CellSage

Understanding and Predicting Battery Lifecycles

Emerging battery and energy storage technologies carry tremendous promise, although there remain challenging gaps in understanding how to measure, monitor, and manage complex battery systems used in a wide variety of applications. In fact, current development of new materials and battery architectures generally outpaces the ability to understand the impact of deploying battery designs for various scenarios.

Battery aging is one area of premier importance. Given battery cell chemistry and usage patterns, there are numerous degradation pathways that possess distinct sensitivities to environmental factors (e.g., temperature), plus the nature and frequency of battery duty cycles.

Currently, battery diagnostics tend to be chemistry or application specific that correlate simple, non-invasive and passive measurements (voltage, current and temperature) to empirical trends of aging. Without a more sophisticated approach, current methods cannot accurately predict battery aging trends outside these specific diagnostics. A more complete picture of battery health is needed, including health metrics such as kinetic performance, capacity loss, conductance fade, power loss, and ancillary quantities.

INL's CellSage (aka Cell's Age) is an advanced research and development software tool that closes this knowledge gap. It provides a means toward more comprehensive battery performance characterization, as well as diagnostics and prognostics of aging mechanisms.

Partnering with DOE, CellSage was developed at INL, leveraging essential contributions from thermodynamics and chemical kinetics of degradation reactions. Regarding the cell as a batch reactor (Fig. 1) permits consideration of multiple aging parameters or stress factors within a highly efficient mathematical framework. Sigmoidal-based mathematics delivers self-consistent and seamless evaluations of rate expressions tied to each aging mechanism.

CellSage modeling provides information that can be used to optimize battery design and usage profiles, but also to develop battery management schemes for complex and variable combinations of operating and environmental conditions. This tool predicts aging path dependence by accounting for how time-variant operating and environmental variables impact battery health during

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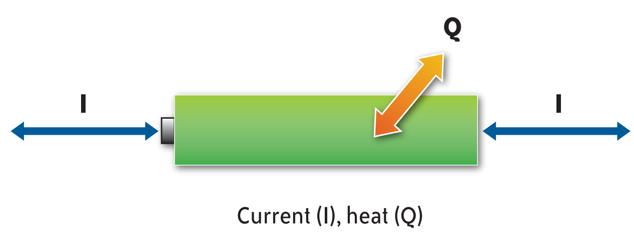

Fig. 1. Modeling an electrochemical cell as a batch reactor. CellSage considers multiple parameters tied to cell aging.

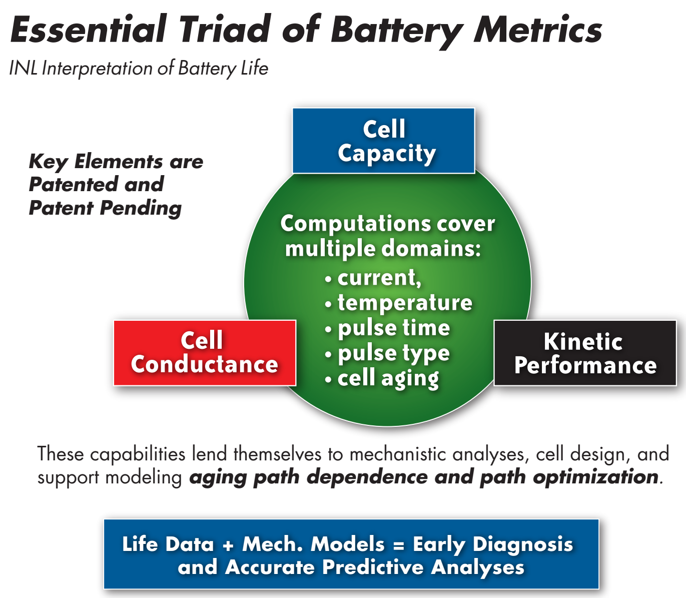

Fig. 2. CellSage battery metrics essential to comprehensive understanding of aging processes that impact performance

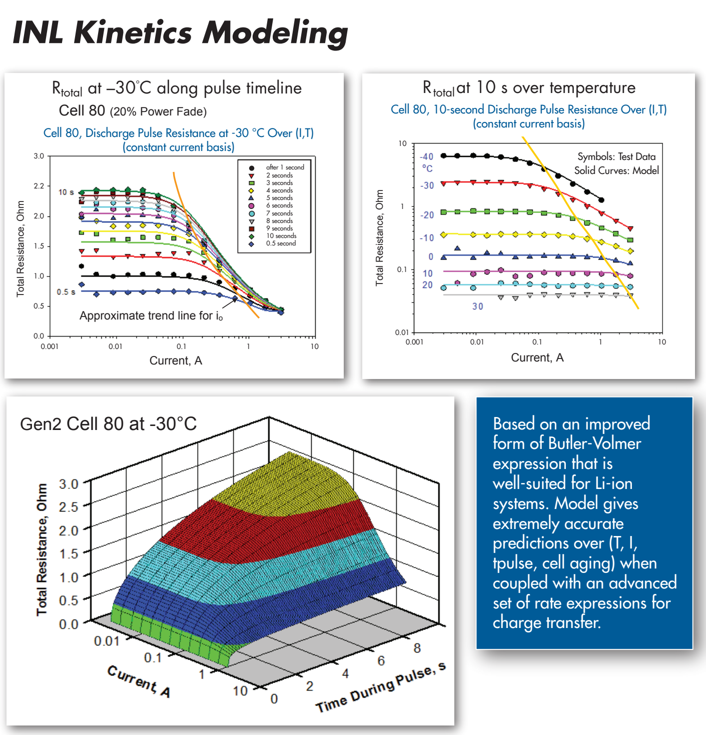

Fig. 3. Example of using CellSage tools for evaluation of cell kinetic performance.

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the entire projected life of the battery. For example, CellSage accounts for accelerated aging at the materials level due to the effects of ambient daily thermal cycling (DTC), which varies with geographic location and with time of year.

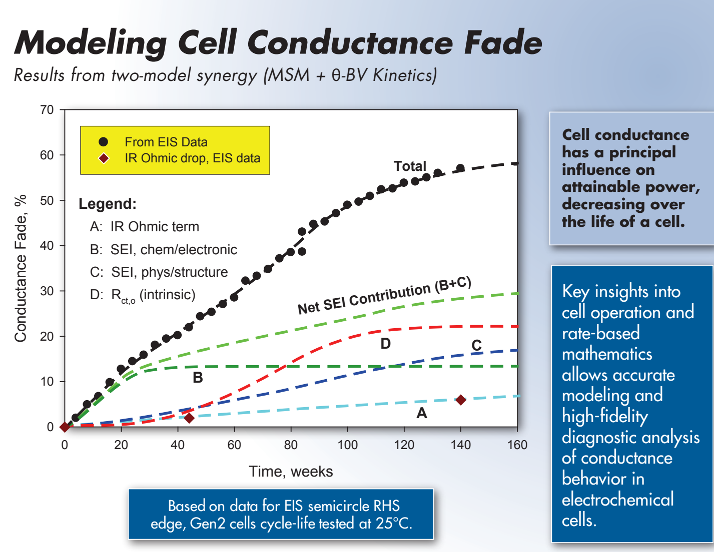
INL's patented, patent-pending, and copyrighted CellSage uses algorithmic modeling solutions to predict battery performance and life in terms of the essential triad of cell capacity, cell conductance, and kinetic performance (Fig. 2).

Changes in battery performance are assessed and documented during unique conditions tied to each discrete time step. This permits CellSage to directly apply chemical kinetics rate expressions at each condition, covering distinct mechanisms that impact battery health (such as loss of active host sites and lithium loss). However, collectively it also accounts for the net change in a chosen metric (e.g., capacity loss) over time for a particular characterization condition.

These capabilities support mechanistic analyses and cell design, leading to aging path dependence modeling and optimization of the "path" in terms of battery usage and management profiles. CellSage modeling can cover multiple domains – electrical current, state of charge, temperature, pulse time, pulse type, and cell aging (e.g., key stress factors).

Simply, cell performance data over time, plus robust mechanistic interpretations provided by CellSage algorithmic models, support early diagnosis, predictive analyses, and improved battery design and usage mapping. Aging trends can be predicted at arbitrary field conditions that are variable over service life,

Fig. 4. Example of using CellSage tools for evaluation of cell conductance fade.



permitting direct analysis of aging path dependence, life optimization, and thermal management design.

CellSage evaluation targets include cell conductance fade, electrochemical kinetics, and loss of energy storage capacity, (Figs. 3–6) and encompass multiple regimes tied to cell operation and aging. These collective modeling capabilities offer the type of insight for understanding of how a cell chemistry responds to multiple arbitrary conditions. When integrated with on-board thermal management, CellSage-enabled electric vehicle battery systems will deliver extended preservation of energy storage capacity far surpassing standard systems.

While utilizing a now-perfected algorithmic modeling scheme, CellSage's computational architecture uses Fortran at its core. This architecture is easily converted to a number of other scientific computing languages and will run on most standard laptop and desktop systems. In a real-time in-situ environment, CellSage can be integrated into battery monitoring and management systems through custom chipsets for relatively low hardware costs (Fig. 7).

Applying CellSage to targeted battery chemistries yields a deeper understanding of battery longevity, enabling a reduction in costly battery warranty claims, compression of development timelines, and mapping of battery use conditions to optimize life. CellSage also supports battery system development by characterizing cell and string performance in a virtually unlimited matrix of arbitrary environmental and operating conditions. The results are improved development cycle times and superior time-to-

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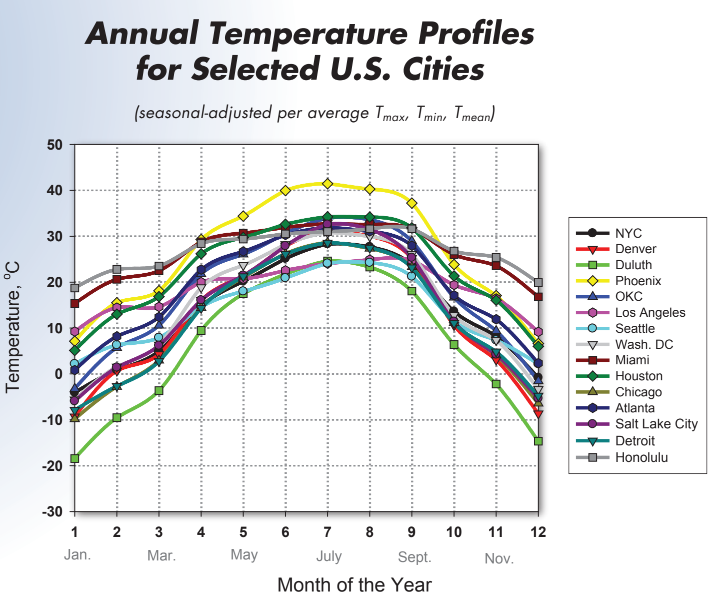
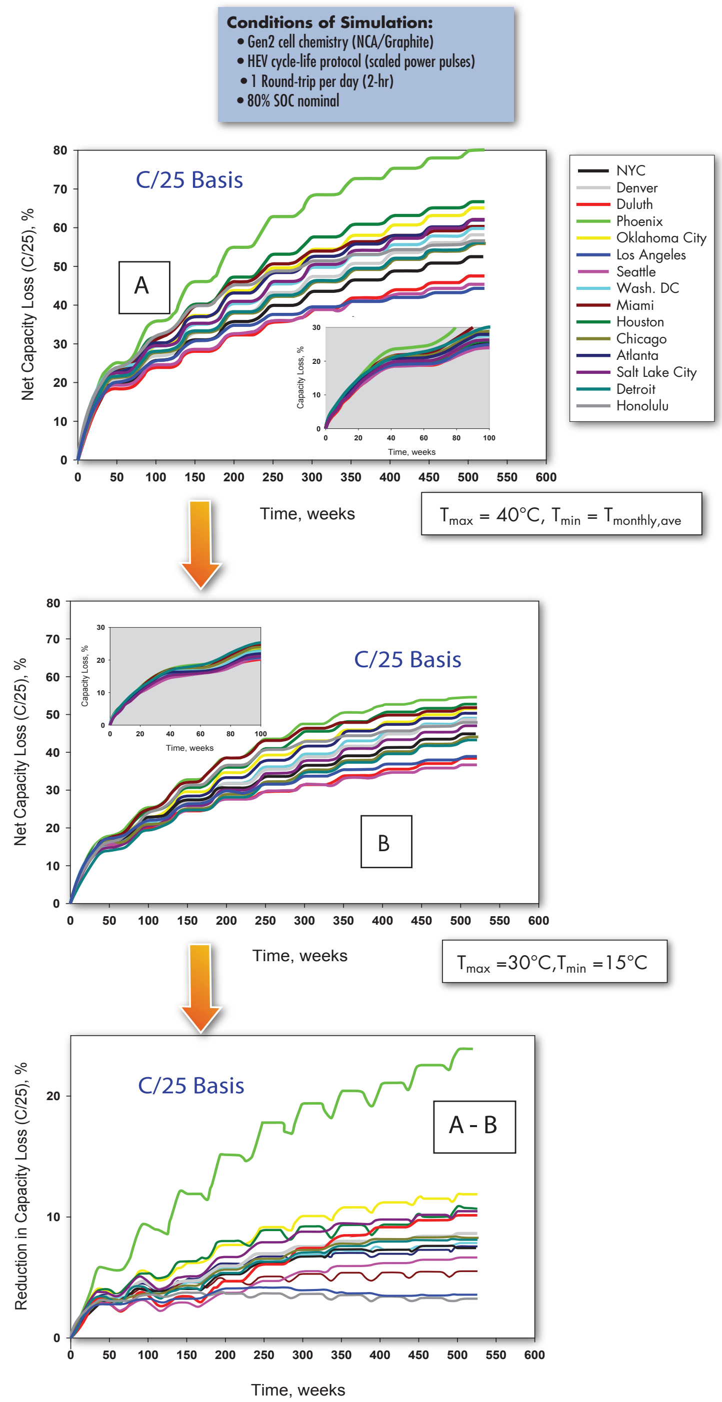
Fig. 5. Annual temperature profiles for 15 U.S. cities used in CellSage simulations of capacity loss over time.





This set of ten-year simulations show the utility of CellSage in predicting capacity loss for the Gen2 Li-ion cell chemistry, considering annual temperature profiles for the various cities, and the impact of daily thermal cycling (DTC). Through this, the impact of thermal management is seen (A-B), where the most benefit is for cities with both colder winters and warmer summers.

Fig. 6. Results from 10-year simulations of capacity losses encountered by Gen2 lithium-ion cells operated at different U.S. cities, under the shown operating conditions.

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market performance, along with higher confidence in meeting battery performance commitments. All of this will serve to improve public perception about the safety and reliability of advanced battery systems.

While it can be used in electric vehicles, CellSage also may be used for applications in the military, space, medicine, electric utilities, telecommunications, some consumer electronics, and specific uses by selected other federal agencies. The CellSage summarize key benefits offers when compared to current technologies are it:

- Performs diagnostics to enable mechanistic evaluation of degradation processes
- Predicts battery life under arbitrary conditions for warranty validation
- Supports optimization of battery pack design and related thermal managements systems for lighter and more economic designs
- Extends battery life and improves safety when integrated with on-board thermal management and monitoring frameworks
- Supports evaluation of disparate aging within cell strings (Fig. 8)
- Supports evaluation of battery secondary-use scenarios
- Can be applied to any device or system that undergoes gradual aging processes, such as those related to biological, geological, morphological, electronic, and mechanical systems.

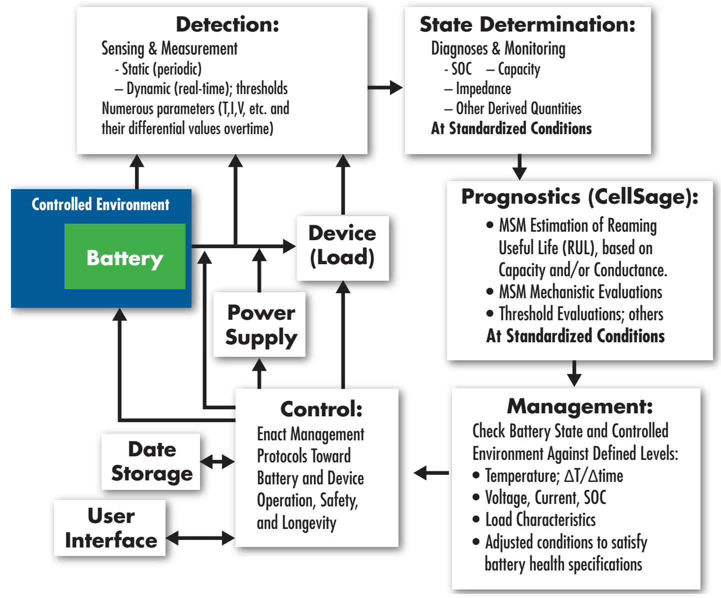

Fig. 7. Incorporation of CellSage within system for battery monitoring, management, and control.

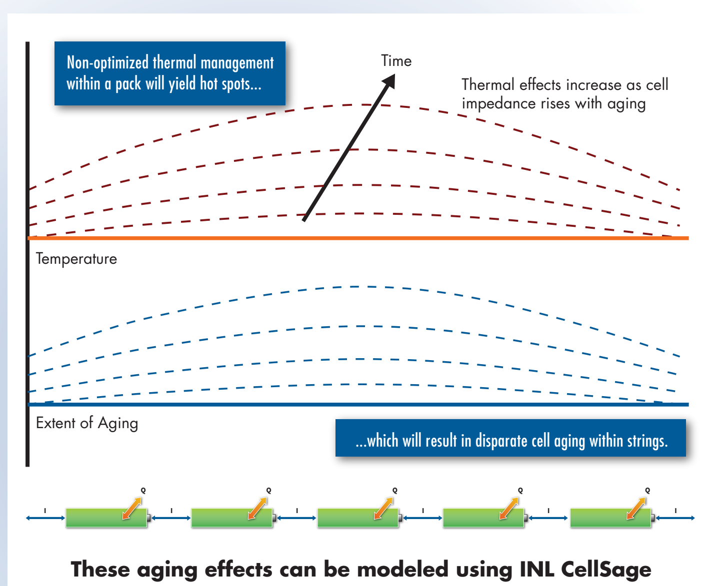

Fig. 8. Example of how CellSage would provide insights into disparate aging within cell strings, modules, and battery packs.

For more information

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