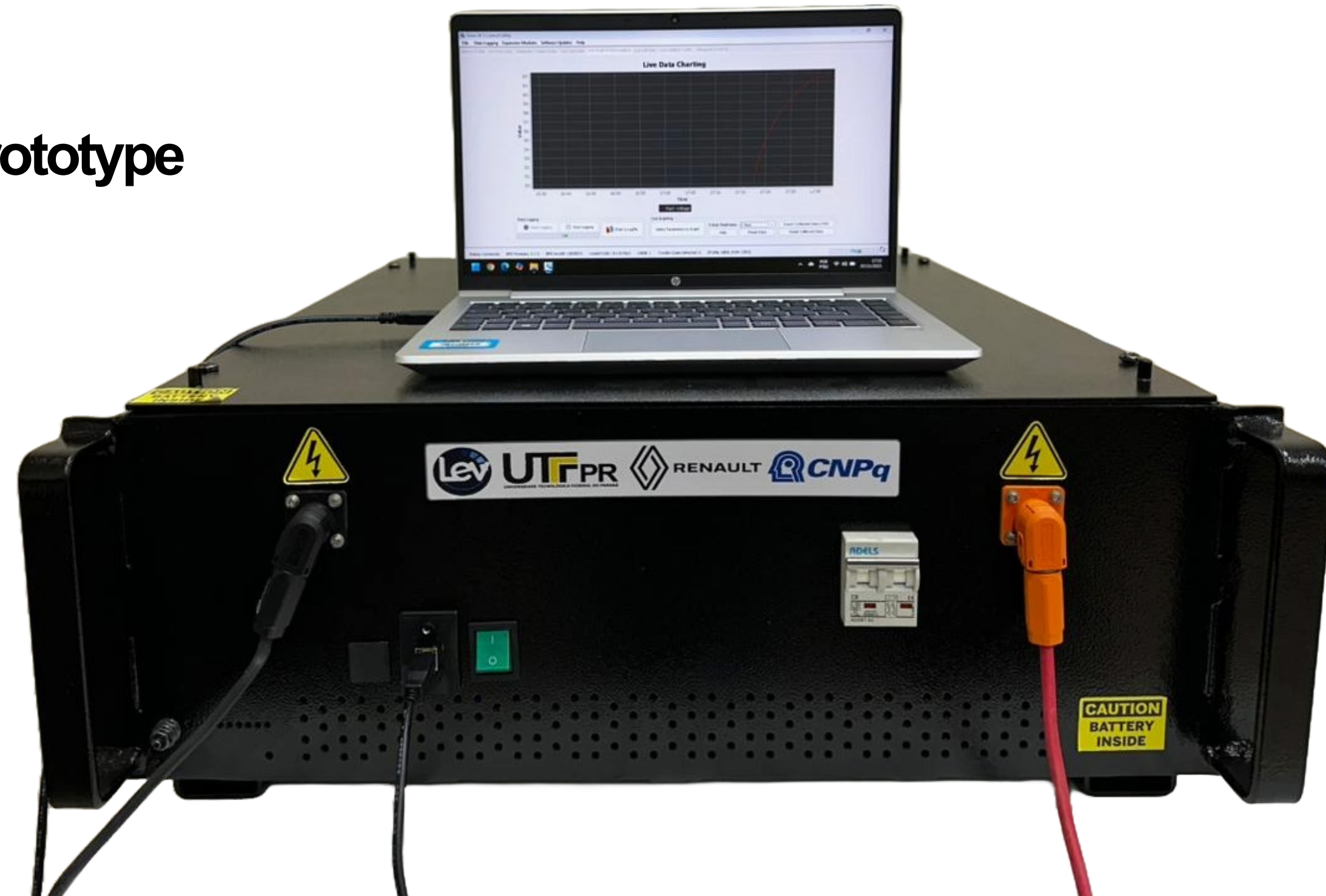
➔ SoH Estimation (Coulomb Counting)



```
>> Dados_aquisicao
Tempo total de execução: 8833.73 segundos
Tempo total de execução: 147.23 minutos
Carga total acumulada (Coulomb Counting): 38.53 Ah
Estado de Saúde (SOH): 58.21%
```

- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

- ➔ **Second-life BESS Validation**
 - **Proof-of-concept (POC) Prototype**



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

➔ Second-life BESS Validation

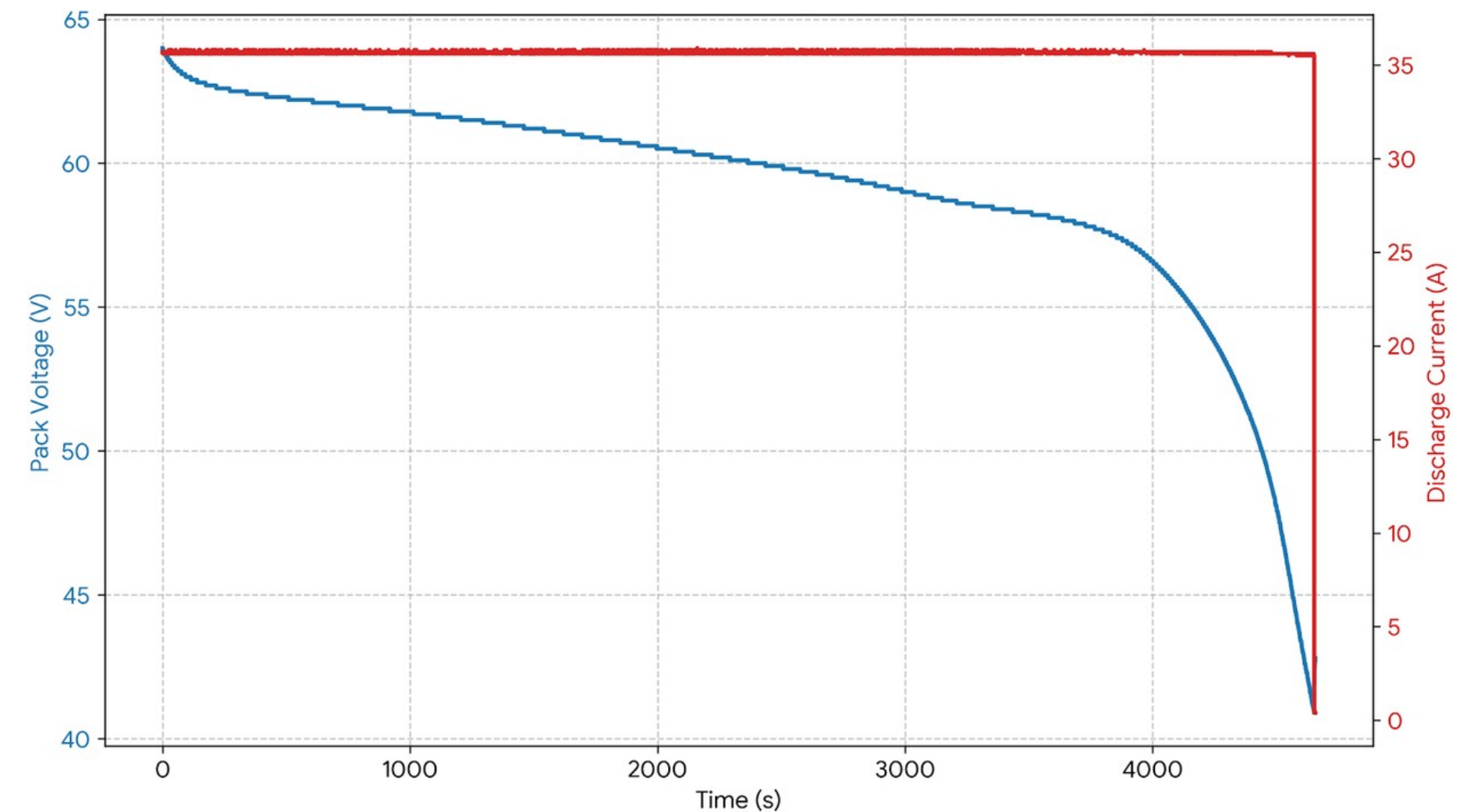
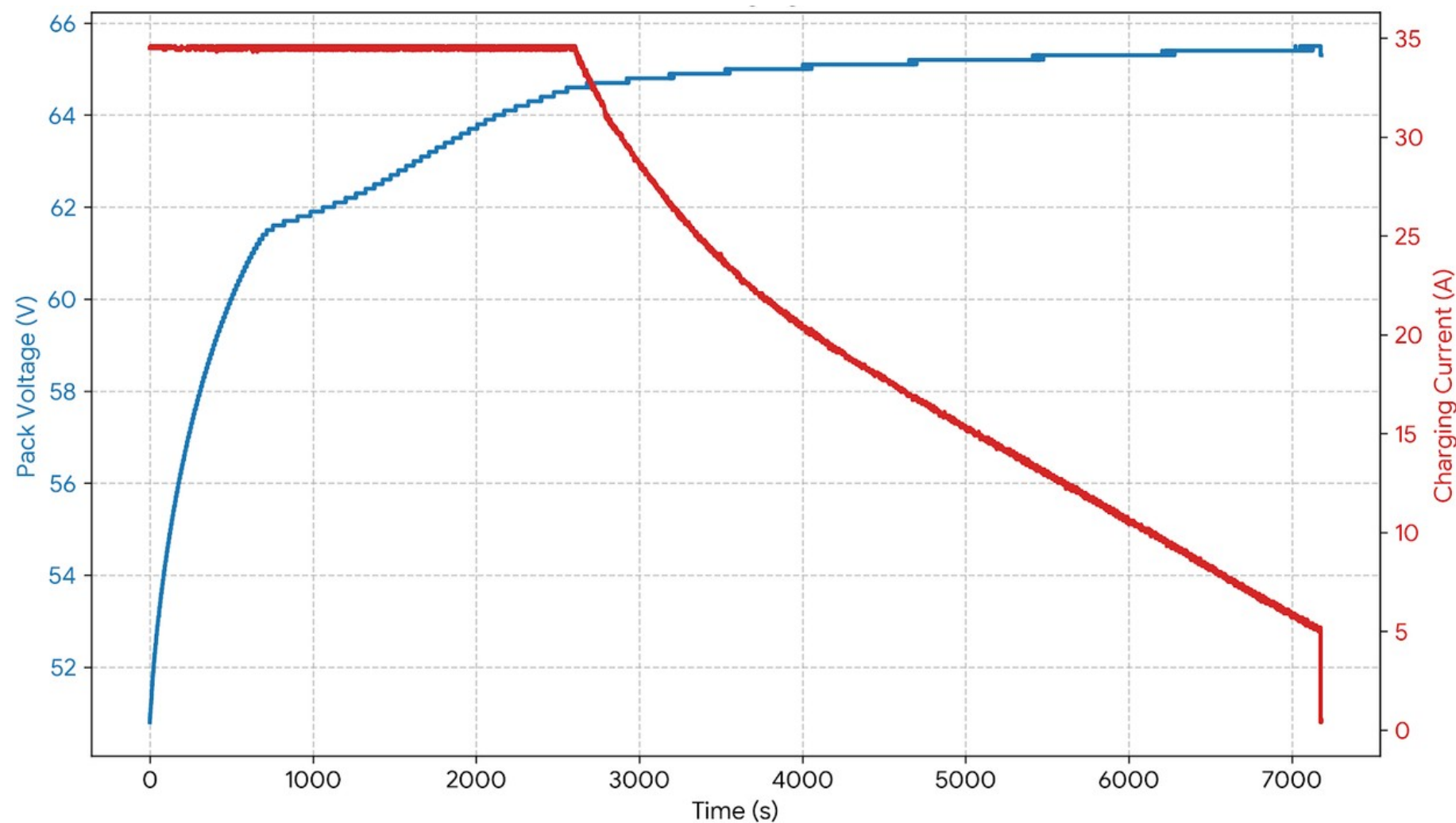
- **PCS: Bidirectional Power Supply EA PSB 11000-40**



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

➔ Second-life BESS Validation

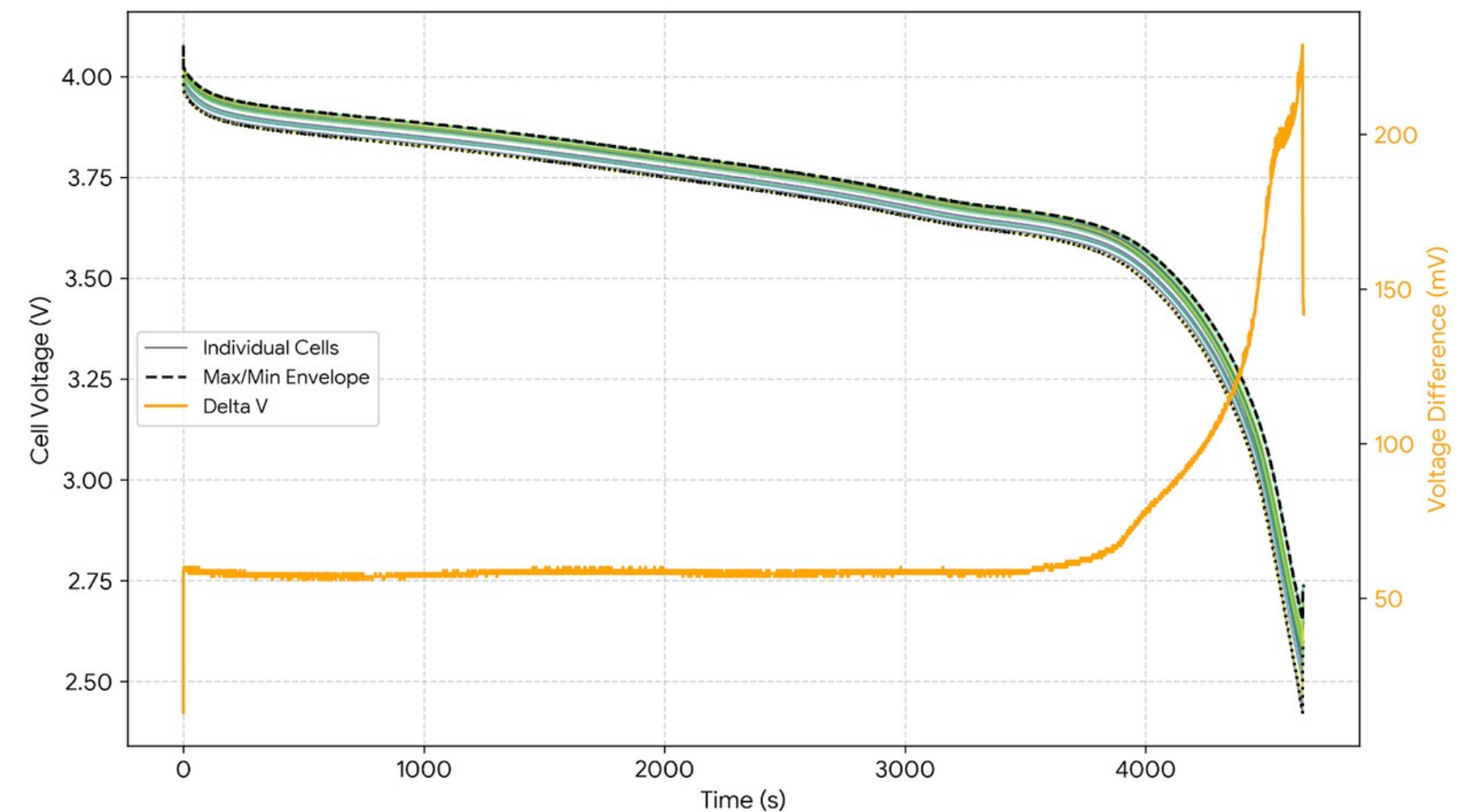
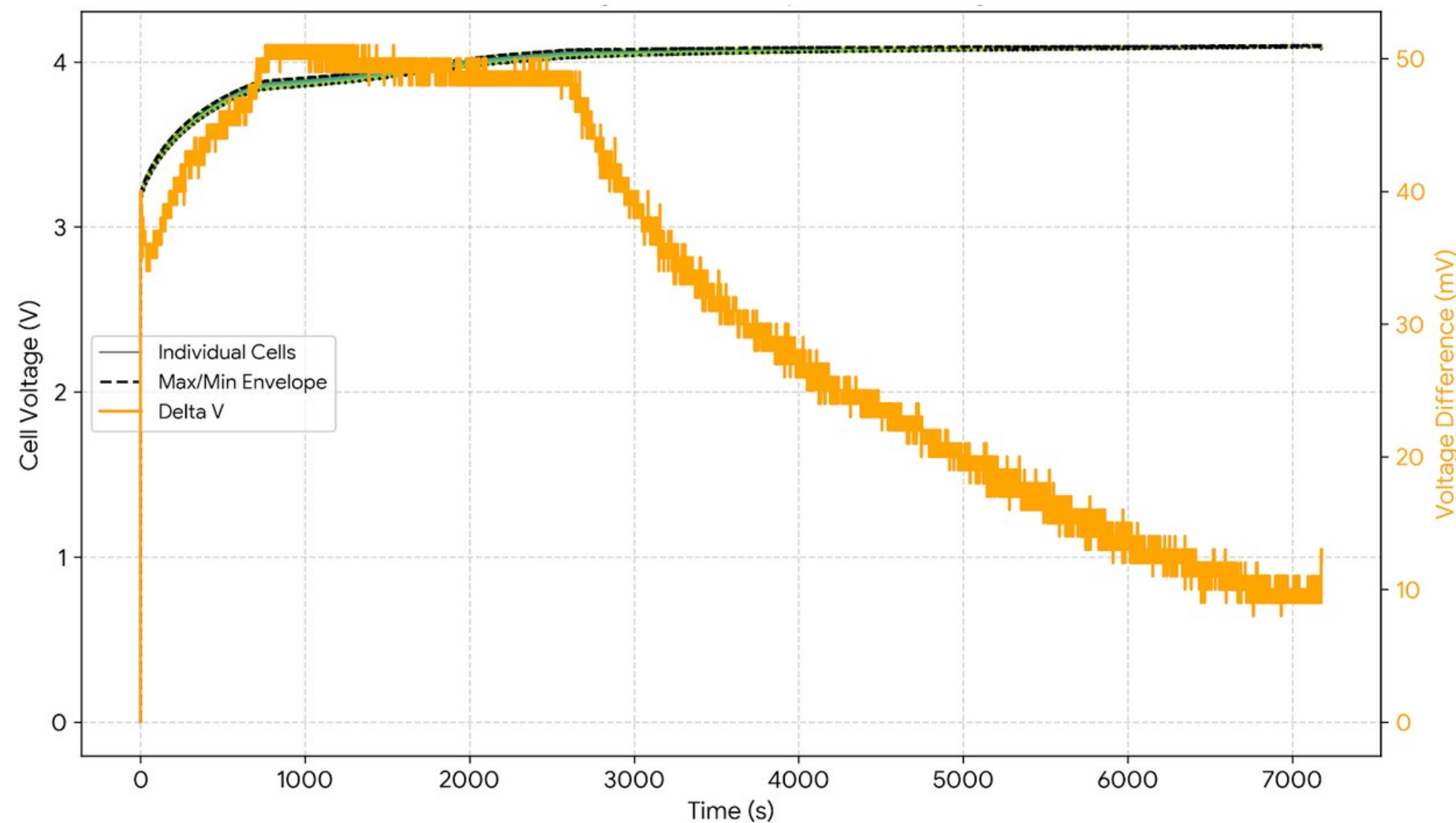
- Charge/Discharge Profiles (CC/CV Charging Method, CC Discharging, 35 A)



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

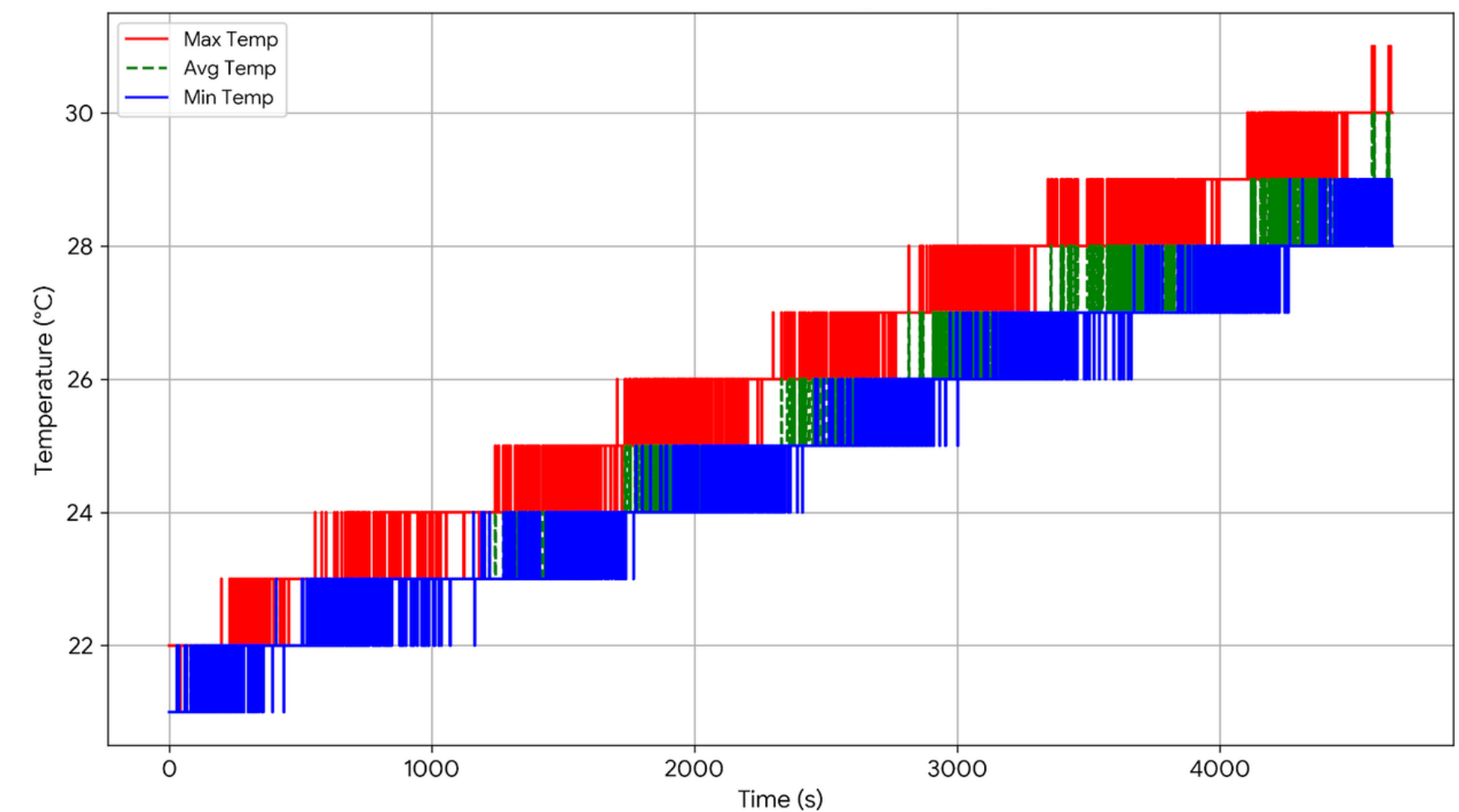
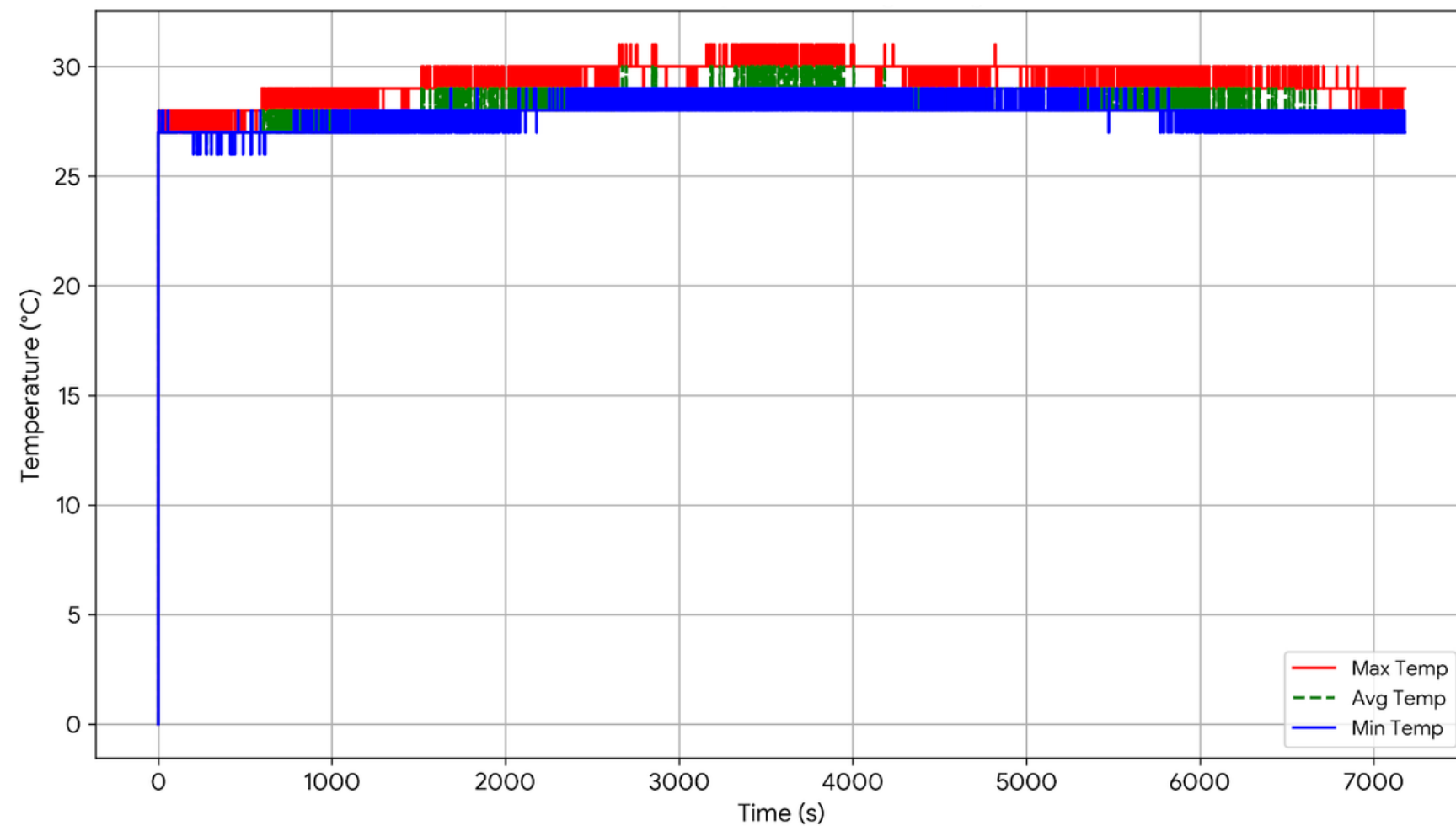
➔ Second-life BESS Validation

- Individual Cell Voltage Trajectories and Pack Imbalance (ΔV)



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

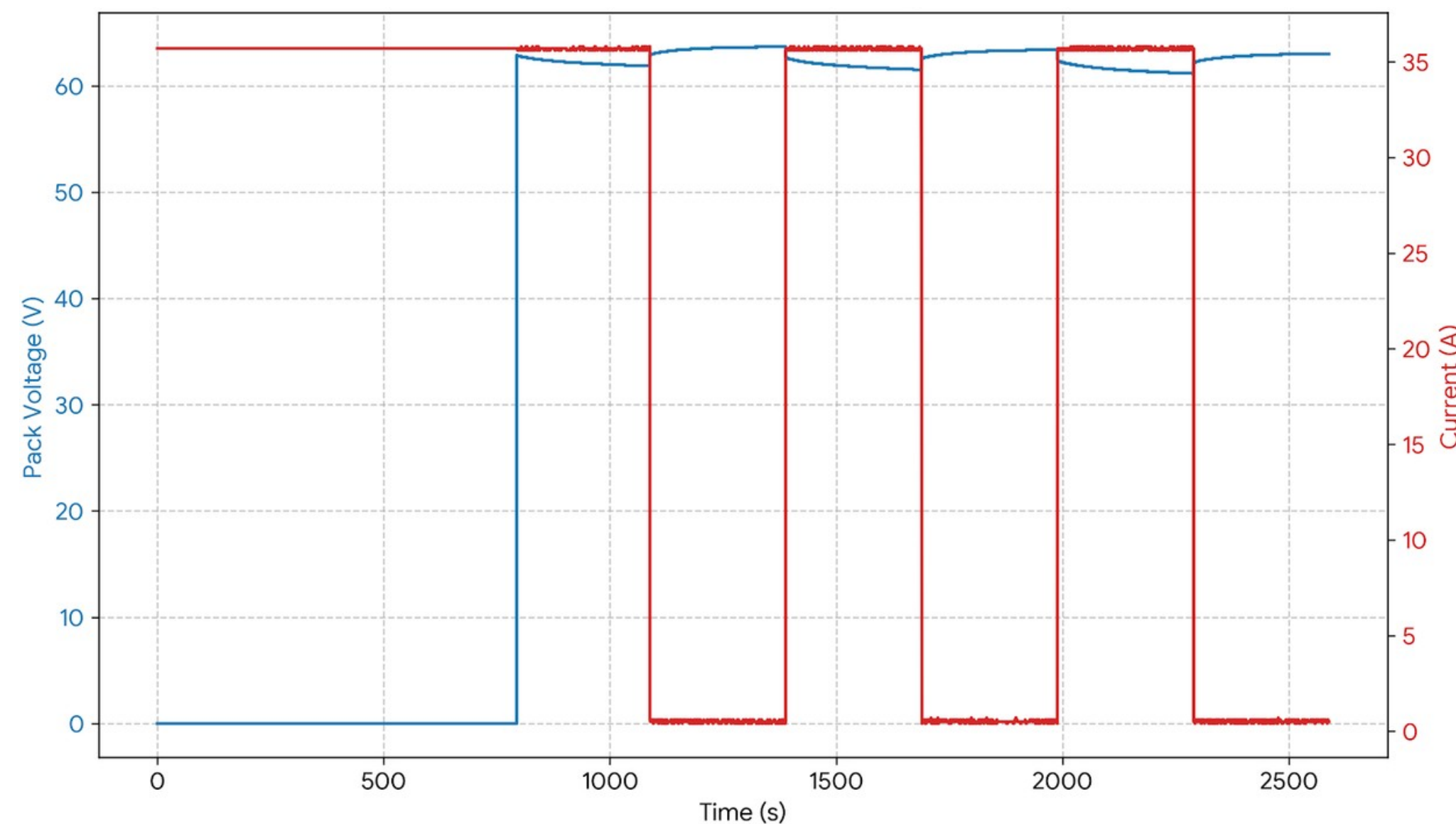
➔ Second-life BESS Validation - Temperature Profiles



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

➔ Second-life BESS Validation

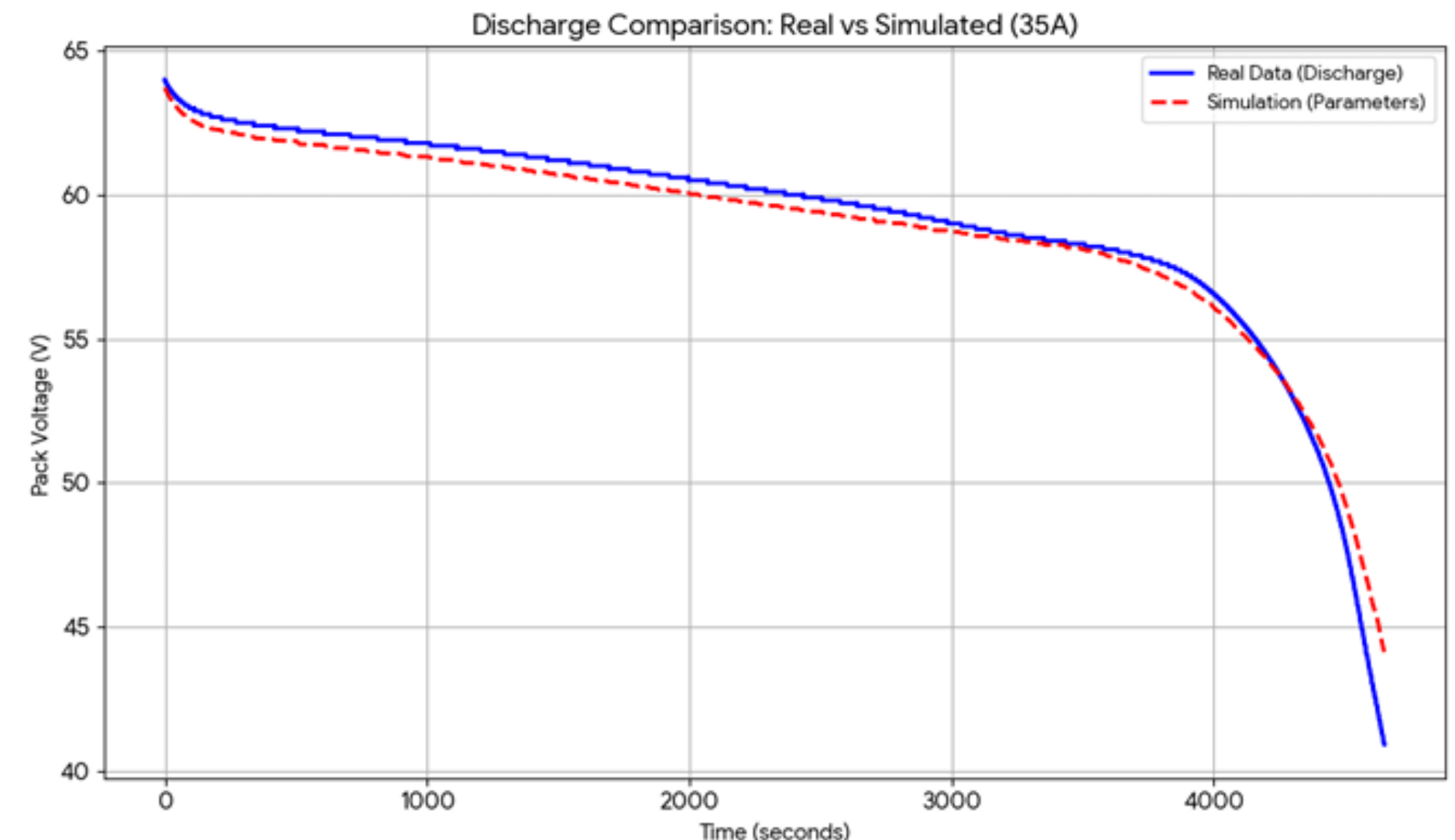
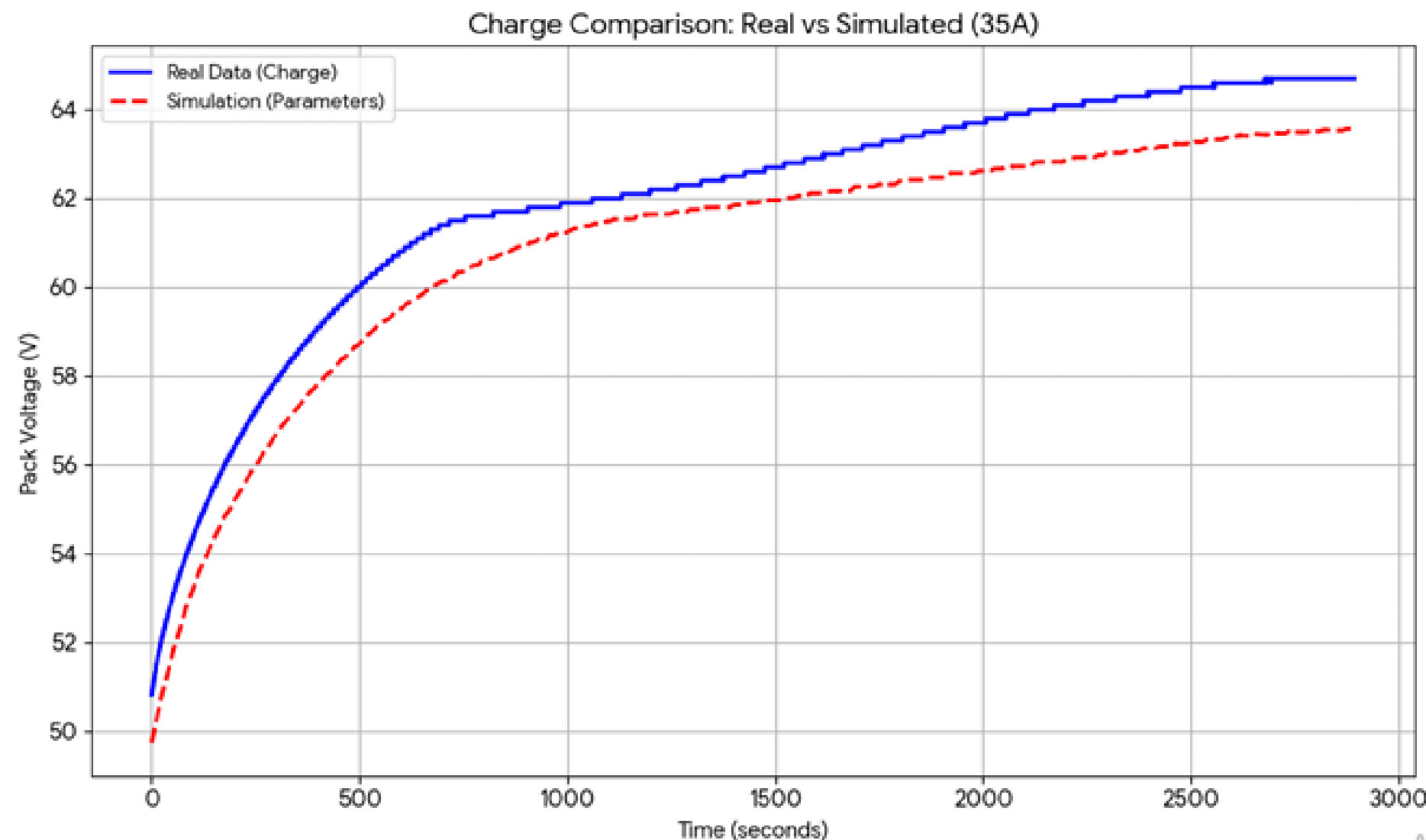
- Operation under Pulsed Discharge Condition



- **A 60V/2.5 kWh BESS: From Research Experience to Guidelines for Industry**

➔ Second-life BESS Validation

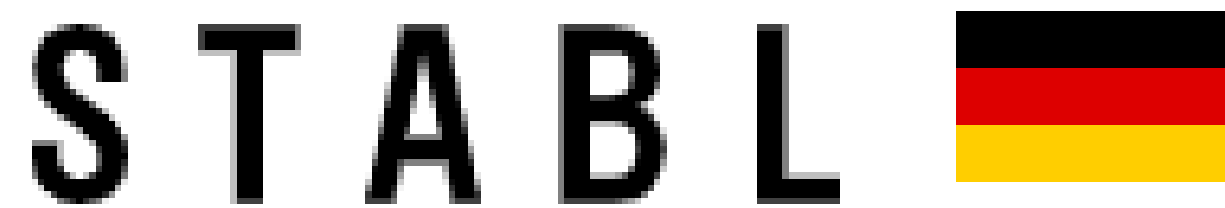
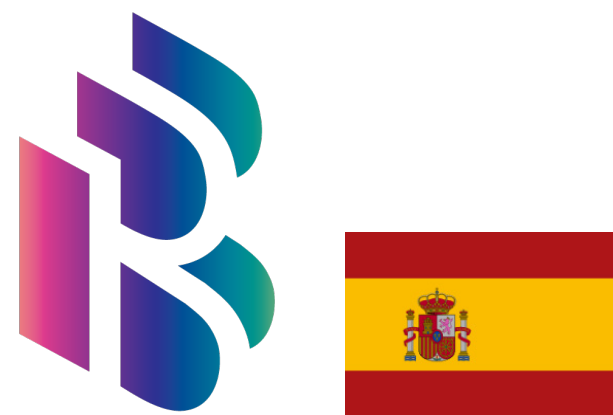
- Simulation Results x Experimental Results



➔ Second-life Batteries

• Startups and Companies

➔ Global



➔ Second-life Batteries

- Startups and Companies















- ➔ Brazil



➔ Second-life Batteries

• Applications

KEY BESS APPLICATIONS

1. RENEWABLE ENERGY INTEGRATION	2. COMMERCIAL & INDUSTRIAL (C&I)	3. GRID SERVICES & ANCILLARY MARKETS	4. EV CHARGING INFRASTRUCTURE SUPPORT	5. OFF-GRID & MICROGRIDS	6. RESIDENTIAL STORAGE	7. BACKUP POWER SYSTEMS
						
						
<ul style="list-style-type: none">• Solar self-consumption• Time-shifting (day → night)• Smoothing intermittent solar/wind output	<ul style="list-style-type: none">• Peak shaving• Load shifting• Demand charge management• Backup power	<ul style="list-style-type: none">• Frequency regulation• Voltage support• Spinning reserve (limited use)	<ul style="list-style-type: none">• Buffer high-power charging loads• Reduce grid upgrade costs• Peak load buffering	<ul style="list-style-type: none">• Rural electrification• Island grids• Mining / remote industrial sites	<ul style="list-style-type: none">• Store solar energy• Use at night• Backup during outages	<ul style="list-style-type: none">• Telecom towers• Data centers• Hospitals (secondary)• UPS / emergency power
Reduces curtailment and increases clean energy use	Lower electricity bills and improved reliability	Supports grid stability and efficiency	Enables fast charging with limited grid capacity	Reliable power in remote or weak-grid areas	Improves energy freedom and resilience	Provides reliable backup during outages

- **Conclusions**

- ➔ **Challenges vs Opportunities Framework**

- ➔ **Disassembling Process: Time and Cost**

- ➔ **Battery pack design-oriented for second-life use**

- ➔ **Standardization across packs**

- ➔ **Automation**

- ➔ **Classification: SoH Estimation**

- ➔ **Battery passport (Regulation)**

- ➔ **AI-based solutions for modeling and estimation (Generative-AI, Transformer, AutoML)**

- **Conclusions**

- ➔ **Challenges vs Opportunities Framework**

- ➔ **BESS Designing: Cost and Safety**

- ➔ **Integrated Mechanical, Electrical and Thermal Design (Multiphysics CAD)**
- ➔ **Redundant Protection**
- ➔ **RUL – Remain Useful Life**
- ➔ **BMS Design**

➔ Second-life Batteries

- Acknowledgement



➔ Second-life Batteries

- Acknowledgement



- Acknowledgement



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