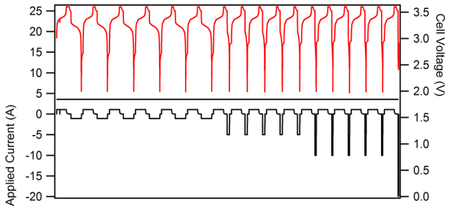
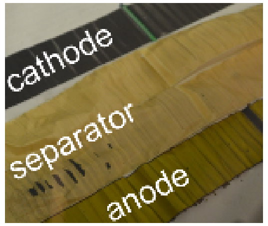
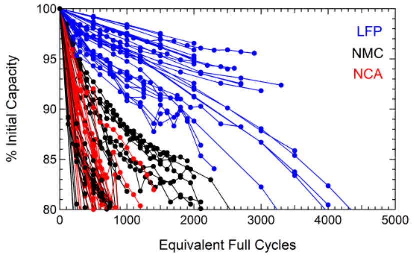
SAND2023-00884C

Sandia National Laboratories

Experiments and Data Requirements to Validate Grid Energy Storage Systems at Different Stages of Development







PRESENTED BY

Yuliya Preger

International Battery Seminar

March 21, 2023

Sandia National Laboratories
U.S. DEPARTMENT OF ENERGY NNSA

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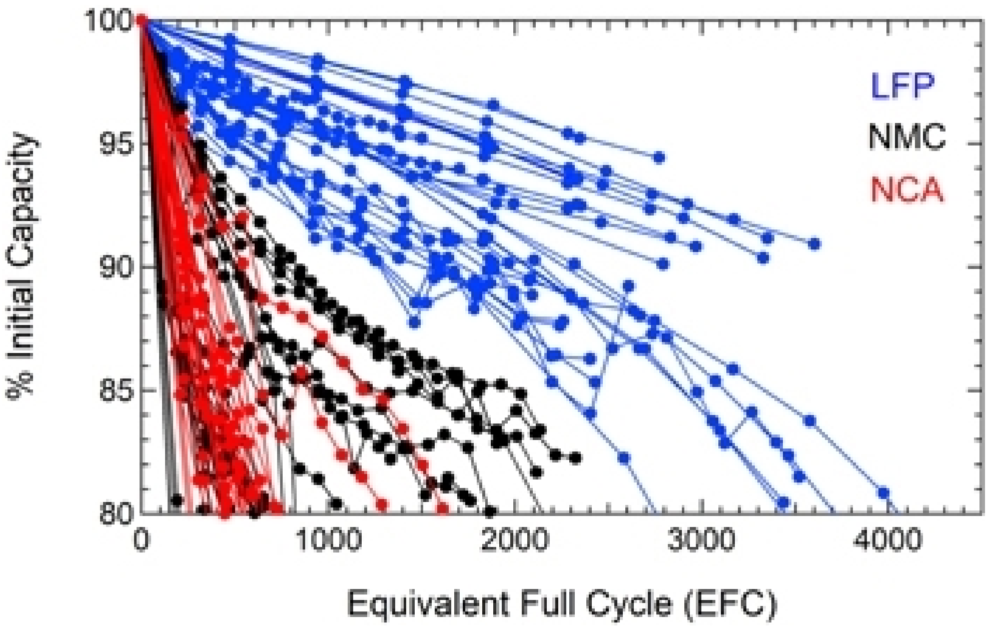
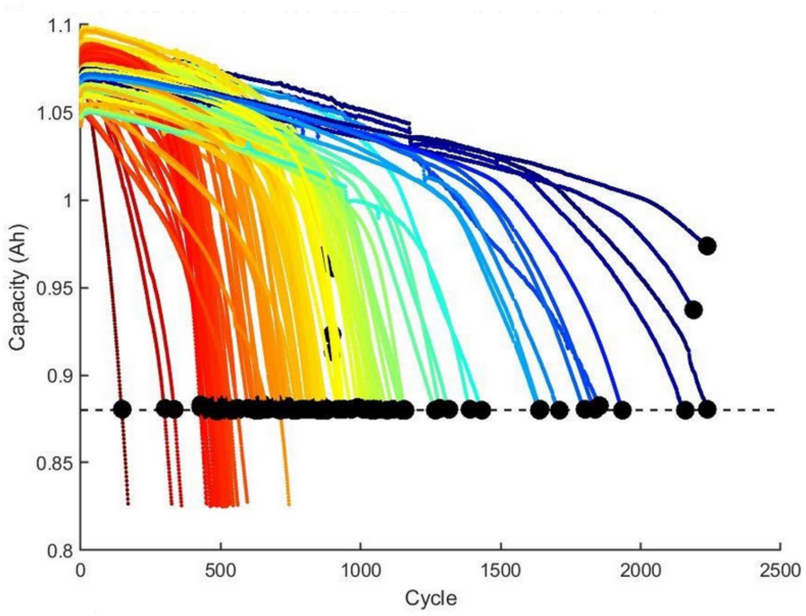
Single cell cycling and modeling can teach us a lot…

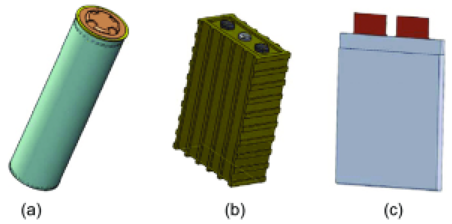


Preger et al. J. Electrochem. Soc. 2020, 167, 120532, “Degradation of Commercial Li-ion Cells as a Function of Chemistry and Cycling Conditions”

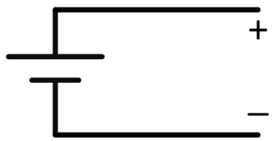


Severson et al. Nat. Energy, 2019, 4, 383, “Data-driven prediction of battery cycle life before capacity degradation”

…But cell performance doesn't always translate to complex system performance



Cells

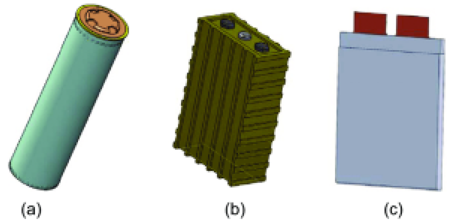


Cell – *The irreducible unit of energy storage*

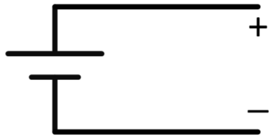
Typ. Cell Voltage: 1V – 4V, depends on chemistry

Typ. Cell Capacity: 1Ah – 100Ah, varies greatly with cell format

…But cell performance doesn't always translate to complex system performance



Cells



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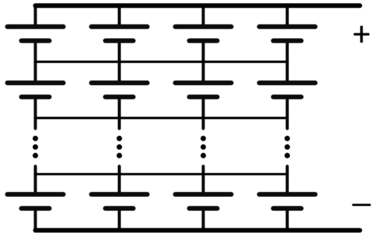
Module/Pack/Subassembly



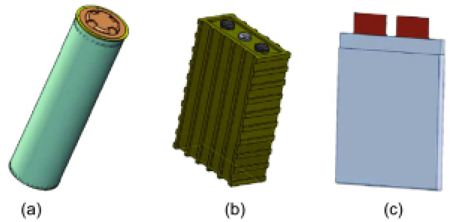
Module – *An assembly of cells in series and parallel combinations*

Usually includes sensors for monitoring, balancing electronics, and protection devices

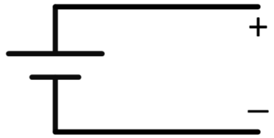
Typ. Module Voltage: 48V – 100V

Typ. Module Capacity: 1kWh – 10kWh

…But cell performance doesn't always translate to complex system performance



Cells



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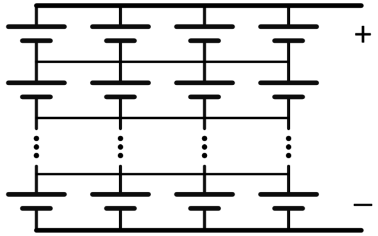

Module – *An assembly of cells in series and parallel combinations*

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Typ. Module Voltage: 48V – 100V

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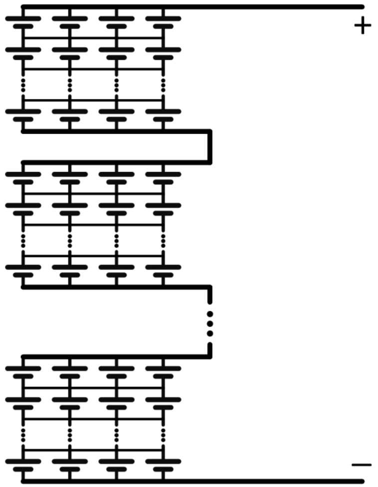
Rack/System



System – *An assembly of modules*

Modules usually series-connected within an individual rack

Racks typically connected in parallel to increase system energy capacity

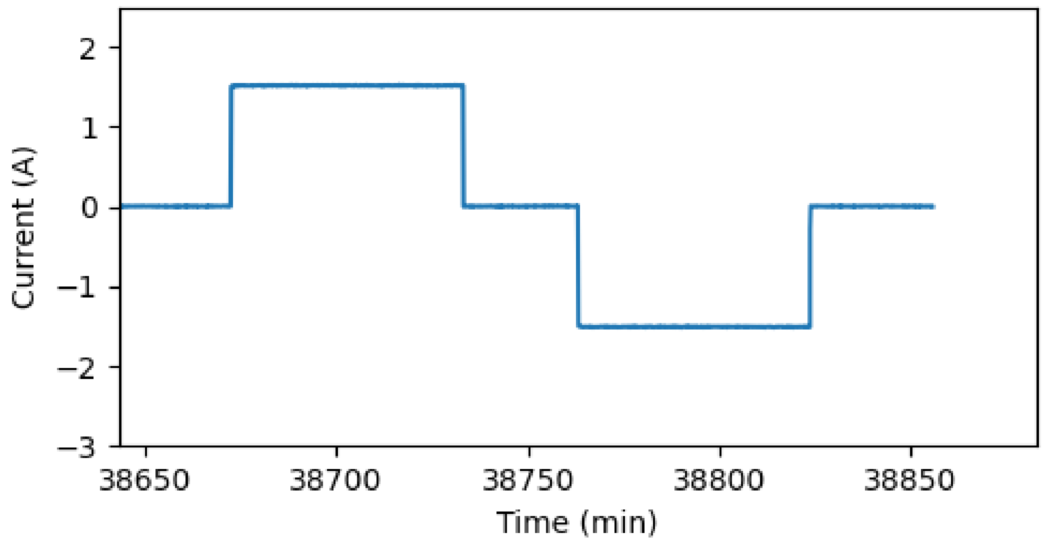
Typ. Rack Voltage: 700V – 1500V

Typ. Rack Capacity: 50kWh – 500kWh

Example 1: Current redistribution among parallel cells

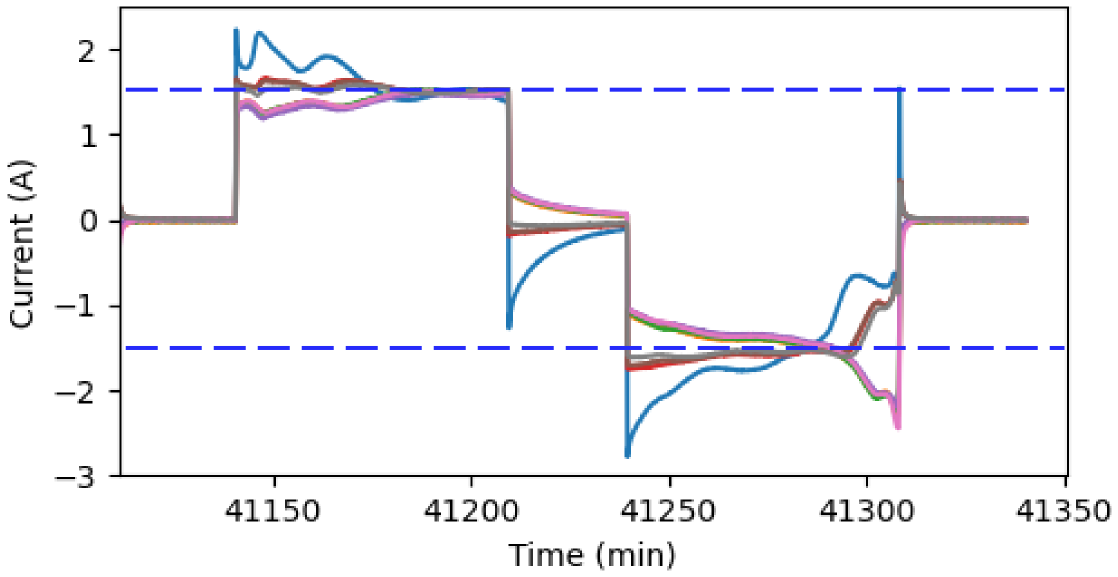
Ideal

Single cell (0.5C/0.5C cycling is 1.5A per cell)



Scale-up

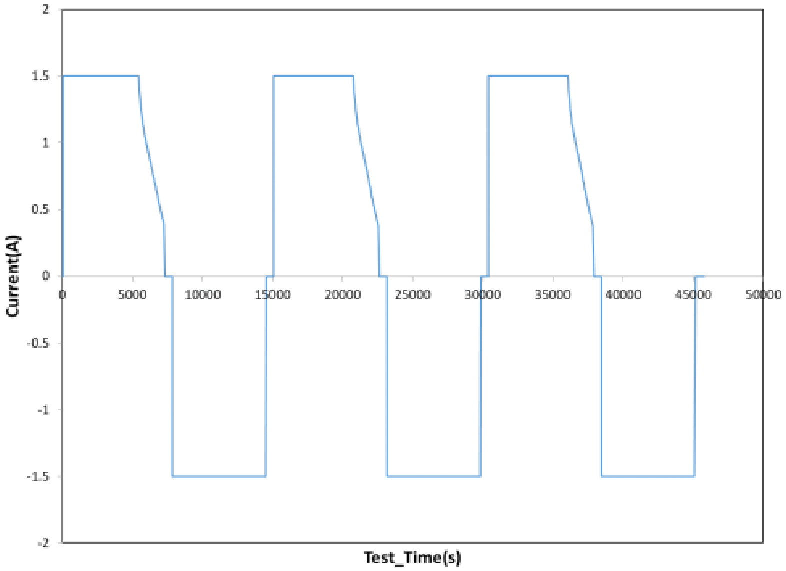
8P-1S module (0.5C/0.5C cycling is 12A per module)



Example 2: Current ripple from power electronics

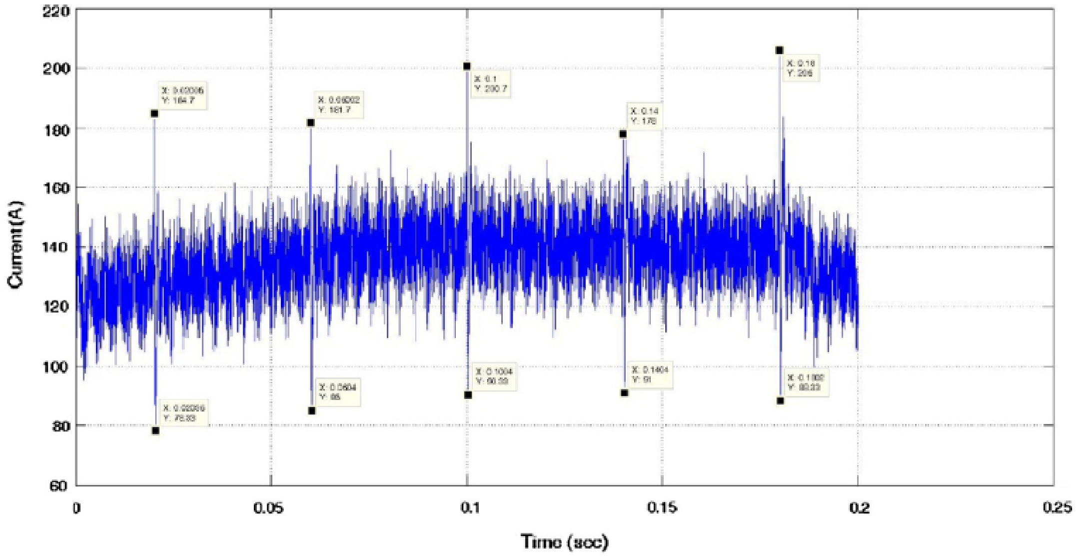
Ideal

Battery tester



Scale-up

EV or BESS



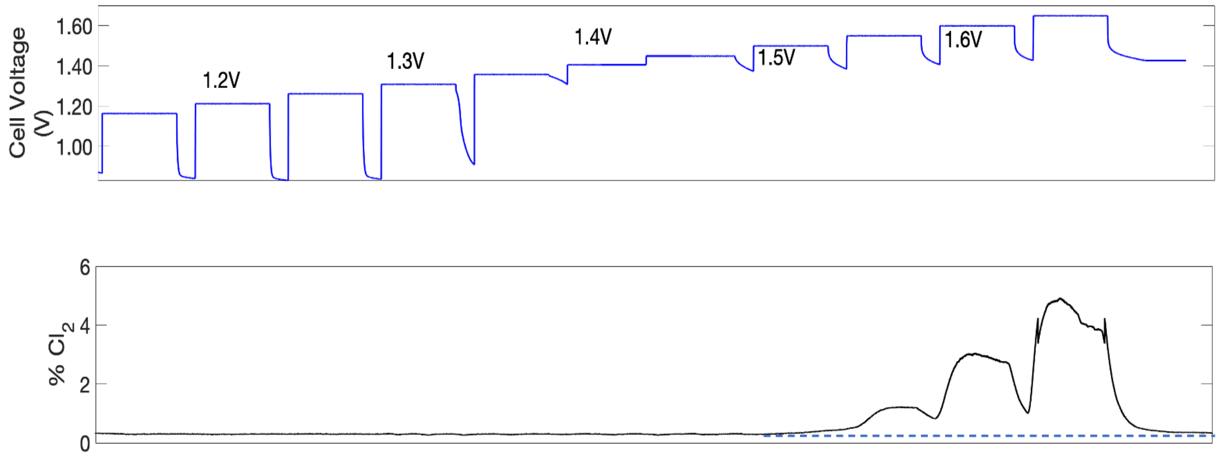
Uddin et al. *Appl. Energy*, **2016**, *178*, 142.

Lab cycling produces clean DC, but fielded systems have AC ripple from semiconductor switching and AC load dynamics

Example 3: Gas evolution in redox flow batteries

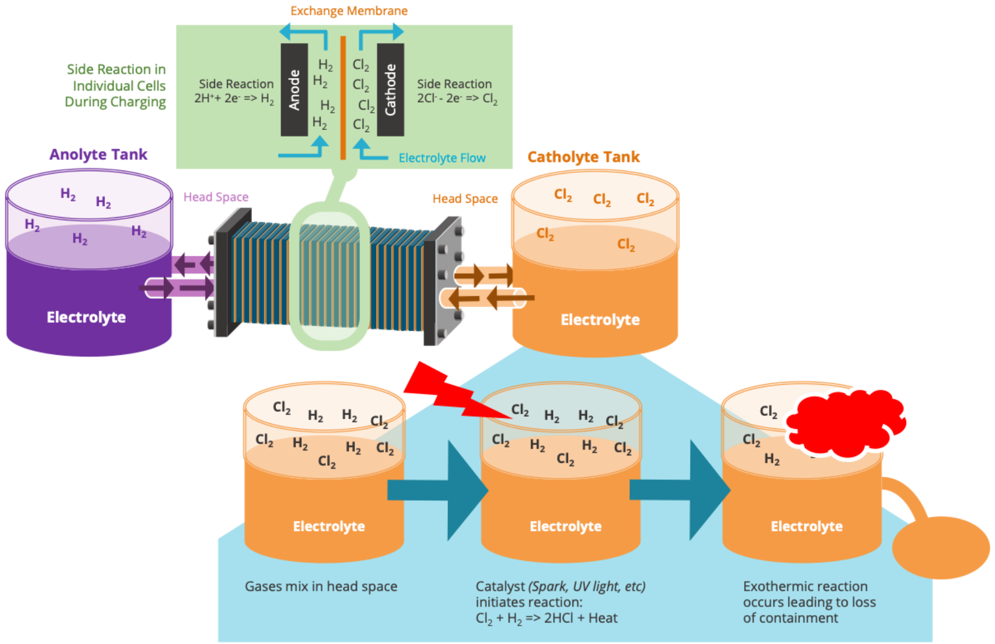
Ideal

Lab-level mixed-acid redox flow cell does not show Cl_2 gas evolution until elevated voltages



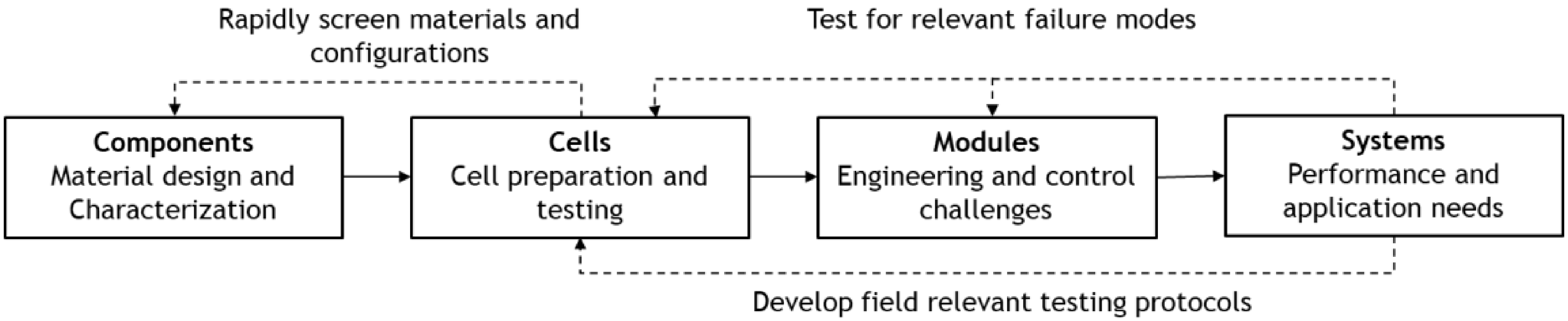
Scale-up

Design of system + environmental exposures likely enabled significant gas evolution and exothermic reaction between Cl_2 and H_2



Wittman et al. "Quantification of Chlorine Gas Generation in Mixed-Acid Vanadium Redox Flow Batteries" ACS Appl. Energy Mater. 2023.

How can more relevant testing be done at an earlier stage of development?



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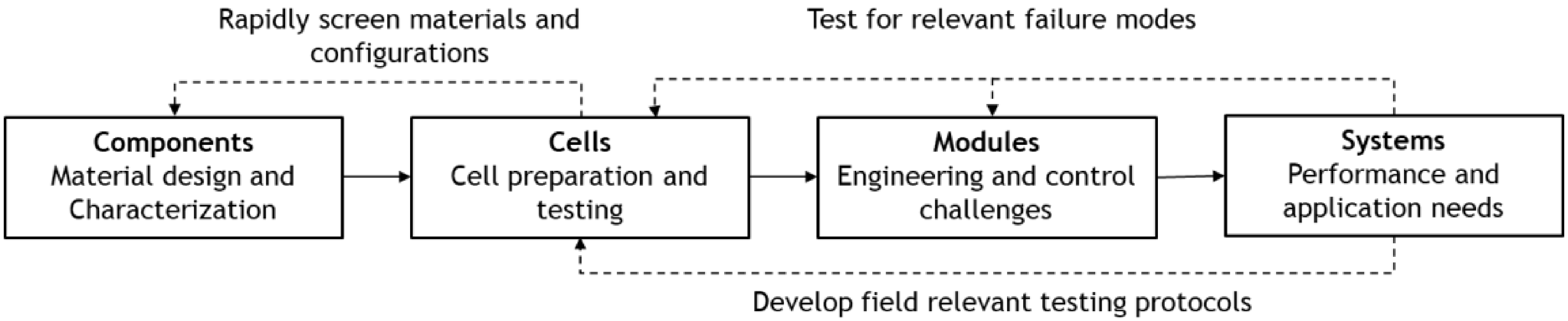

Key elements

1) Test under the relevant use cases and environmental conditions
2) Complete FMEA to ensure relevant diagnostic data is being collected
3) Collect and consolidate data across scales to close the feedback loop

Closing the data gaps between cells and systems

We built labs and software to collect and consolidate data from all levels of battery operation for rapid technology iteration. The testing conditions are informed by environmental and system-level effects observed in field applications.

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Field Application Data (ESTP, Demonstrations)
Collect normal & abuse data and environmental effects (T, humidity) from field systems

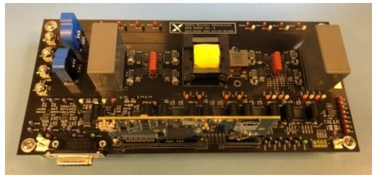
DC-Rack Data with Power Electronics (APEX,ESCAL)
Determine the impact of DC power quality (pulses and harmonics) on cell behavior

Module-Level Data (BEST, BATLab)
Assess the effect of cell-to-cell variation on safety and performance

Cell Data (BTF, BATLab)
Design industry-relevant performance & abuse testing and quality assurance checks

BTF

BEST



APEX

ESCAL

ESTP

Closing the data gaps between cells and systems

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BLC[1]

Open-source software stack to consolidate cell and system data (Dedicated SNL labs in parentheses)

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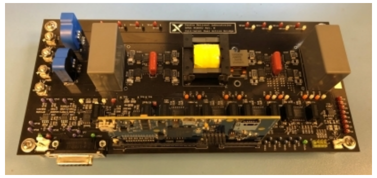
APEX


ESCAL


ESTP

[1]V. De Angelis, Y. Preger, B. Chalamala "Battery Lifecycle Framework: A Flexible Repository and Visualization Tool for Battery Data from Materials Development to Field Implementation" ECSarXiv, 2021

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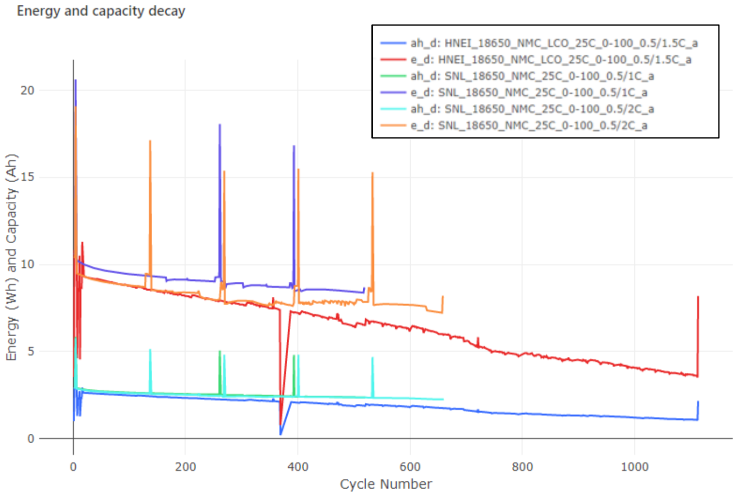
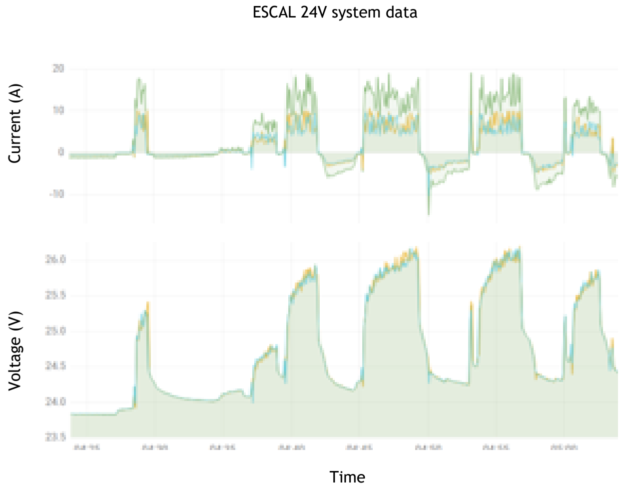
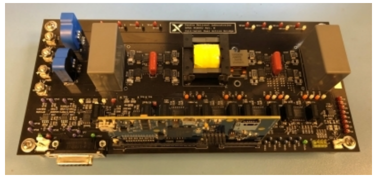
Cell and system data in one dashboard






BTF

BEST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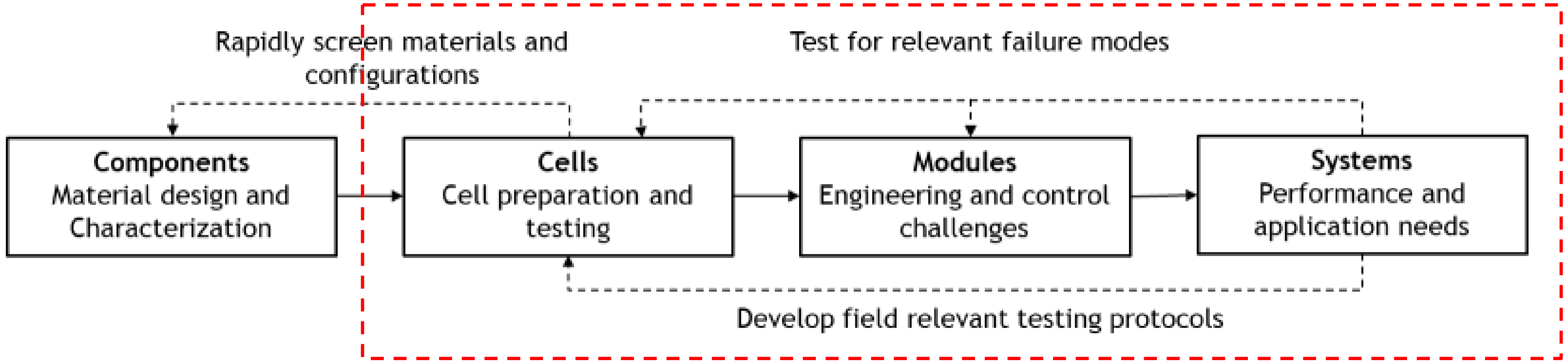
Closing the performance gap between cells and systems for rechargeable Zn-MnO_2 batteries



Use case: off-grid solar plus storage systems for remote communities

FMEA: Key concerns were failure induced by extreme temperature and depth of discharge

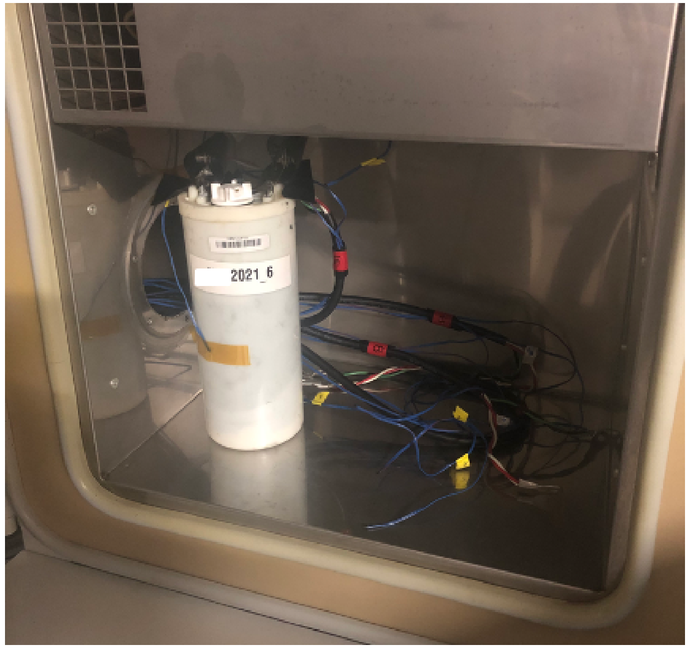
Data collection: Lab - Cell-level capacity fade, SOC, and temperature
Field – System-level load, SOC, temperature, voltage, and current

POC: Reed Wittman

Closing the performance gap between cells and systems for rechargeable Zn-MnO_2 batteries

Lab

Field

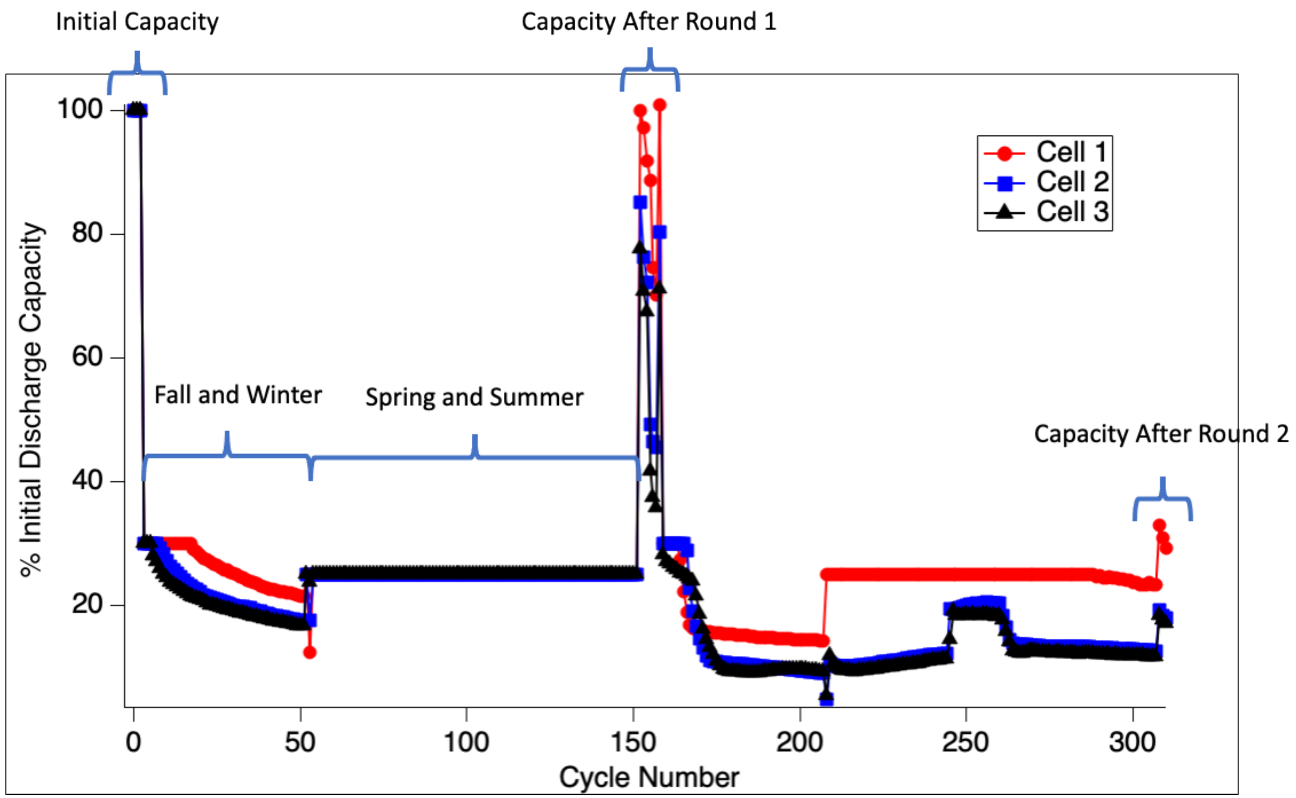


Cell Specs: 140 Ah/180 Wh

System Specs: 3 kW / 13 kWh

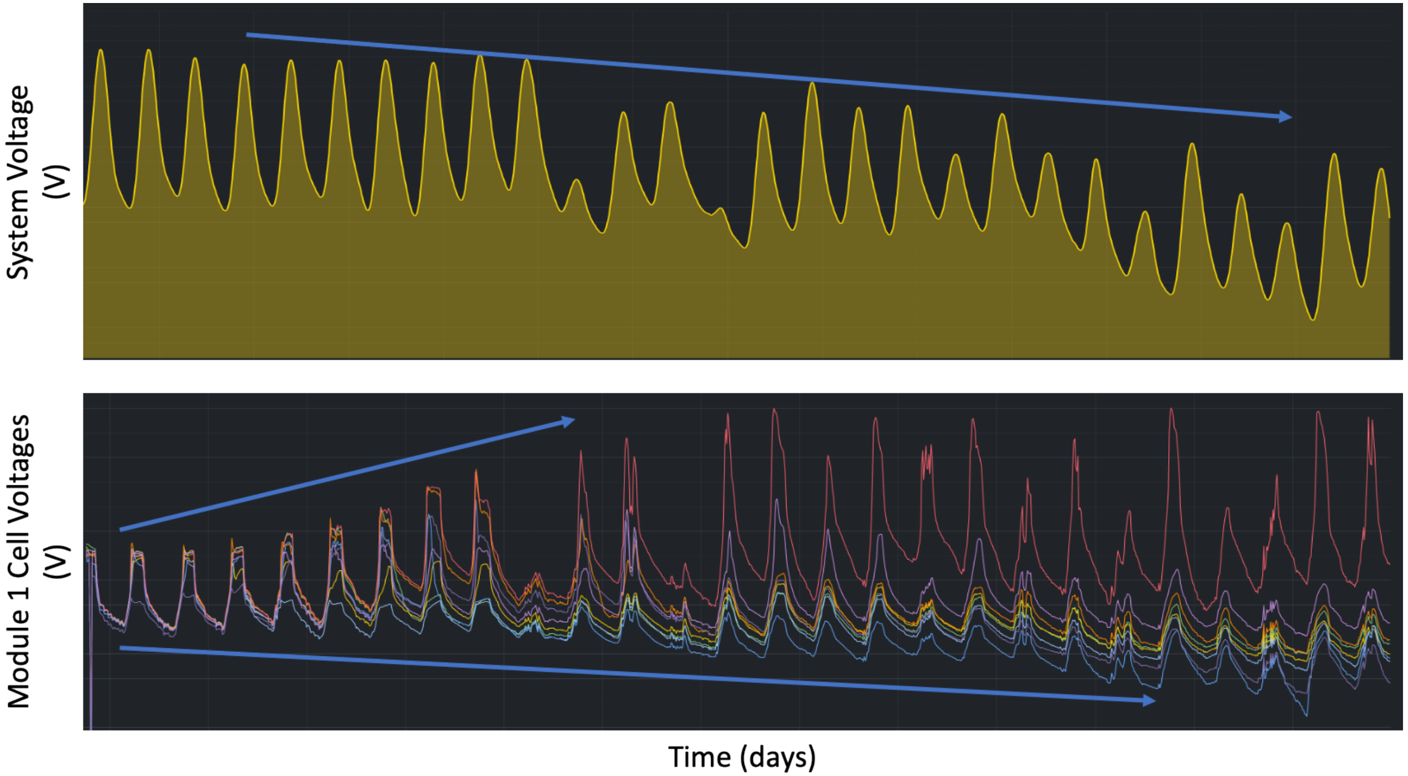
Lab cycling with the relevant use case

- Used solar aging protocol and temperature variation (Fall: 17°C, Winter: -4°C, Spring: 17°C, Summer: 30°C)
- After 90 days of testing, predicted cells would last ~2 years
  - Added heater to account for cold temperature-induced failure after Round 2
- Fielded systems failed after 6 months
  - Interactions between connected cells?
  - Intensity of field usage (malfunctioning appliances in household)?



Next step: better data collection to develop better lab testing protocols

Shift from module- to cell-level monitoring improved insights into actual conditions experienced by fielded batteries



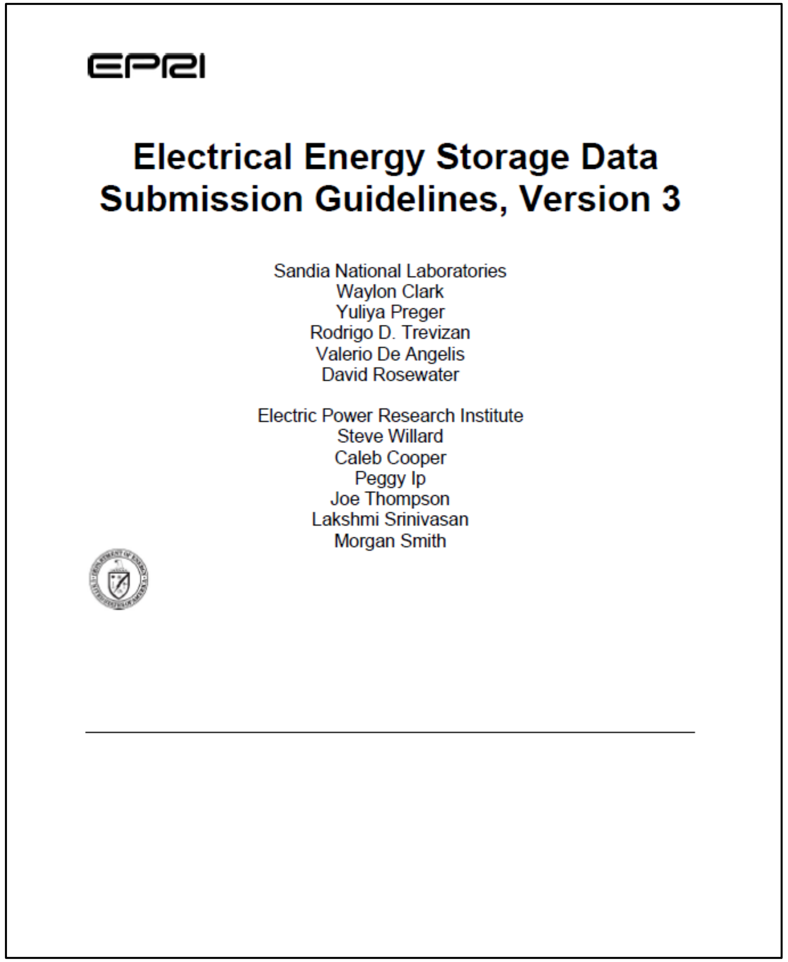
Data collection for fielded systems informed by EPRI-SNL Electrical Energy Storage Data Submission Guidelines

Performance assessment and maintenance of an operating system cannot be done without the right data.

Issues are often discovered after a system is already operating, when it is very challenging to change data collection practices.

The data guide informs stakeholders on:

- What data are needed for given functions
- Impact of data architecture
- Data point optimization


EPRI

Electrical Energy Storage Data Submission Guidelines, Version 3

Sandia National Laboratories
Waylon Clark
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Caleb Cooper
Peggy Ip
Joe Thompson
Lakshmi Srinivasan
Morgan Smith

Version 2: https://www.epri.com/research/products/3002022119
Version 3: https://www.epri.com/research/products/000000003002025977

Data collection for fielded systems informed by EPRI-SNL Electrical Energy Storage Data Submission Guidelines

Subcomponent	Data Needed for Diagnostics
Battery modules	Module temperature Rack, module, cell voltage Rack current Balancing indication SOC, SOH history Alarms/warnings
HVAC	HVAC status data Enclosure temperature humidity Ambient temperature, humidity Alarms/warnings
Computers and ancillary equipment (BMS, EMS, UPS)	Communication and processing related alarms/warnings
Inverter	Harmonics, frequency, voltage excursions
Utility transformer, protective and switchgear	DGA and other traditional assessment data

Define data points that are most important for use cases like operations, maintenance, and asset management

Data collection for fielded systems informed by EPRI-SNL Electrical Energy Storage Data Submission Guidelines

Data Sampling	
% of container-level data sampled	100
% of HVAC system-level data sampled	100
% of inverter-level data sampled	100
% of BMS-level data sampled	100
% of Battery rack-level data sampled	100
% of module-level data sampled	100
% of cell-level data sampled	100
Data Totals and File Size	
Total data points	25,201
Data points per second	22,424
Total bits per second (Assume each data point is int16)	403,216
Total bytes per second	50,402
Gigabytes per day (24 h)	4.35

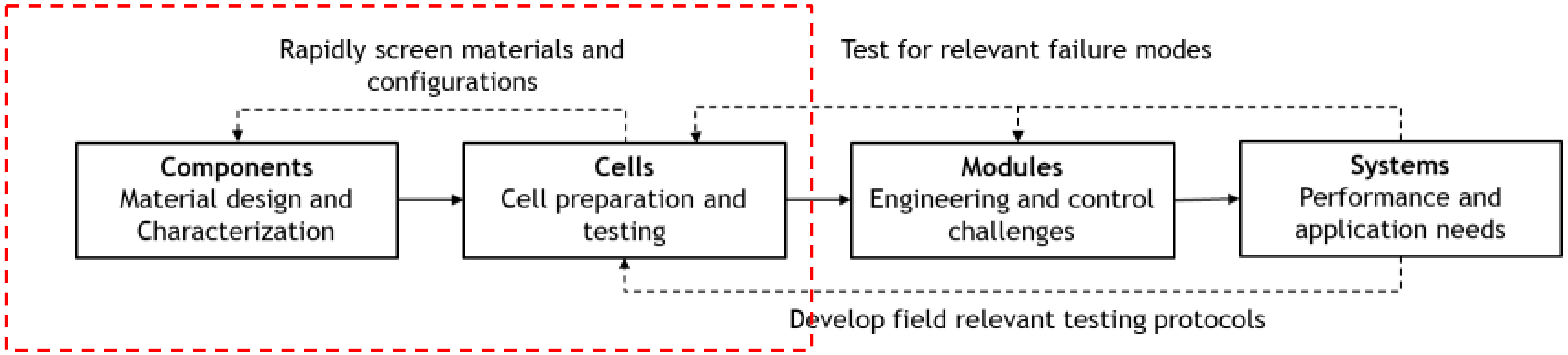
Data Sampling	
% of container-level data sampled	100
% of HVAC system-level data sampled	100
% of inverter-level data sampled	100
% of BMS-level data sampled	100
% of Battery rack-level data sampled	100
% of module-level data sampled	50
% of cell-level data sampled	0.1
Data Totals and File Size	
Total data points	7,933
Data points per second	6,100
Total bits per second (Assume each data point is int16)	126,928
Total bytes per second	15,866
Gigabytes per day (24 h)	1.37

Help users align the amount of data they wish to collect with the limitations of the data architecture

Closing the safety gap between materials and cells for advanced Li batteries

Safety profile of a new battery is typically evaluated at the final product stage, but at that point it is costly and time consuming to address safety concerns

Most research on Li-ion battery safety came *after* end-use safety incidents

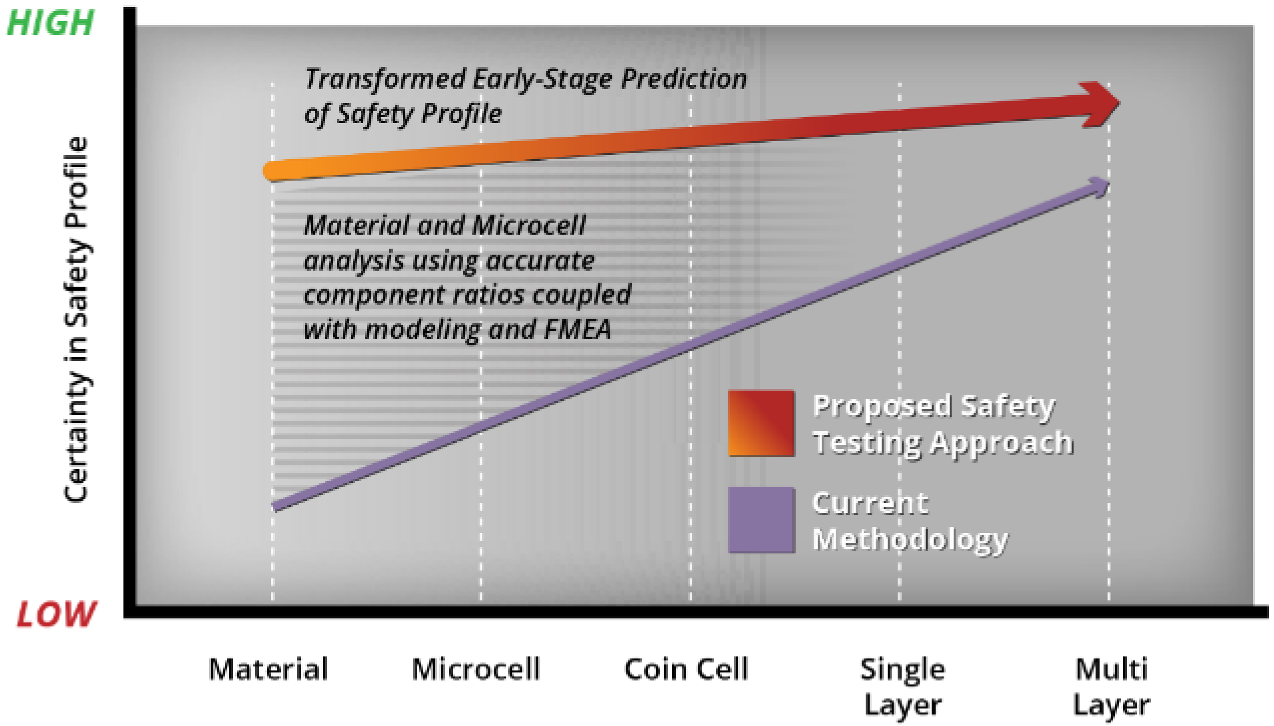


Closing the safety gap between materials and cells for advanced Li batteries

Goal: De-risk the development of emerging technologies by characterizing failure hazards earlier in development

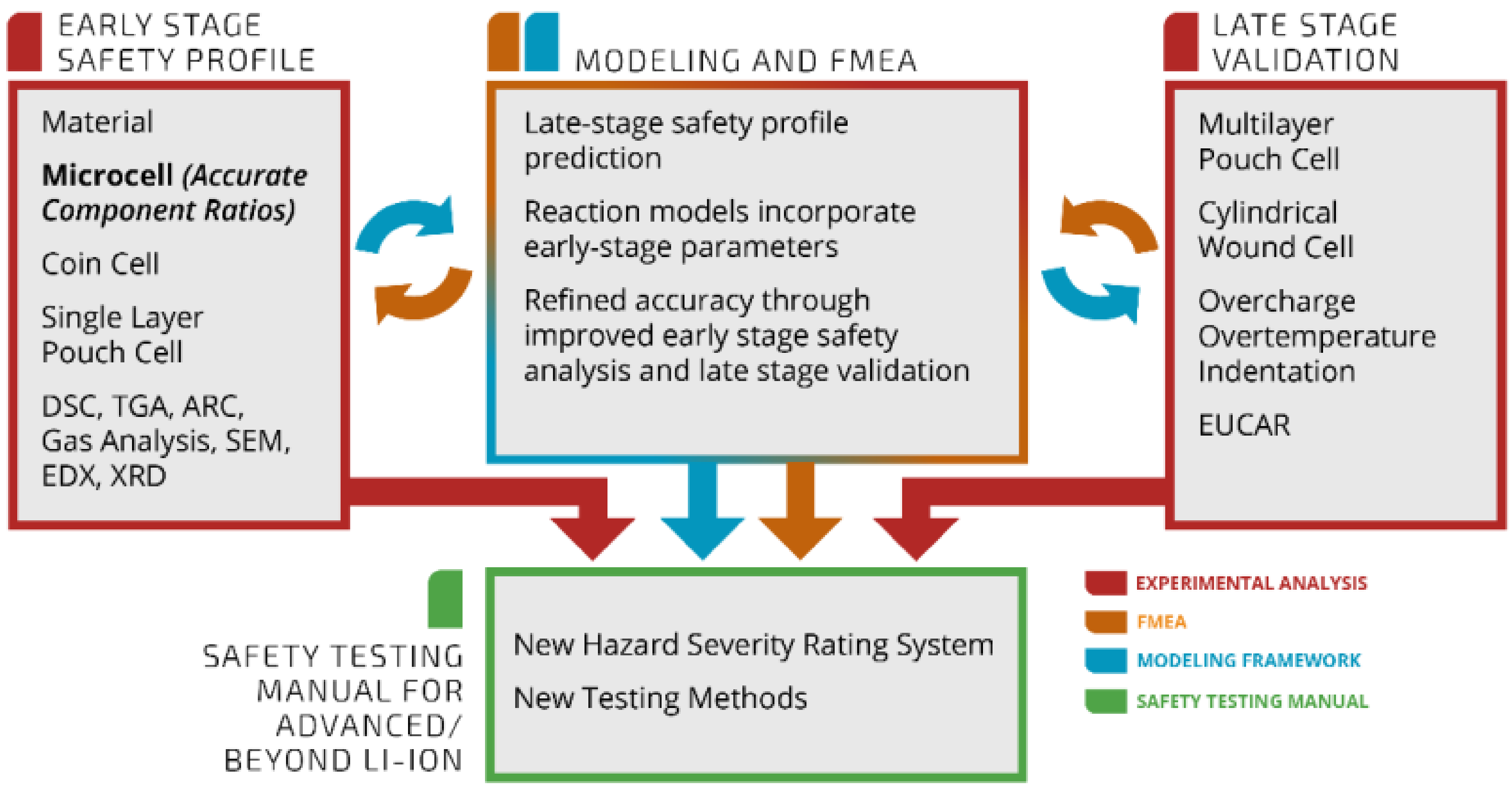
Technology Themes

1. Li metal batteries with liquid electrolyte
2. Li metal batteries without liquid electrolyte
3. Batteries with anodes other than Li/Gr/Si
4. Batteries with non-commercial cathodes



POC: Loraine Torres-Castro

Approach for earlier safety profile prediction

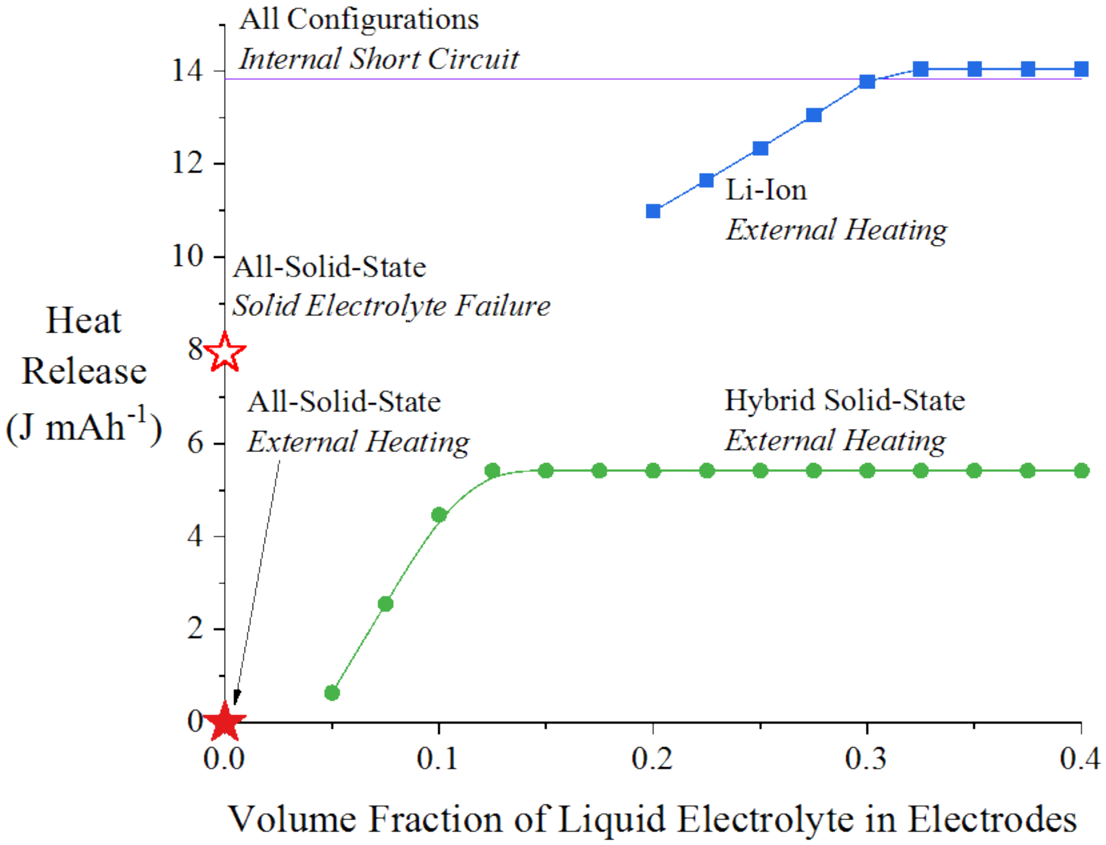


Key model outputs: amount and rate of heat release, exotherm onset, amount and type of gas produced

Safety assessment begins with an FMEA and basic models

- Initial FMEA led to consideration of three different failure modes:
  1. External heating
  2. Internal short circuit
  3. Solid electrolyte failure

- Heat release from each failure mode assessed for Li-ion, solid-state battery (SSB) w/ liquid electrolyte, and ASSB w/o any liquid

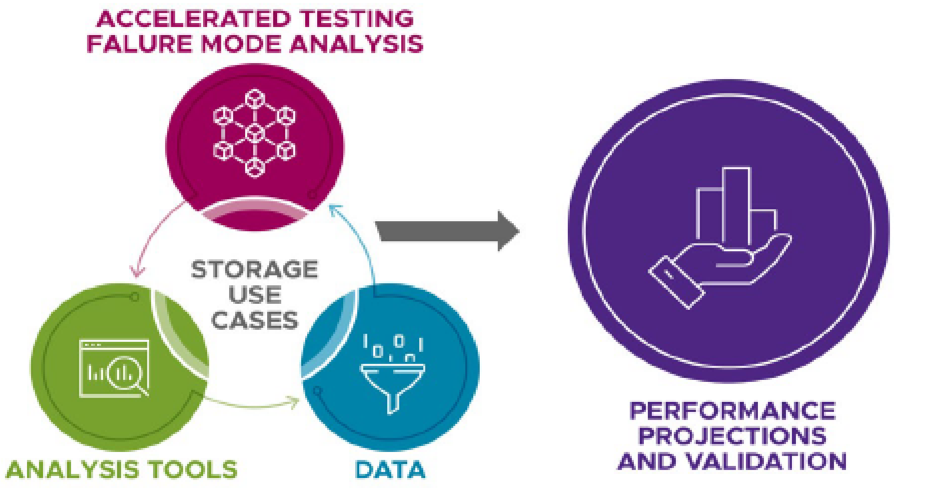


Early modeling emphasized the importance of keeping the solid electrolyte intact, informing future experimental priorities

Bates et al. "Are solid state batteries safer than Li-ion batteries?" Joule, 2022.

DOE is supporting broader efforts to complete relevant testing at an earlier stage of development

Energy Storage Grand Challenge Rapid Operational Validation Initiative (ROVI) goal is to use data-driven insights to develop accelerated testing and validation methods for new technologies that will yield 15+ years of investment-grade performance projections with only one year or less of data required.

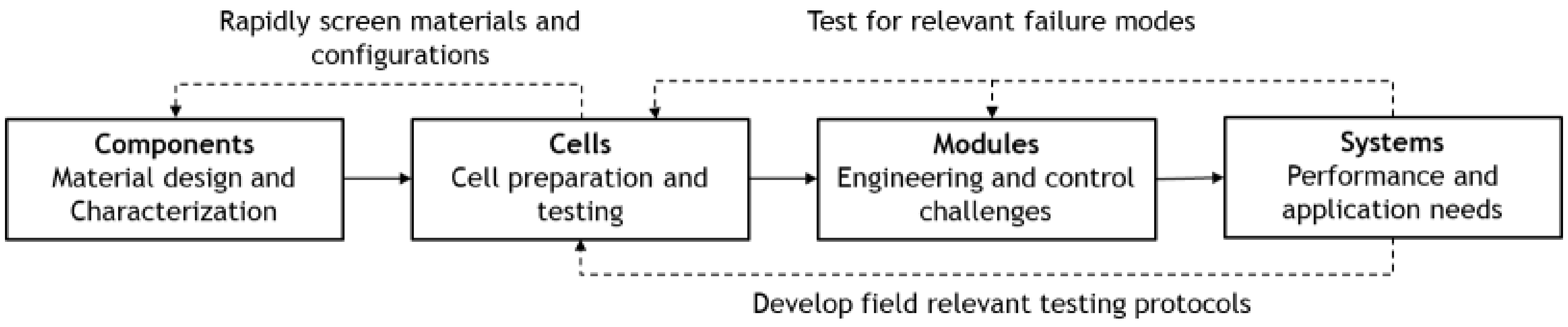


ROVI has three key elements, along with detailed use-cases, that integrate in a comprehensive framework to provide a suit of life predictions tools.

ROVI will inform data collection requirements for DOE-funded demonstration projects

Summary

- Performance of energy storage components in the lab does not translate to scaled systems
- More relevant testing can be done at an earlier stage of technology development by:
  - testing under the relevant use cases and environmental conditions
  - completing an FMEA to ensure relevant diagnostic data is being collected
  - collecting and consolidating data across scales to close the feedback loop
- Approach is being applied to Zn battery performance, advanced Li-ion safety, and future DOE efforts



Acknowledgments

- Funded by the U.S. Department of Energy, Office of Electricity, Energy Storage program. Dr. Imre Gyuk, Program Director.
- Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

Battery Lifecycle Framework
Valerio De Angelis
Irving Derin
Joseph Lubars

$Zn-MnO_2$ demonstration
Reed Wittman
Armando Fresquez
Henry Guan
Robert Wauneka
David Rosewater
Stan Atcitty

EPRI-SNL Data Guide
Waylon Clark
Rodrigo Trevizan
Valerio De Angelis
David Rosewater
Steve Willard (EPRI)
Caleb Cooper (EPRI)
Peggy Ip (EPRI)
Joe Thompson (EPRI)
Lakshmi Srinivasan (EPRI)
Morgan Smith (EPRI)

Early SSB Safety Work
Loraine Torres-Castro
Alex Bates
John Hewson
Katie Harrison
Steve Harris (LBNL)

ARPA-E SSB Safety Collaborators
Judy Jeevarajan (ULRI)
Partha Mukherjee (Purdue)
Paul Albertus (UMD)

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