



Maximizing the Value of Every Battery

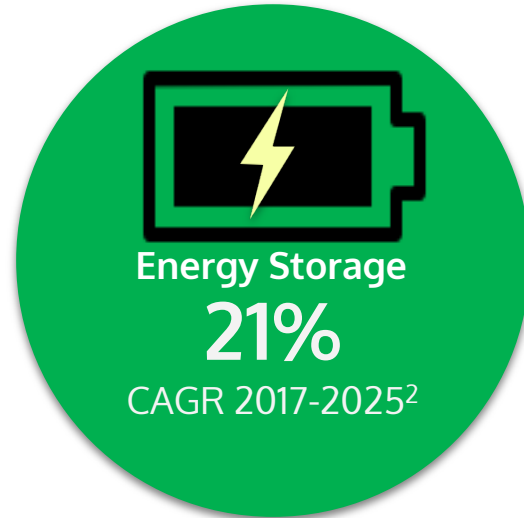
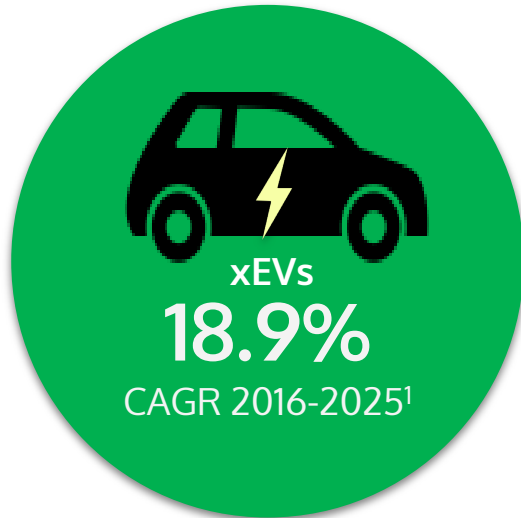
Insitu Impedance Testing for SOH Measurements

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5/4/2022



Background

- Battery Markets

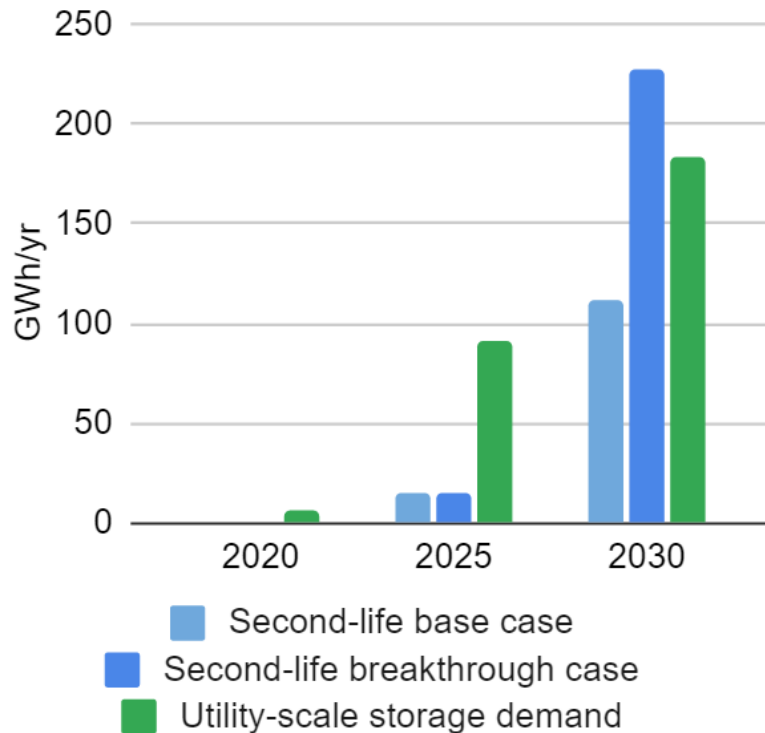


¹ Frost & Sullivan: Global Electric Vehicle Market Outlook, March 2018

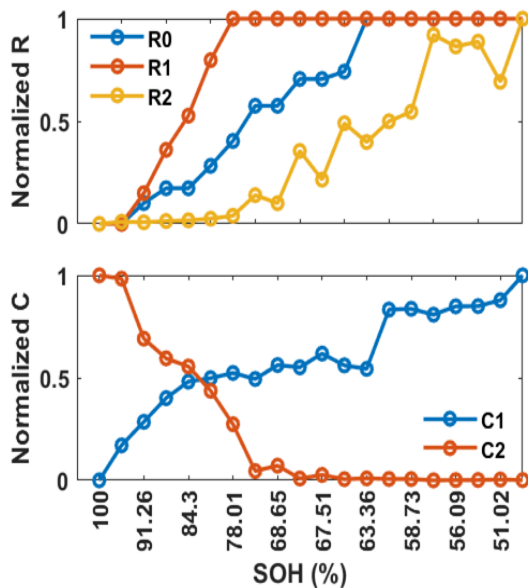
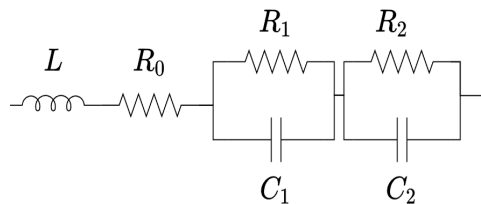
² Grand View Research: Lithium-Ion Battery Market Analysis By Product (Lithium Cobalt Oxide, Lithium Iron Phosphate, NCA, LMO, LTO, Lithium Nickel Manganese Cobalt (NMC)), By Application, And Segment Forecasts, 2018 - 2025, December 2017

³ Navigant: Market Data Electric Trucks and Buses, Q4 2018

What about all those batteries?

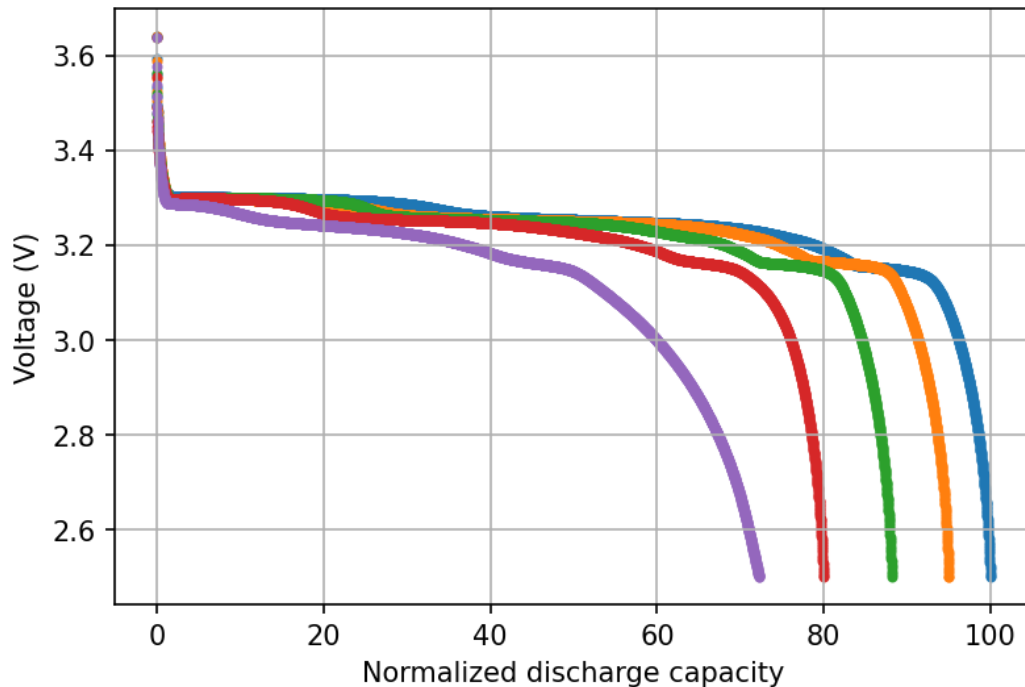


What Does Degradation Look Like?



Ohm's law

Voltage Curves LFP cell - 1/3C discharge



Voltage Window

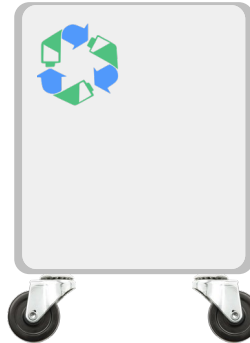
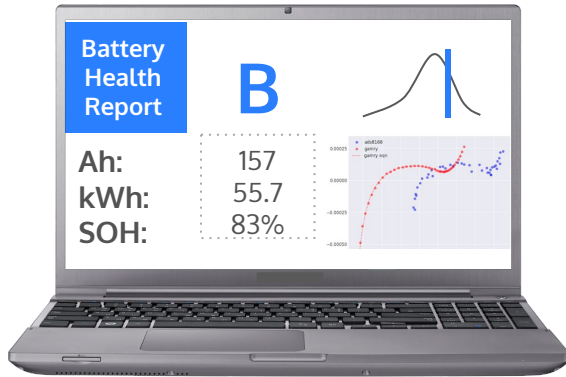
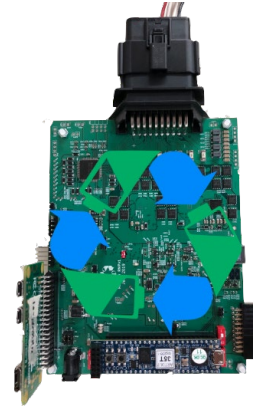
Rejoule's Solution

- Fast grading tools
- Analytic tools: SOH models
- Maximizing the value of every battery



Improved Impedance Measurements

- Multi-frequency ac-signal excitation
- Standardized hardware development
- Patent pending electronics hardware technology



\$4.8M in non-dilutive government funding

National Science Foundation



\$225K SBIR - Phase I

\$1M SBIR - Phase II

California Energy Commission



\$2.9M GFO-19-310:
2LB repurposing &
integration w/ Solar

Project
partners:



CalSEED & CalTestBed

Cal**SEED**

\$150K Concept award:
Product prototype

\$450K Prototype award:
Scale from module
to pack

Cal**TestBed**

\$160K External validation
of products

2LB Energy Storage System

Deploy 2LB at 2 sites, behind-the-meter C&I solar + battery in California, planned operation Q4 '22

Funded by:



Prime: 

- Prime recipient of grant
- Battery testing and grading
- Battery matching
- BMS integration



- ESS integration



- EMS and system integration



- Solar Integration,
- workforce training



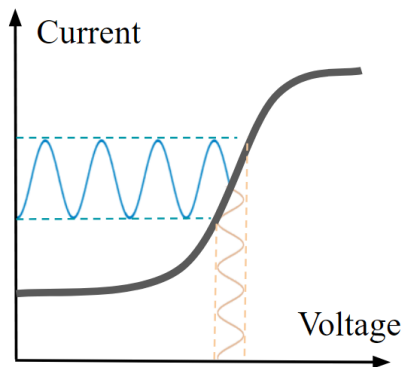
- Battery supply

SOH Measurement Approach

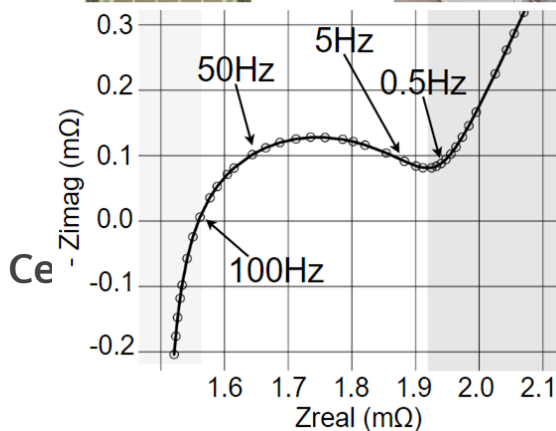
- Cycling
 - Expensive
 - Time consuming

- Insitu impedance testing: electrochemical impedance spectroscopy (EIS)
 - Non-invasive technique of gaining insights into *any* closed system

EIS Test

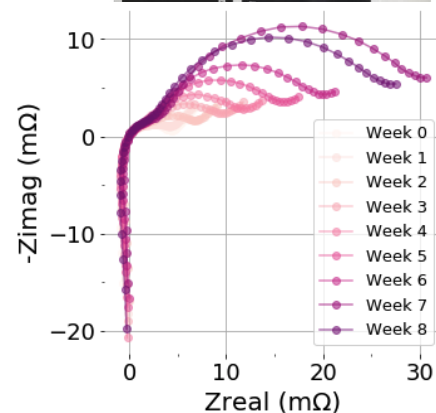


Signal Processing



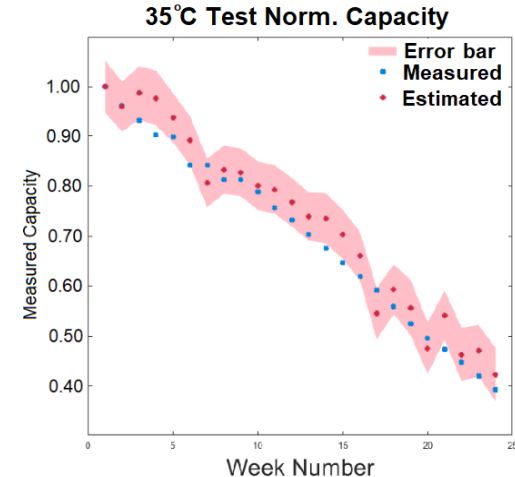
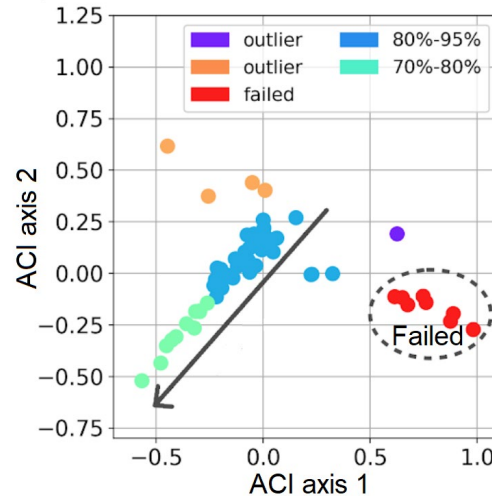
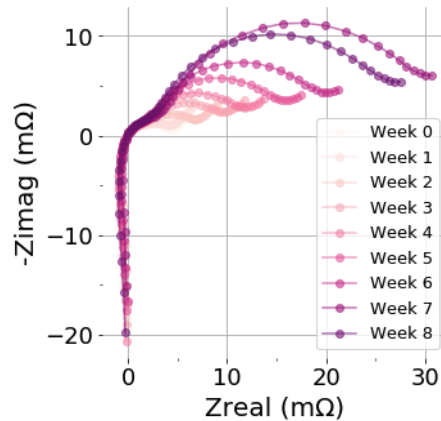
Nyquist plot

Modeling



Improved Battery Modeling with EIS

- ML techniques to match capacity with Nyquist plot parameters
- Failure detection using only EIS spectra (<70% SOH capacity)



Rejoule has Tested Different Battery Types



Cells

Chemistries: NMC, NCA, and LFP

Form Factors: Cylindrical and Prismatic

First life application: Tesla Model 3 and Electric Forklift

Modules

Chemistries: LMO, NMC and LFP

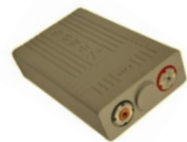
Form Factors: Pouch, Cylindrical, and Prismatic

First life application: Nissan LEAF, Electric Truck and Electric Bus

Module Configuration: 2S2P, 4S99P, 8S1P

Case Studies Summary: 50X Faster, Within +/-2% Error

Rejoule was able to get within 3% accuracy with only 50 samples



	 Cycling Time		 Speed	 Accuracy
3.2V LFP Prismatic Cells	~240 min	5 min	48x	+/- 2%
12.8V LFP Cylindrical Modules	~360 min	5 min	72x	+/- 2%
26V LFP Modules	~540 min	5 min	108x	+/-2%

Case Study 1: 500 Used Electric Truck Modules Graded



Module Specs:

Voltage: 12.8 V

Energy: 1.76 kWh

Configuration: 4S 99 P

Chemistry: LFP

	Test time	Accuracy
Benchmark (cycling)	<i>6 hours</i>	<i>n/a</i>
ReJoule	<i>5 minutes</i> <i>(60x faster)</i>	<i>+ /- 2%</i>
ReJoule	<i>30 seconds</i> <i>(720x faster)</i>	<i>+ /- 3.5%</i>

Case Study 2: 115 New and Used Forklift Cells Graded



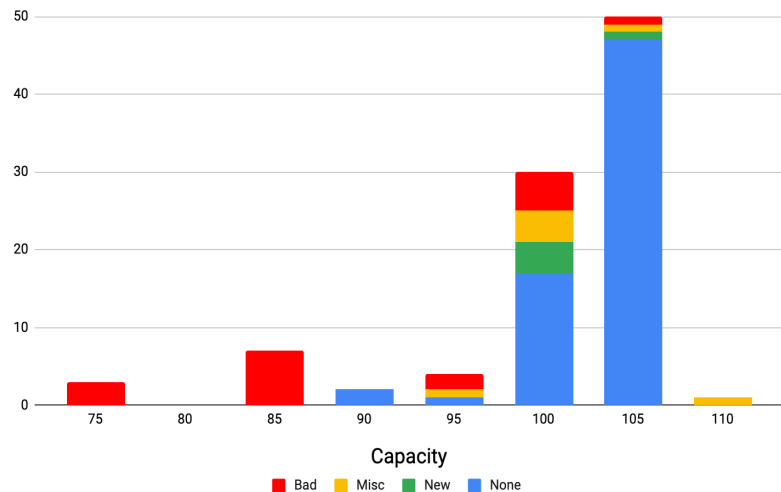
Cell Specs: Voltage: 3.2 V

Energy: 320 Wh

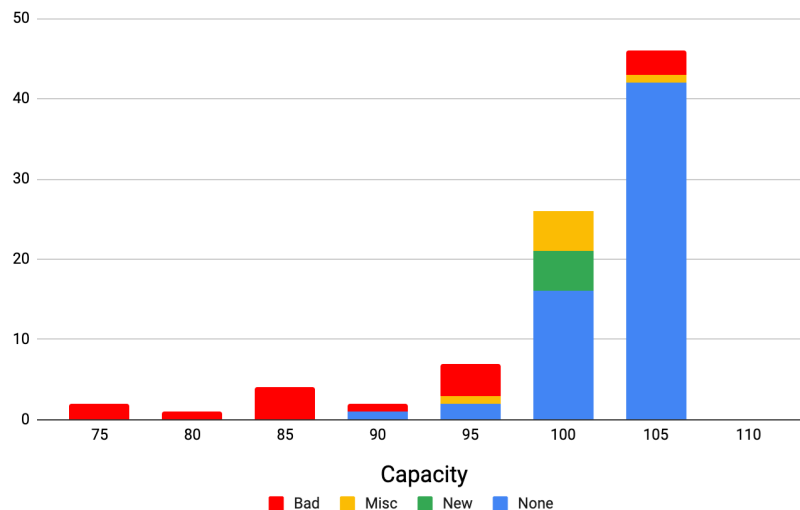
Results: 5 min test <2% benchmark; 1 sec test 2% benchmark

Chemistry: LFP

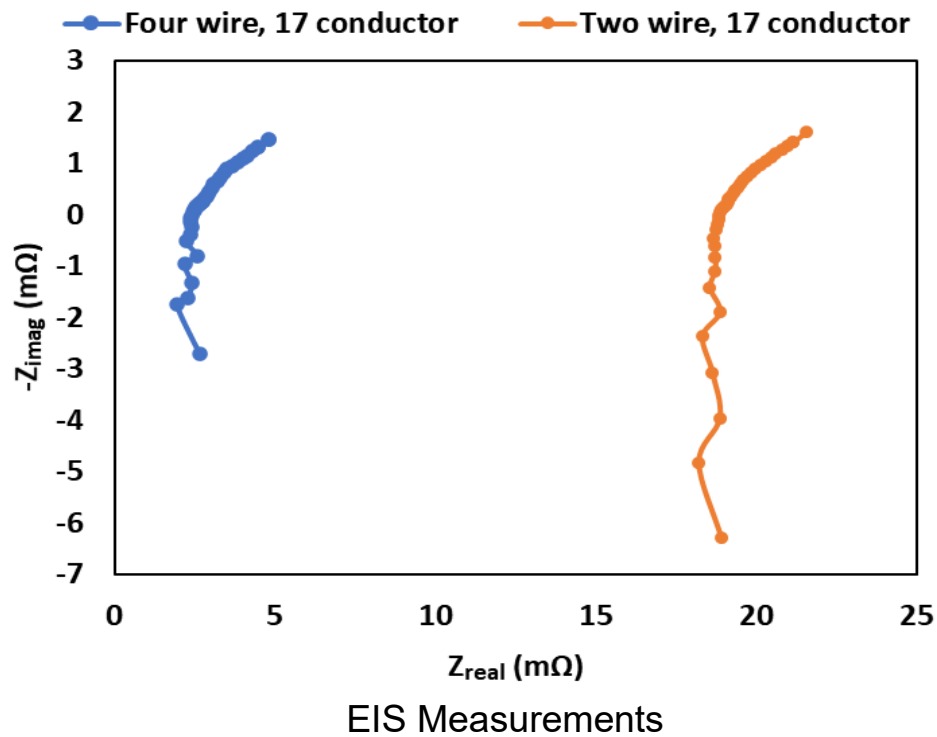
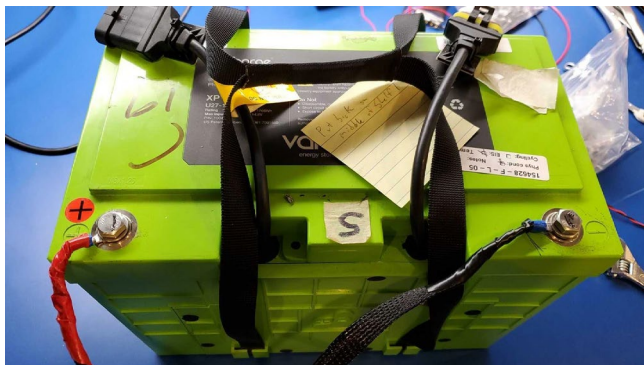
CC-CV cycling



EIS prediction



Case Study 3: Reliable Data Resources



Other Challenges: Documented In Our Blog



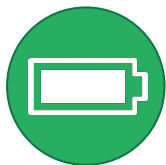
Blog 1 Disassembly: no standard design, damage is possible



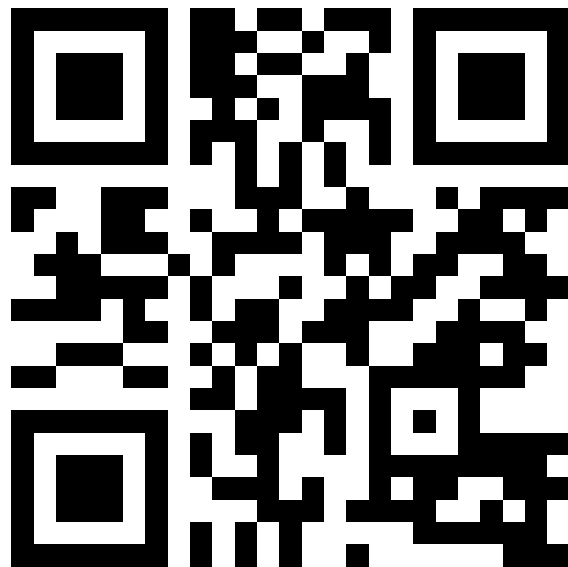
Blog 3 Lack of critical info: battery specs, historical usage



Blog 4 Cell imbalance: no battery degrades in the same way



Blog 5 Battery placement: permitting, fire codes, site needs



<https://www.rejouleenergy.com/>



Thank you for your time!

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Summary

- Rejoule develops battery module and pack-level EIS for fast diagnostics for repurposing and aftermarket
- Able to model SOH using data from fast EIS test, accuracy within 2%, benchmarked against cycle test
- Able to train models <50 samples
- **Actively seeking fleet and OEM partnerships**