Ridgetop Group Inc
Engineering Innovation
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CellSage™
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A Modeling Tool for Diagnostic and Predictive Evaluations of Battery Life and Mission Readiness

Technology developed by: Idaho National Laboratory (INL)
Licensed & Enhanced by Ridgetop Group Inc.

INL STIMS approvals that pertain to this material:
INL/CON 10-18404, 10-20237, 11-20789, 11-23573, 12-24418, 12-27166, 13-30586

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INL
Idaho National Laboratory
www.inl.gov

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About Ridgetop Group & Idaho National Laboratory

Ridgetop Group Facilities in Tucson, AZ

- Incorporated in 2000 & Servicing:
  - Aerospace, Automotive, Industrial, & Government
- Technology leader in reliability engineering, QA, condition-based maintenance (CBM), prognostic health management (PHM), & integrated vehicle health management (IVHM) applications
- Engineering design services, circuitry for harsh environments, prognostics, & CBM/PHM/IVHM solutions
- AS9100D and ISO 9001 Certified Quality Management System (QMS) and Facilities

INL Facilities in Idaho Falls, ID

- INL is part of the U.S. Department of Energy's complex of national laboratories
- The laboratory performs work in each of the strategic goal areas of DOE:
  - Energy, National Security, Science, and Environment
- INL is the nation's leading center for nuclear energy research and development

CellSage Introduction – Click Here

CellSage Overview

What is it?

- CellSage is an advanced battery and cell aging software simulation tool, and can assess how various battery chemistries age and degrade in response to different usage profiles and operating conditions in Electric Vehicles and other battery powered systems
- CellSage calculates more than 20 vital health metrics and aging effects, including state of charge (SOC), capacity loss, cell/battery conductance loss, and power fade.
- This leading-edge simulation platform allows battery end users to create “what if” scenarios to weigh the impact of operational and environmental stress factors on battery performance and battery health. The simulations results and analysis provided by CellSage will help select the most appropriate battery for a given mission.
- CellSage is offered as a cost-effective tool that can model various types of chemistries and can accurately predict how a particular battery cell will degrade under real world operating conditions.

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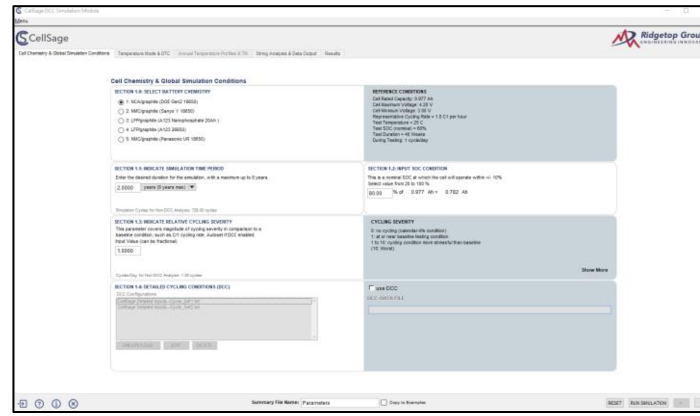

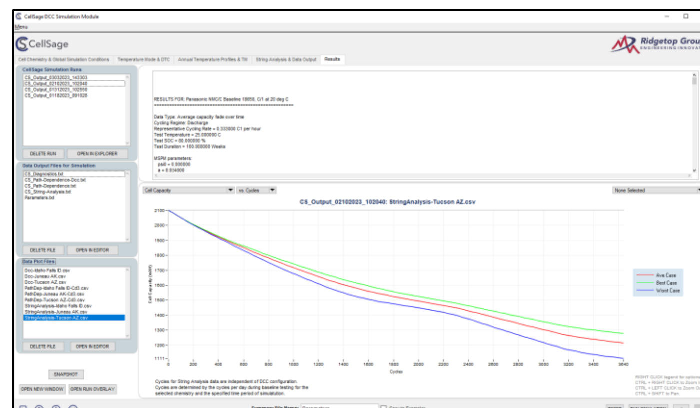

CellSage Value Proposition

- Under license from the Department of Energy's Idaho National Laboratory, Ridgetop Group has enhanced and extended CellSage to offer commercial and government customers an advanced toolbox and methodology for determining long term performance of batteries used in electric vehicles, stationary power backup systems, smart Battery Management System (BMS) designs, and the technology can even be applied to identify secondary use-cases for batteries after they have served their initial purpose and mission.
- Target Markets with Existing Customers & Partners: Electric Vehicles, Grid Energy Storage, Robotics, UAV/UAS/, etc.
- Our emphasis: maintain high-fidelity knowledge of battery aging to ensure mission planning & completion.

Technology Benefits and Value Proposition

- Decrease lifetime testing time by at least 50%
- Reduce Cost of Battery Packs by at least 5 - 20%
- Refine battery management strategies to reduce battery aging by at least 10 - 25%

Incentive: reduce uncertainty and risk to promote greater investment in battery energy storage and related products.

Patents

- US Patent 9,625,532
- US Patent 8,521,497
- US Patent 8,467,984
- US Patent 8,346,495
- US Patent App. 17/015,369
- US Patent App. 62/705,611

Awards and Contracts

- 2015 R&D 100 Finalist
- 2020 R&D 100 Finalist

Need & Solution

- Military, government, and commercial applications need tools like CellSage to help improve safety, reliability, and optimized charging protocols for target use cases by investigating their aging mechanisms and characterizing their degradation profile as it relates to:
  - Dynamic duty cycle conditions, environmental stress factors, and disparate aging among cells in the battery pack.
- Industry needs accurate physics-based modeling tools that can determine the baseline operational envelop of batteries as they age and degrade for target applications and missions.
- CellSage supports modeling, simulation, and analysis of baseline cycle life testing, diagnostics, predictions, and optimization of charge and discharge protocols.
- CellSage is adaptable to application-specific analysis of battery lifecycle trends in support of project planning, reduction of investment risk, and ongoing system monitoring and control to maximize battery life.

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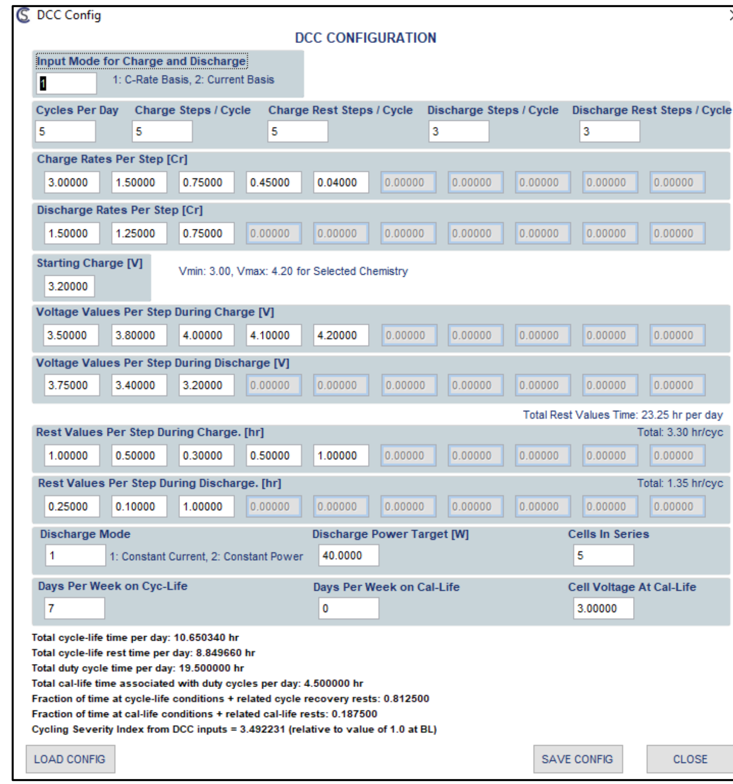
CellSage Detailed Cycling Conditions (DCC)

The CellSage DCC Module provides path dependency and string analysis data output results for a simulated duty cycle defined by the program user. This module supports interactive entry from an end user to define key application specific simulation conditions.

There are 5 main GUI tabs in the software application:

1. Cell Chemistry & Global Simulation Conditions
2. Temperature Mode & DTC
3. Annual Temperature Profiles & TM
4. String Analysis & Data Output
5. Results

The software application is offered through evaluation trials and annual term license agreements.



Typical Input Parameters

- Cell Chemistry
- Simulation Time (up to 8 years)
- SOC
- Relative Cycling Severity
- Detailed Cycling Conditions (DCC) configuration file to model application dependent duty cycles.
- Temperature Mode (Single T or Annual Temperature Profile to one or more US Cities)
- Thermal Management (TM) Conditions
- Daily Thermal Cycling (DTC) Conditions
- String Analysis Conditions

Note: Ridgetop and INL can provide customized simulation models for particular applications and chemistries via software services.

Data Outputs (DCC Module)

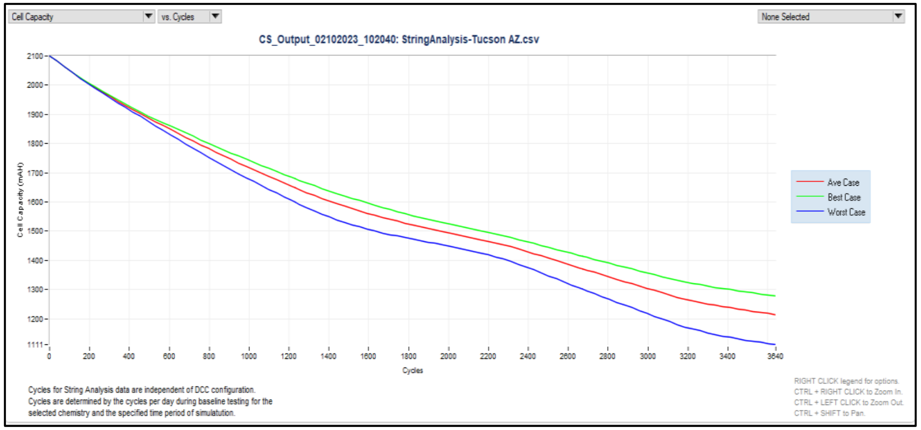
The CellSage DCC Module produces three main data output files that cover mechanistic evaluation of performance change over an arbitrarily chosen aging path.

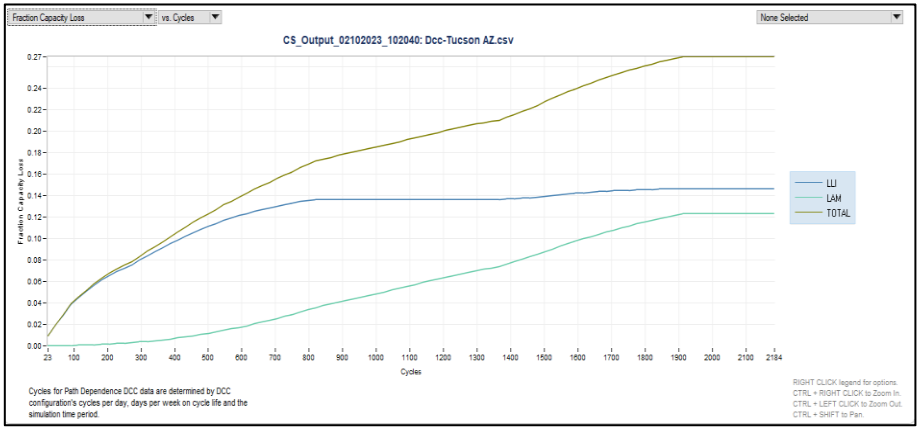
1. **CS-STRING_ANALYSIS:** This file provides analysis of available power over aging in terms of a reference voltage context and a power-at-range metric that incorporates the effect of capacity loss over time for EV, HEV, and PHEV applications.
2. **CS-PATH_DEPENDENCE**: This file provides simulated cell/battery aging at any sequence and combination of T, SOC, cycling regime over time, and also accounts for the detrimental effects of daily thermal cycling (DTC), which is dependent on the presumed geographic location of battery usage. Outputs also cover thermal management scenarios of choosing Tmin and Tmax of the battery enclosure. This file covers the arbitrarily-chosen conditions that reflect a battery duty cycle and ambient working conditions of the battery-driven product. "Path dependence" is a crucial consideration since each unique usage path for a battery within a given product will produce a unique aging path and history. One ultimate advantage to CellSage is to optimize the usage path to minimize the battery aging to satisfy life and performance requirements.
3. **CS-DIAGNOSTICS**: This file provides the intermediate simulation results determined by the regression models embedded within the CellSage software. This file is designed for inspection and validation of the simulation results.

Data Outputs Continued

Partial List of Data Output Plots:

1. String Capacity Loss vs. Weeks & Cycles
2. Fraction Capacity Loss vs. Weeks & Cycles
3. Total AH through String vs. Weeks & Cycles
4. Ohmic Resistance vs. Weeks & Cycles
5. Net Ohmic Heat vs. Weeks & Cycles
6. Fraction of Effective Discharge Power vs. Weeks & Cycles
7. String Capacity Loss (%) vs. Weeks & Cycles
8. Power at Vstart vs. Weeks & Cycles
9. Power Over Vrange vs. Weeks and Cycles





Standard Battery Libraries in CellSage

Libraries of representative cell chemistries from select battery vendors:

- Panasonic – NMC/Graphite (UR18650A)
- Sanyo – NMC/Graphite (UR18650Y)
- A123 – LFP/Graphite (25560-type and Nanophosphate 20AH)
- DOE NCA/Gr chemistry – NCA/Graphite
- LTO/LMO
- LiCoO2/Graphite

NOTE:

- *New cell chemistries can be imported into CellSage with existing baseline cycle life testing data.*
- *Ridgetop and INL also offer engineering services for application specific cycle life testing.*

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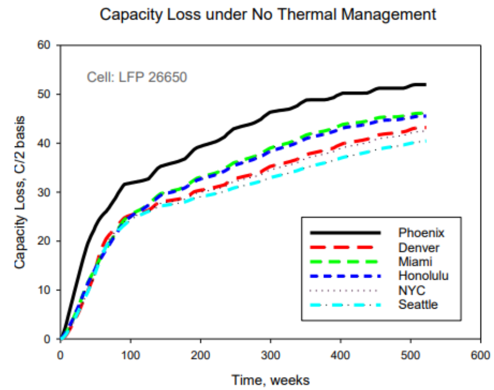
Example Simulation Results for EV Case Study

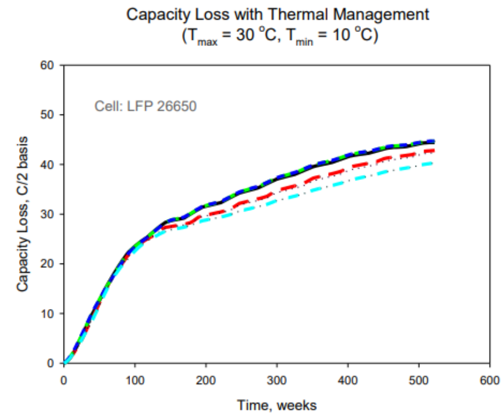
2014 Chevy Spark that uses the A123 LFP 26650 battery chemistry in CellSage

LFP Cell Aging in Select US Cities

With and Without Thermal Management

- Daily Thermal Cycling Included
- C/2 cycling basis
- 90% SOC basis





Thermal Management at the shown conditions compresses the capacity loss curves to a more consistent basis, allowing the battery to be used in diverse geographical regions.

CellSage Key Benefits

- Simulates wide range of baseline cycle life testing conditions
- Predicts battery life under arbitrary simulation conditions for warranty validation
- Performs diagnostics to enable mechanistic evaluation of degradation processes
- Supports optimization of battery pack design and related thermal management 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
- Supports evaluation of battery secondary-use scenarios
- Can be applied to any device or system that undergoes gradual aging processes and can be embedded into a smart battery management system (BMS) design

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Target Customers & Technology Pipeline

Existing Customer Segments

- Robotics Industry
- Electric Vehicle Manufacturers & Suppliers
- Grid Energy Storage
- Power Tool Industry
- Universities, Researchers, & Government Agencies

Future Target Customer Segments

- Laptop Manufacturers
- Battery Manufacturers
- Unmanned Aerial Systems (UAS) / UAVs
- Etc.

Technology Pipeline & Projects

- Q1 2023 – New chemistry import feature and expansion of cell chemistry library.
- Q2 2023 to Q3 2023 – Implementation of CellSage Kinetics Module and integration of common battery duty cycles for specific EV drive profiles and grid applications.
- Q2 2023 to Q4 2023 – Conducting customer case studies, adding global temperature profiles, and collaboration projects with select universities and battery manufacturers.

Summary

- **The immediate benefit of CellSage is to provide a basis for diagnosing and predicting battery performance and aging over arbitrary conditions, thereby improving battery design, performance and management.** Knowledge of path dependence aging gives insights to optimizing usage conditions to prolong the lifetime of batteries in service and to predict if warranties are met.
- Battery aging trends in vehicle and grid energy storage applications will vary over diverse usage conditions, where foremost parameters are geographic location, load patterns and frequency, and the extent of thermal management.
- Complex usage conditions and application specific duty cycles can be simulated, including effects from annual temperature cycles, SOC, cycling type/magnitude, and daily thermal cycling (DTC).
- This capability enables improvements in cell materials, string dynamics, and battery management schemes.
- CellSage is also poised to assist Battery Second-Use applications by simulating whether or not recycled batteries from primary EV applications can be used in second-life systems such as backup micro-grids or low end consumer electronics.

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