Institute for Integrated Energy Systems

Second-life battery diagnostics using electrochemical impedance spectroscopy

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Citation: Murphy, L.; Crawford, C. (2025) Second-life battery diagnostics using electrochemical impedance spectroscopy *IESVic Energy Brief*

Published: August 18, 2025

ISSN 2818-159X (Print)
ISSN 2818-1603 (Online)

Key messages

- The second-life battery industry is nascent and reliant on uncertain battery inputs
- Electrochemical impedance spectroscopy is a promising method for battery characterization tests
- Policies such as the EU battery passport are beginning to emerge to aide in creating a circular economy for Lithium-ion batteries

Importance: The variability of second-life battery degradation is an industry obstacle

Retired electric vehicle batteries are set to increase exponentially over the next 20 years, raising questions about how to manage them in a sustainable and economical way. Re-using Lithium-ion batteries in less demanding “second-life” applications can reduce overall life cycle costs, curb emissions, and alleviate pressure on the recycling industry (Dong et al., 2023). However, this emerging market faces serious challenges as second-life batteries are prone to uncertain performance decline (Figure 1).

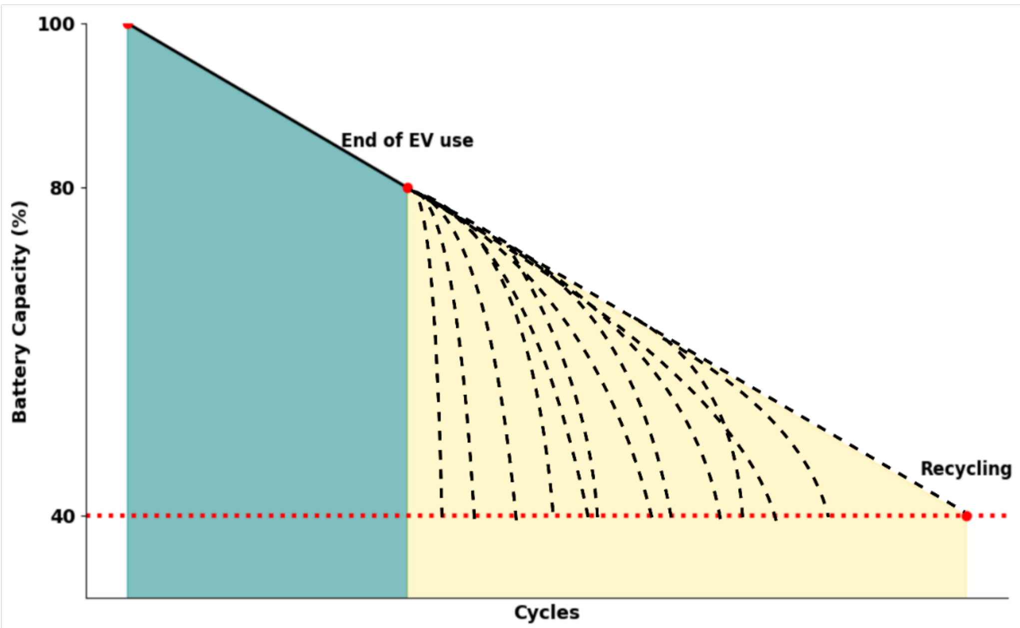

Figure 1: A simplified battery capacity trajectory segmented into first and second life.

Appropriate sorting of these second-life batteries at the time of repurposing based on their condition can help eliminate unpredictable degradation, thereby reducing financial and safety risks for re-purposing companies. To optimize this process, diagnostic tools and testing are used to help determine whether these used batteries should be re-used or recycled; the industry standard currently is to run a full charge-discharge test to determine energy capacity. However, the sorting methods for these batteries also requires consideration of their practicality based on speed and cost, which must also be balanced with accuracy.

Opportunities and barriers: EIS measurement sensitivity is a double-edged sword

To help decide whether a battery is suitable for a second use, we have investigated a health testing method called. Electrochemical Impedance Spectroscopy (EIS). EIS measures how a battery resists the flow of electricity by sending small electrical signals through it. This provides data regarding internal chemical changes within the battery which yield insights on present and future degradation. Using this data, we trained a machine learning model to classify batteries for re-use or recycle. We found that EIS outperformed a more traditional capacity measurement-informed model by a factor of over 15% accuracy (Murphy & Crawford, 2025). With EIS tests taking only a few minutes to perform, they're also much faster than charge-discharge testing. This makes EIS a strong initial screening approach to provide a fast and more detailed assessment of battery health to complement a charge-discharge capacity test.

While EIS measurements work well due to their sensitivity to battery degradation, they are also reactive to other factors such as temperature, state of charge, and current, which can make it difficult to decipher the differences between battery wear and testing conditions. In the PRIMED battery testing lab, we are cycling retired Nissan Leaf batteries and taking regular EIS measurements using advanced hardware provided through a partnership with Pulsenics to study how environmental and operational conditions affect the results. For example, we have found that EIS data may vary by approximately 50% between 10 and 40 degrees Celsius, and 15% between 0 and 100% state of charge. These effects may lead to incorrect assessments when prospective second-life batteries are not tested in a controlled environment.

Next steps: Addressing the challenges of second life battery diagnosis in industry

As EIS continues to show promise in evaluating the health and performance of SLBs, incorporating operational variables like temperature and state of charge which affect measurements in real-world conditions is a logical next step. The PRIMED dataset will support researchers in exploring how these factors influence battery diagnosis. As SLB diagnostic tools advance, policymakers and industry standards must be flexible to keep pace with the evolving market. In particular, start-up battery re-purposing companies often face prohibitively high up-front costs for battery re-certification accreditation (McCrossan & Shankaravelu, 2021). Regulatory support and adaptation to new battery certification methods can help lower these barriers. OEMs may have useful lifetime cycling data that is not available to repurposing companies without explicit coordination. Europe is leading in this direction with the upcoming "battery passport" (Gianvincenzi et al., 2024). This will require data transparency in keys areas such as battery usage, materials, carbon footprint, and health data, that can help facilitate a circular economy for Lithium-ion batteries.

References

Dong, Q., Liang, S., Li, J., Kim, H. C., Shen, W., & Wallington, T. J. (2023). Cost, energy, and carbon footprint benefits of second-life electric vehicle battery use. *iScience*, *26*(7), 107195. https://doi.org/10.1016/j.isci.2023.107195

Gianvincenzi, M., Marconi, M., Mosconi, E. M., & Tola, F. (2024). A Standardized Data Model for the Battery Passport: Paving the Way for Sustainable Battery Management. *Procedia CIRP*, *122*, 103–108. https://doi.org/10.1016/j.procir.2024.01.014

McCrossan, C., & Shankaravelu, K. (2021). A Review of the Second Life Electric Vehicle Battery Landscape from a Business and Technology Perspective. *2021 IEEE Green Technologies Conference (GreenTech)*, 416–423. https://doi.org/10.1109/GreenTech48523.2021.00071

Murphy, L., & Crawford, C. (2025). *Data-Driven Classification of Lithium-Ion Batteries for Second-Life Applications. Journal of Energy Storage.* https://doi.org/10.1016/j.est.2025.117994