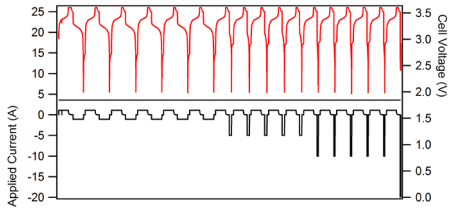
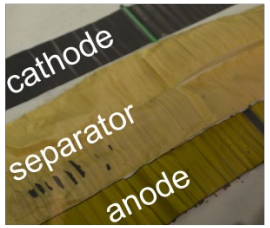
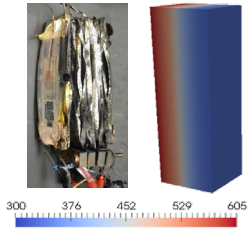
Impacts of Module Configuration on Lithium-ion Battery Performance and Degradation







PRESENTED BY

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Presentation #303
DOE OE Energy Storage Peer Review
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PROJECT OBJECTIVE AND MISSION ALIGNMENT

OBJECTIVE: Quantify the impact of lithium-ion module series-parallel configuration on energy throughput, voltage divergence, and current flow over the course of cycling

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  - Development of better controls for battery management systems
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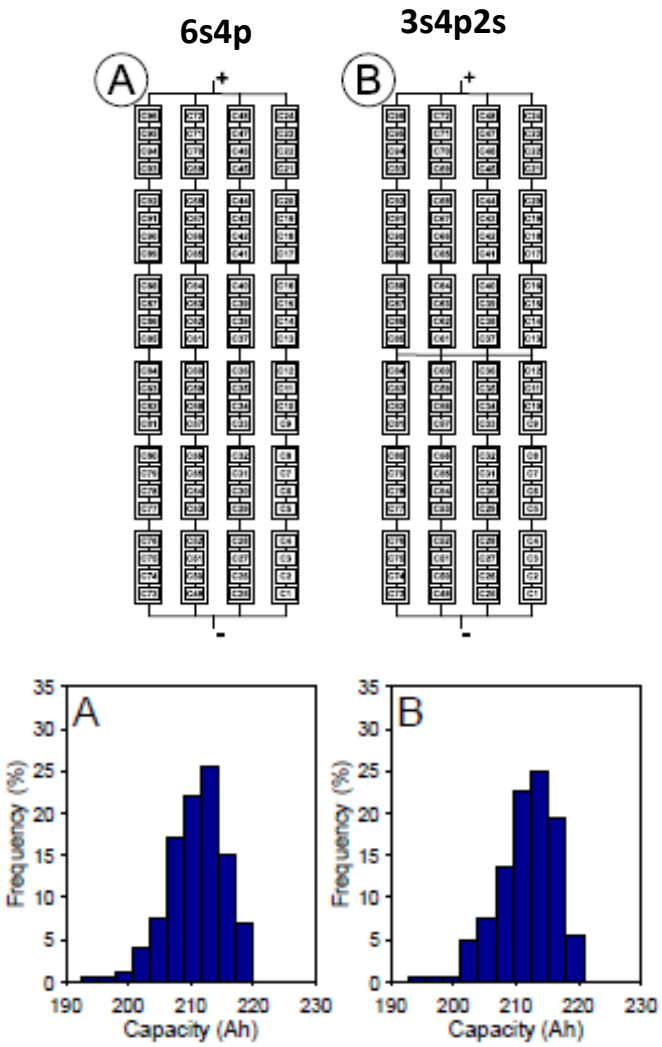
ALIGNMENT WITH CORE MISSION OF DOE OE:

- Energy storage systems contribute to resilience, reliability, and flexibility of energy infrastructure
- Greater insight into module performance will lead to the development of more reliable energy storage systems

PREVIOUS LIT ON MODULE TESTING

- Most studies are computational
- Most experimental studies are very brief: <10 cycles or just single charge/discharge
- Very few module configurations have been explored experimentally: 6p1s or less (in many cases, just 2p1s)
- Very few studies give cell-level results

Typical computational approach

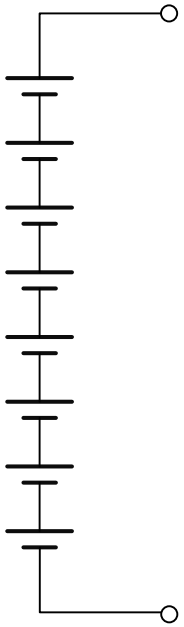


Baronti et al. IEEE, 2014, "Investigation of series-parallel connections of multi-module batteries for electrified vehicles"

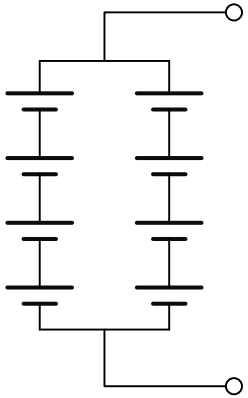
PROJECT METHODOLOGY

Explore range of configurations, from all series to all parallel

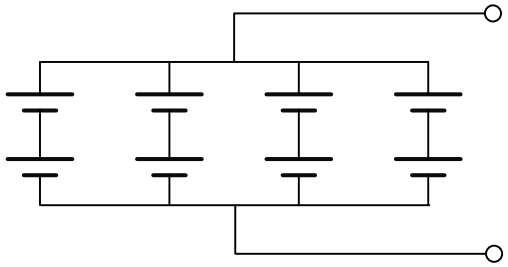
8S-1P



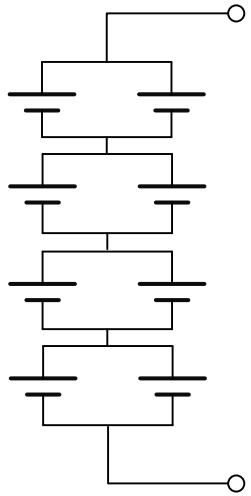
4S-2P



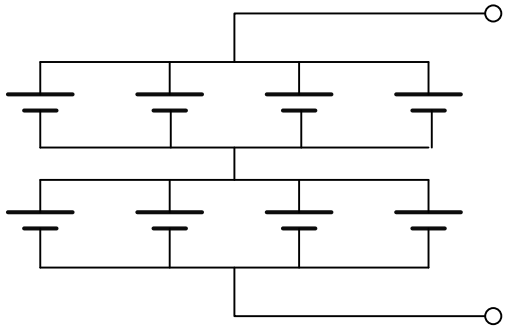
2S-4P



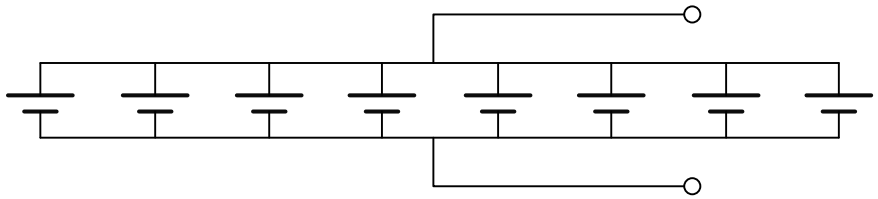
2P-4S



4P-2S



8P-1S



PROJECT METHODOLOGY

Designed a unique module board that replicates normal electrical operation while implementing (1) cell-level V/T/I monitoring and (2) allowing cell removal for state-of-health assessment

Module-Level Monitoring

- Voltage
- Current

Cell-Level Monitoring

- Voltage: battery tester aux channels
- Current: battery tester aux channels + closed-loop Hall effect sensors (magnetic field)
- Temperature: thermocouples

PROJECT METHODOLOGY

Phase 1: Cycling of modules with low cell-to-cell variation and without balancing

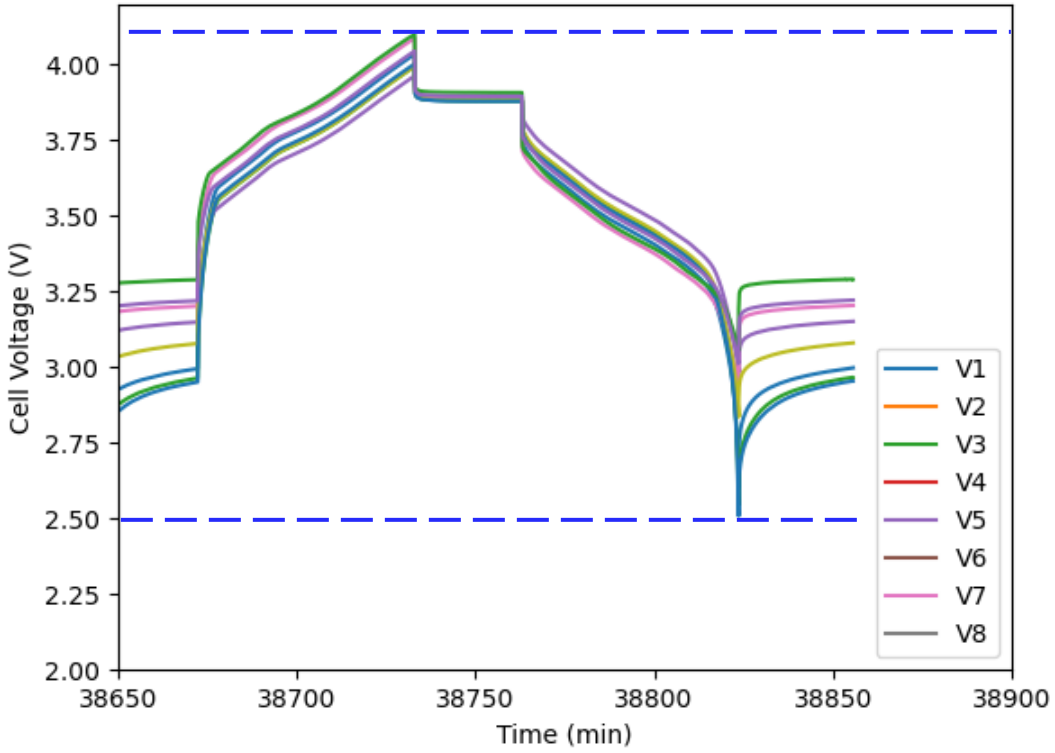
Scope of Cycling

- 3 Ah 18650 NMC cells* with limited cell-to-cell variation
- 400 cycles per module
  - Mild 200 cycles: 0.5C/0.5C, 2.5-4.1 V
  - Aggressive 200 cycles: 0.5C/1.5C, 2.3-4.2 V
- All experiments repeated with a second set of cells

Operating Controls

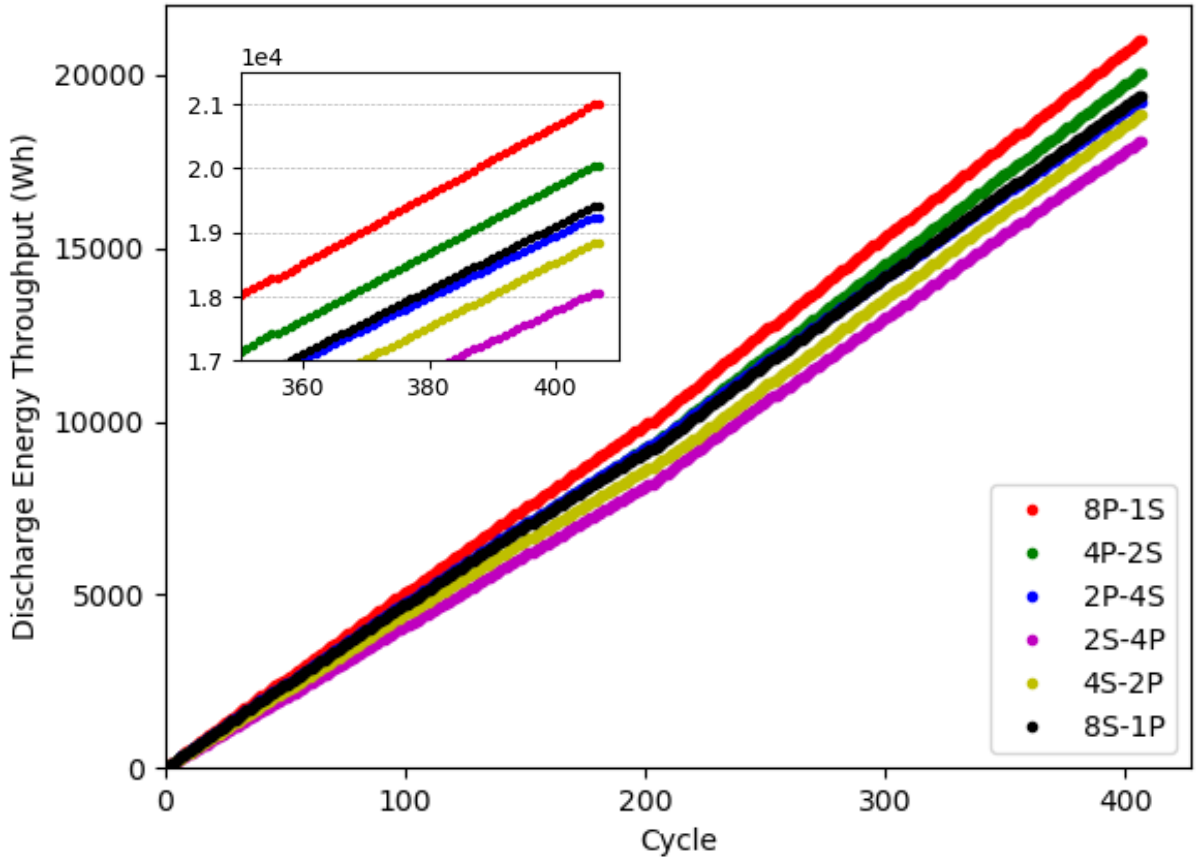
- No battery management system
- Module moves on to next step once any cell hits charge/discharge voltage limits
- Safety: Abort limits based on cell-level voltage, current, and temperature

Module moves on to next step once any cell hits the voltage limit



*Builds on previous SNL single-cell testing projects

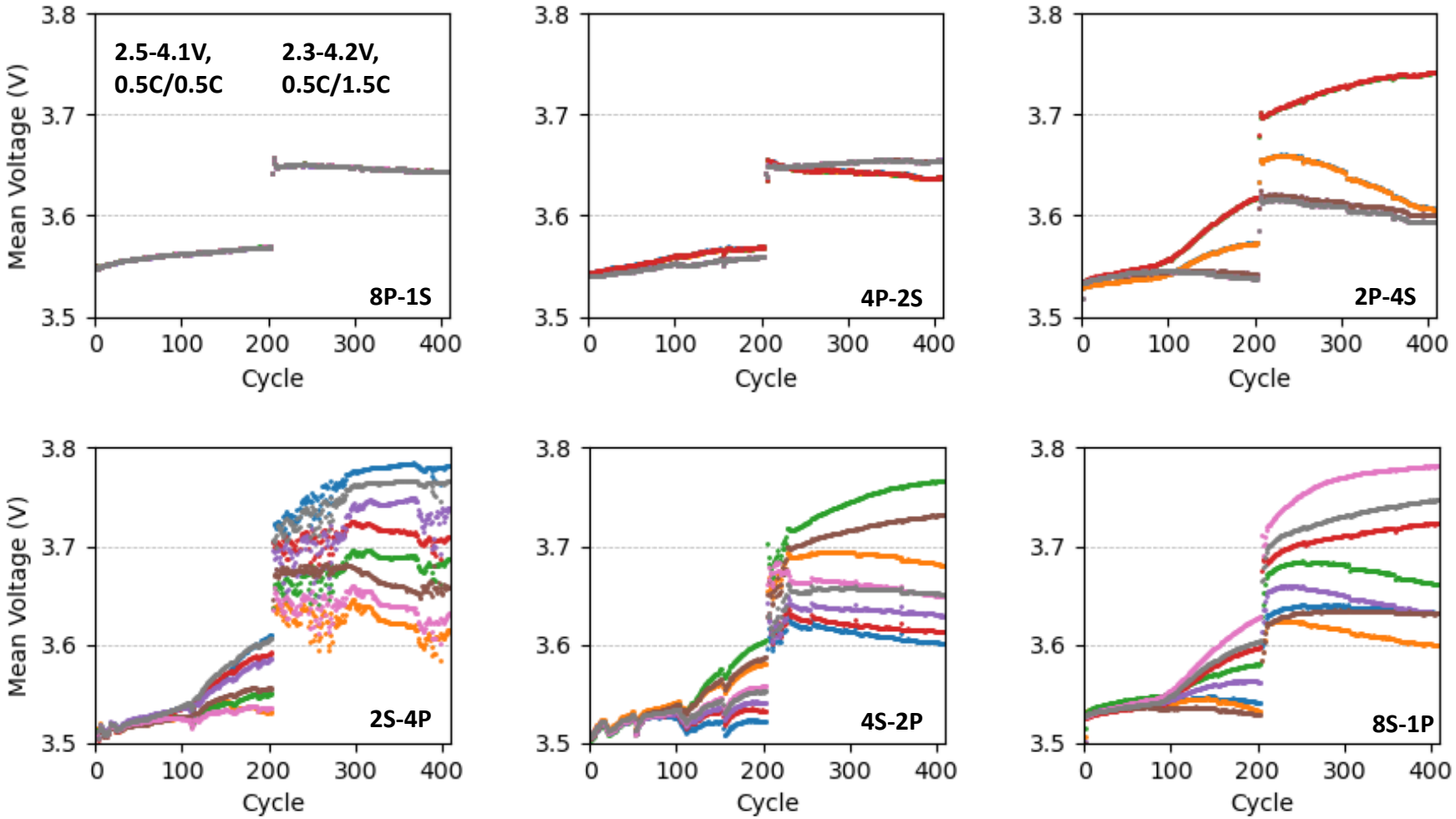
PROJECT RESULTS: MODULE ENERGY THROUGHPUT



All 8-cell modules should have the same total energy, but after 400 cycles, the parallel modules show up to 15% higher energy throughput

*similar results for 2nd set of cells/modules

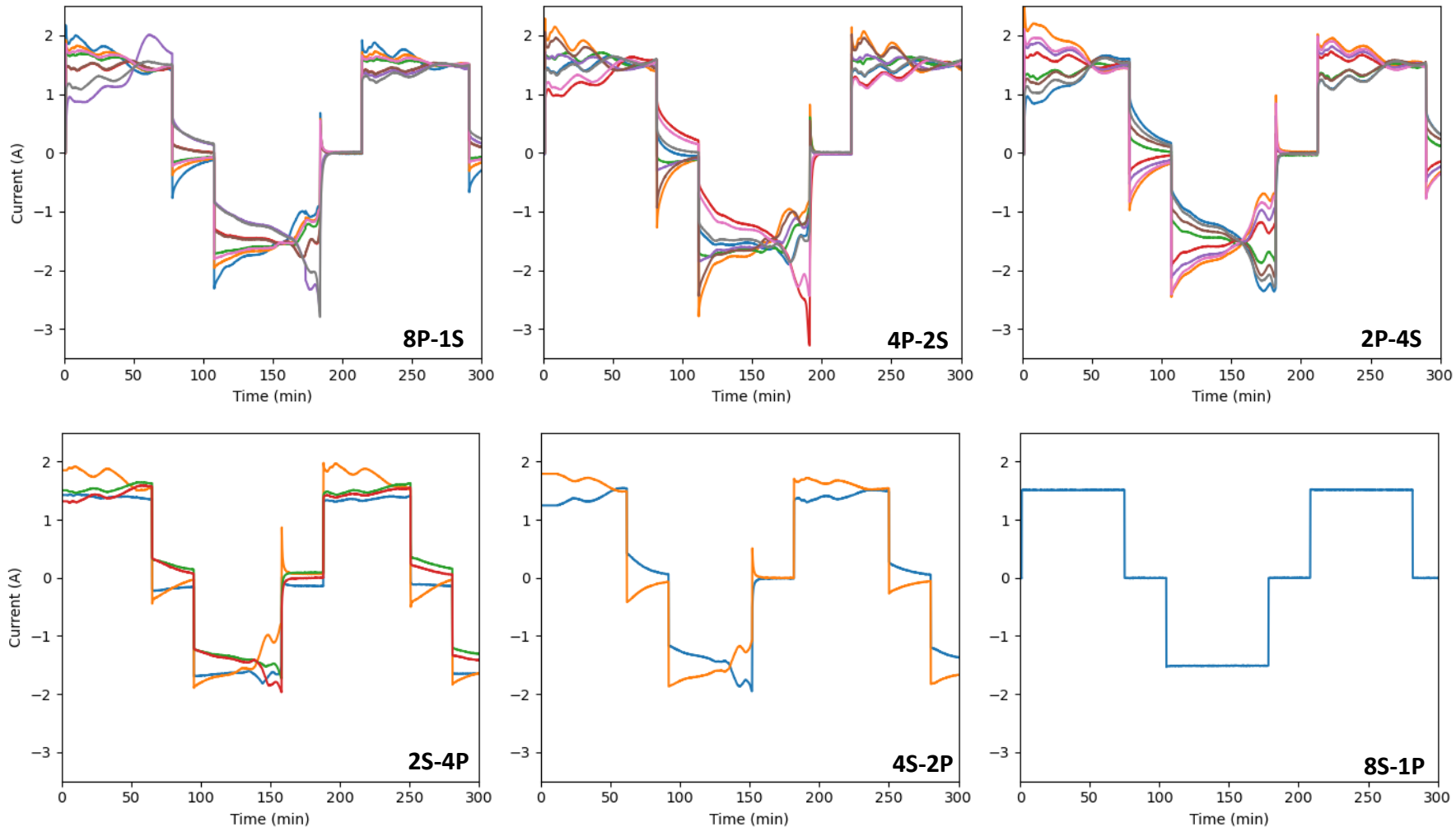
PROJECT RESULTS: CELL VOLTAGE DIVERGENCE



Lower discharge energy throughput in increasingly series configurations attributed to cell-level voltage divergence

*similar results for 2nd set of cells/modules

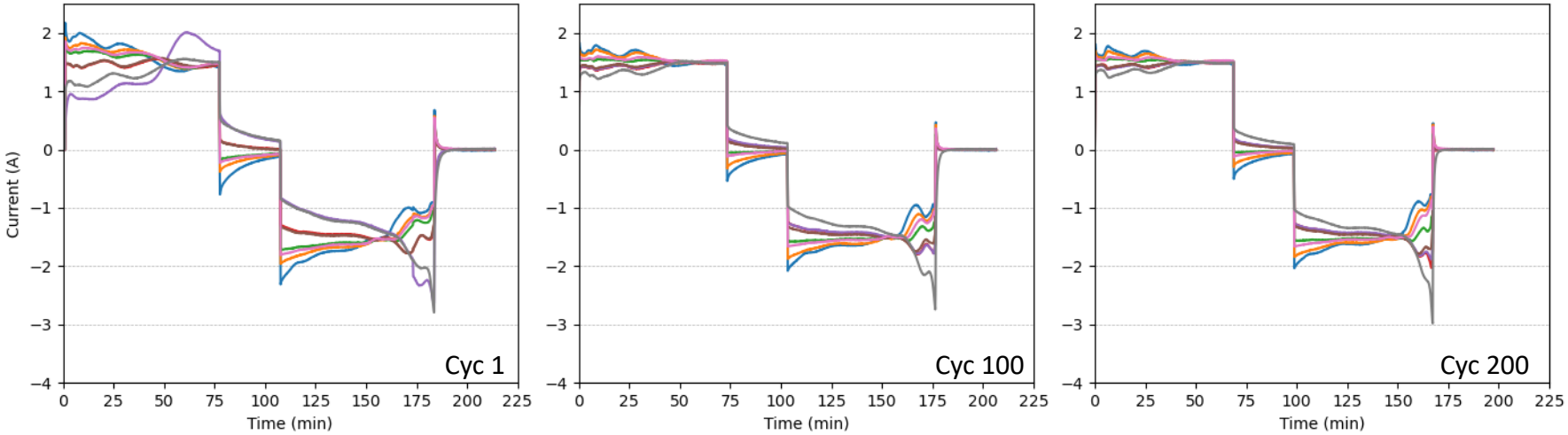
PROJECT RESULTS: CURRENT BALANCING



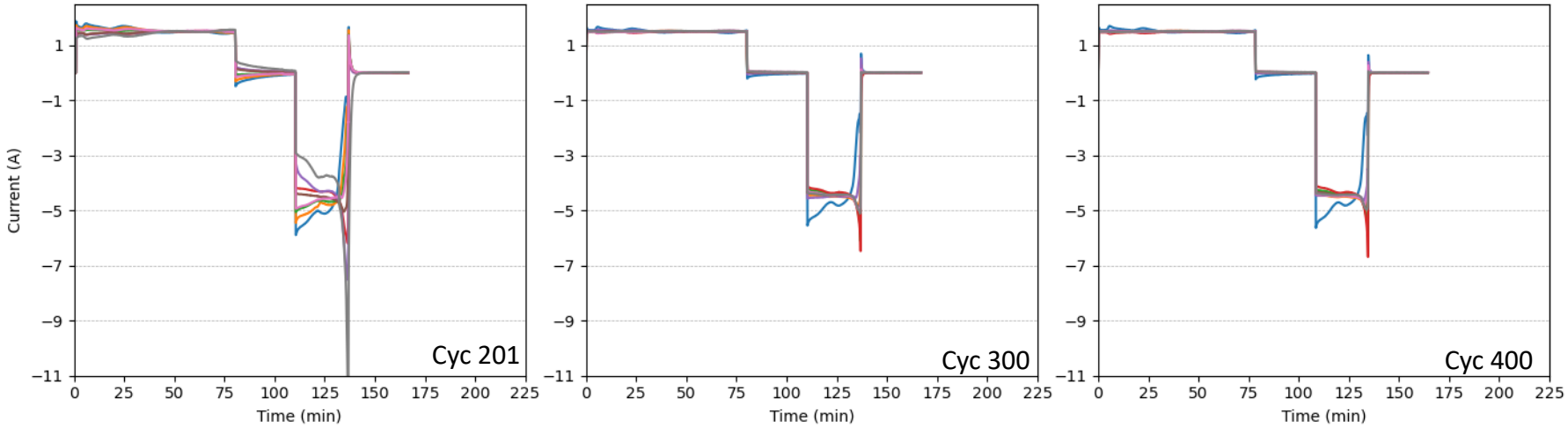
Parallel cells will naturally balance since they are directly connected. Cell-level current sensing shows the magnitude of balancing in the first five hours of cycling (current more than 50% higher than average).

PROJECT RESULTS: CURRENT BALANCING OVER TIME

2.5-4.1V, 0.5C/0.5C



2.3-4.2V, 0.5C/1.5C



Magnitude of current balancing in 8P-1S module decreases over time

*similar results for 2nd set of cells/modules

INNOVATIONS AND IMPACTS

- **Developed a unique module board that replicates normal electrical operation while implementing (1) V/T/I cell-level monitoring and (2) allowing cell removal for state-of-health assessment**
  - Revised design will be shared open-source with many interested battery testing groups

- **Generated the broadest module cycling dataset in the open literature (one of a handful with cell-level monitoring)**
  - Quantified the magnitude of phenomena such as cell-level voltage divergence and parallel cell current balancing
  - Data will be shared in Battery Archive (public SNL-developed database used in over 60 countries)

Several ESS manufacturers and utilities have already expressed significant interest in the data as they are in the process of vetting different energy storage product configurations and improving their system models.

FUTURE DEVELOPMENT

EXPERIMENT

✓ Phase 1: Module cycling with low cell-to-cell variation

- Phase 2: Module cycling with high cell-to-cell variation

- Phase 3: Module cycling with high cell-to-cell variation, with power converters + battery management system
  > Developing new lab focused on battery module/power converter interface

MODELING

- Compare results to open-source battery system modeling software (collab with Srikanth Allu, ORNL)
  - How accurate are existing models?
  - Can we extract underlying cell parameters?

PROJECT ACKNOWLEDGMENTS

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For questions about this presentation: ypreger@sandia.gov, jmuelle@sandia.gov

Project Outputs

1. Invited Talk: Preger. Y.; Mueller, J.; Baker, G.; Fresquez, A. “Beyond single cell characterization: Impacts of module configuration on Li-ion battery performance and degradation” at the 2022 Electrochemical Society Fall Meeting, Atlanta, GA, October 2022.

2. Manuscript: Impact of Module Configuration on Lithium-ion Battery Performance and Degradation: Part I. Energy Throughput, Voltage Divergence, and Current Flow

3. Manuscript: Impact of Module Configuration on Lithium-Ion Battery Performance and Degradation: Part II. Impact of Parallelization