Battery State of Health Estimator

Cooperative Research and Development Final Report

CRADA Number: CRD-23-24455

NREL Technical Contact: Paul Gasper

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-91880
November 2024

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Cooperative Research and Development Final Report

Report Date: October 22, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Renewance, Inc.

CRADA Number: CRD-23-24455

CRADA Title: Battery State of Health Estimator

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Vehicle Technologies Office

Joint Work Statement Funding Table showing DOE Commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$100,000.00
TOTALS	$100,000.00

Executive Summary of CRADA Work:

NREL has developed a software tool to enable Renewance to estimate the degradation of batteries from basic information such as the type of battery and the application of that battery during its first life, so that used batteries may be evaluated for potential repurposing at low cost. This software tool utilizes NREL's BLAST-Lite battery degradation modeling code, which was updated with additional models for commercially produced lithium-ion batteries as a part of this CRADA. The software tool enables users to input details such as battery type and application so that lifetime estimates can be made without any programming or expert battery knowledge. The application input loads in saved values for parameters such as cycles per year, depth-of-discharge, and other battery operating parameters from a file defined by Renewance. These parameters may be modified to refine simulations for specific batteries.

The software tool also incorporates a degradation model optimization tool, whereby existing battery degradation models may be tuned according to measured battery health. This ensures that new models still predict degradation behaviors expected from a certain battery chemistry, but with the overall degradation rate tuned to a specific battery make and model. The new model can then be saved for estimating the degradation of other similar batteries.

An additional task was planned to utilize machine-learning to enable battery health diagnosis from rapid EIS measurements to accelerate the screening of used batteries. This task was not completed due to lack of available data for training a machine-learning model.

CRADA benefit to DOE, Participant, and US Taxpayer:

Further development of open-source software tool BLAST-Lite for predicting the lifetime of commercially produced Lithium-ion batteries (NREL SWR-22-69).

Summary of Research Results:

Task 1: Integrate New and Updated Battery Degradation Models

NREL shall integrate the new and updated battery degradation models based on publicly available battery degradation data into the previous reuse estimation algorithm with logic to handle the additional inputs and specificity enabled by this update. The primary metric used for this evaluation is estimated battery state of health based on basic input parameters by market segment such as battery type, original nameplate performance characteristics, and application history as well as any additional parameters required by the updated degradation models.

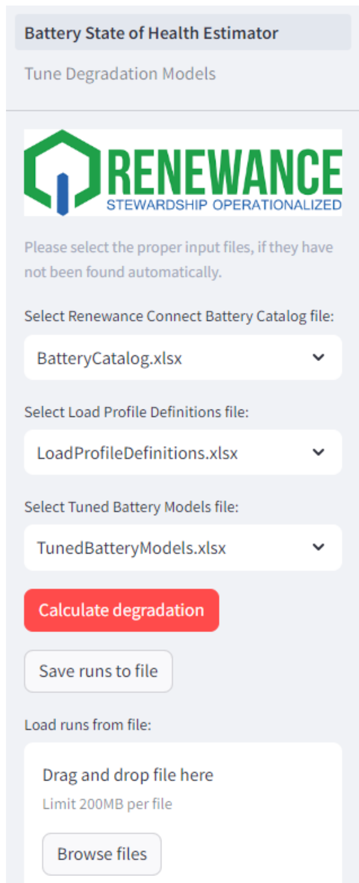

Figure 1: Sidebar of the 'Battery State of Health Estimator'. Pages at the top allow users to swap between estimating battery degradation or tuning a degradation model to data (Task 3). Various files with lists of battery types and load profiles (first life applications) are loaded to give users presets for most required simulation inputs. Once degradation is calculated, users may save results or reload previously saved simulations.

Five additional battery degradation models were added to the software during this work:

- Sony-Murata NCA-GrSi cells fit to data reported in [1]
- Four models of commercial lithium-ion cells tested at NREL and reported in [2]

These new models were incorporated into the existing BLAST-Lite software [3]. Further improvements made to the BLAST-Lite software also include restructuring how models are solved to dramatically reduce computation time for certain types of simulations used by Renewance, and making the library into a PyPi package, allowing Renewance to update the software as NREL may add new degradation models or new capabilities to the BLAST-Lite software in the future.

The BLAST-Lite battery degradation models were then used as the core modeling component for the 'Battery State of Health Estimator' interface. The Battery State-of-Health Estimator tool enables Renewance to quickly screen incoming end-of-first-life batteries by giving estimates of a battery's health without needing to make any capacity measurements, acting as a qualitative way to sort batteries to second-life applications or for recycling. The tool allows the user to quickly load common inputs such as battery characteristics and operating profiles from spreadsheets defined by Renewance, as well as enabling the user to manually change inputs as needed to modify a simulation. Simulations can be saved to file and reloaded as needed.

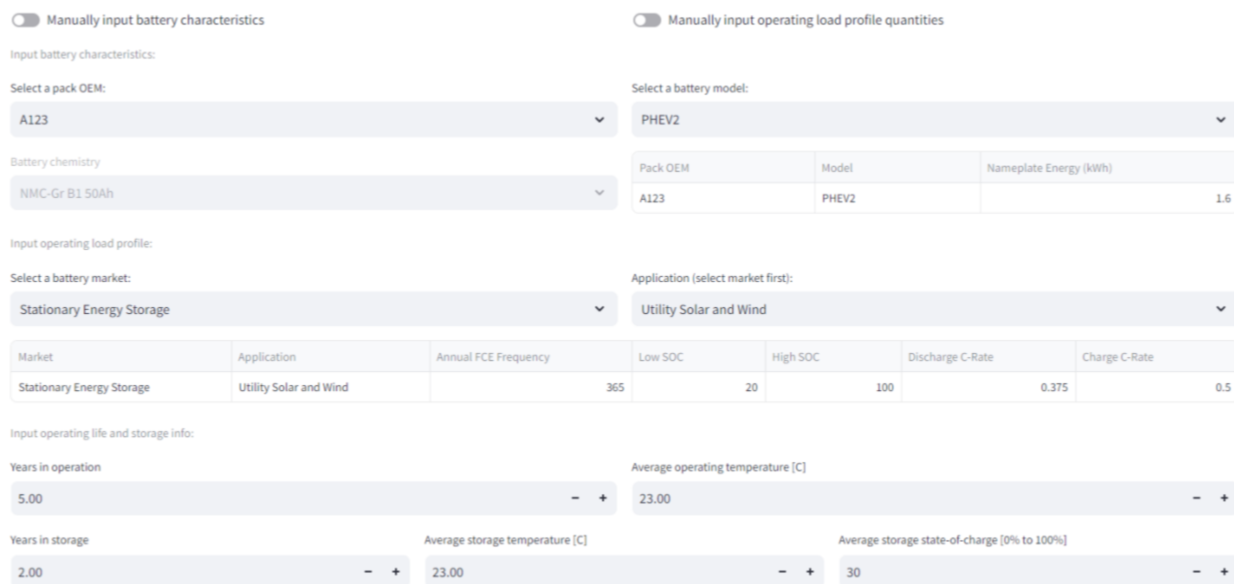

Figure 2: Main input screen for the 'Battery State of Health Estimator' interface. The user either loads battery characteristics and the first life operating load profile from the preset inputs via drop-down menus, or manually edits values for battery chemistry and operating load profile. The user must then input details such as the years in operation, years in storage, and storage conditions before calculating battery degradation.

	Run Name	Pack OEM	Model	Nameplate Energy (kWh)	Chemistry	Market	Application
0	24-08-26_162741	A123	PHEV2	1.6	NMC-Gr B1 50Ah	Stationary Energy Storage	Utility Solar and Wind
1	24-08-26_164104	A123	PHEV2	1.6	NMC-Gr B1 50Ah	Electric Vehicle	Passenger EV
2	24-08-26_164136	A123	PHEV2	1.6	NMC-Gr B1 50Ah	Electric Vehicle	Commercial EV

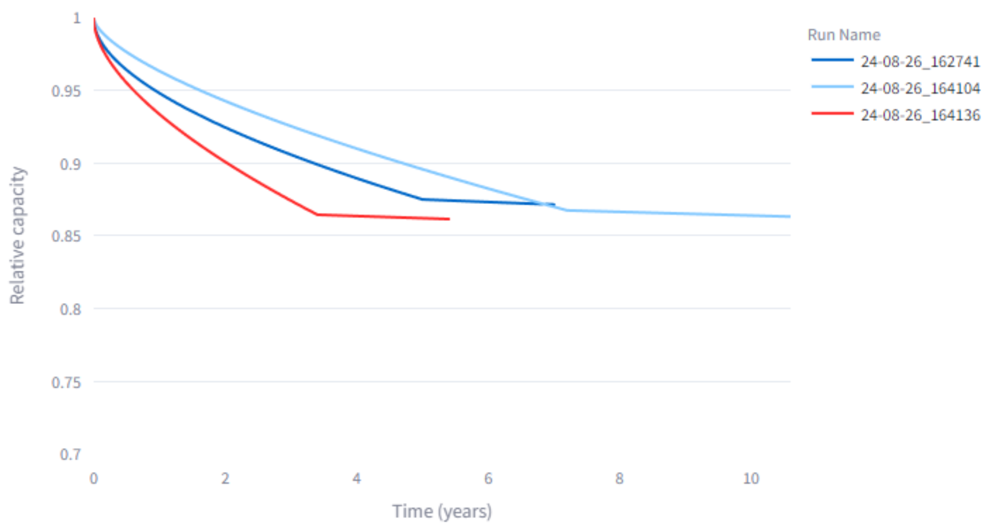

Figure 3: Example of simulation outputs. All of the inputs for any given simulation are written to a table, and the output degradation trajectories for all simulations are plotted on a graph. These simulations can be saved to an Excel file and reloaded.

Task 2: Develop Diagnostic Models

2.1 Renewance to provide battery test data to NREL

2.2 NREL shall use battery test data provided by Renewance to develop diagnostic models for use by the algorithm. The exact purpose of these new models will be determined by the availability and scope of the data provided but may include additional outputs concerning battery safety. Data provided may include open circuit voltage (OCV) at battery receipt, measured percent residual capacity, and electrochemical impedance spectroscopy (EIS) testing results.

This work was not completed due to lack of available training data from Renewance to train any useful diagnostic models.

Diagnostic data from traditional battery diagnostic tests can still be utilized to update battery degradation model predictions, as described in Task 3.

Task 3: Update Battery Life Predictions

Because BLAST-Lite is trained on publicly available battery degradation data, it is not possible to have degradation models for all battery types that Renewance might encounter. Knowing this, the Battery State-of-Health Estimator has a 'Tune Degradation Models' page, which provides users with the capability to use measured battery capacity to tune existing battery degradation models for a new battery type. These tuned models are saved to a file to be used in future simulations and can be loaded and re-tuned as Renewance acquires more battery test data to further refine estimates of battery health.

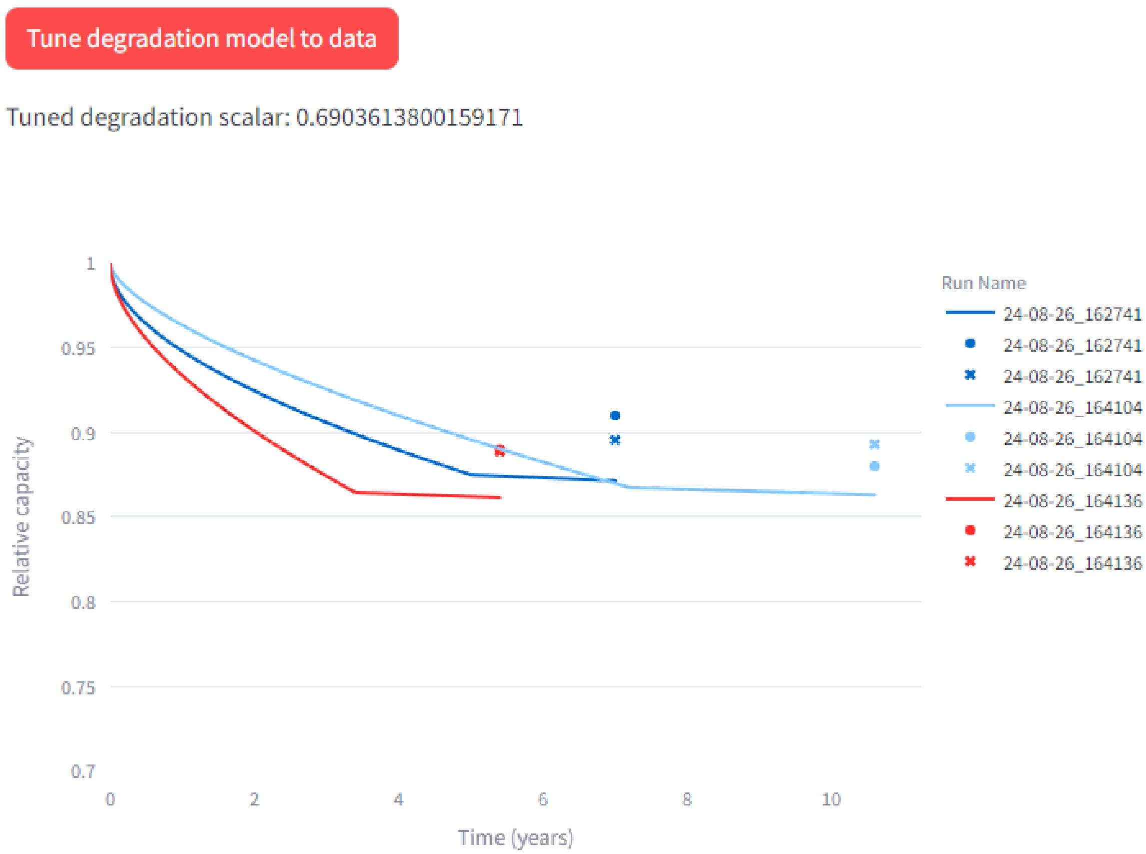

Figure 4: Example of tuning simulations to measured capacity data. The simulations shown above were used to modify the existing battery degradation model based on theoretical capacity measurements (circle markers). The example capacity measurements have a lower degradation rate than predicted by the models; the tuned degradation scalar is thus lower than 1, showing that the model tuning has correctly determined that the model should predict a slower degradation rate to match the measured capacity data as closely as possible ('x' markers). The resulting tuned model can be saved under a new name to enable users to make calibrated degradation predictions for future simulations for the same battery type.

Task 4: Project Reporting

NREL to submit brief monthly progress reports on tasks 1, 2 and 3.

Task 6: CRADA Final Report

This document is the CRADA Final Report prepared and submitted in accordance with the terms of this agreement.

References

[1] L. Wildfeuer, A. Karger, D. Aygul, N. Wassiliadis, A. Jossen, and M. Lienkamp. "Experimental degradation study of a commercial lithium-ion battery". *Journal of Power Sources* 560 (2023) 232498. https://doi.org/10.1016/j.jpowsour.2022.232498.

[2] P. Gasper, A. Saxon, Y. Shi, E. Endler, K. Smith, F.M. Thakkar. "Degradation and modeling of large-format commercial lithium-ion cells as a function of chemistry, design, and aging conditions". *Journal of Energy Storage* 73 (2023) 109042. https://doi.org/10.1016/j.est.2023.109042.

[3] P. Gasper and N. Prakash. https://github.com/NREL/BLAST-Lite

Subject Inventions:

None

ROI:

None