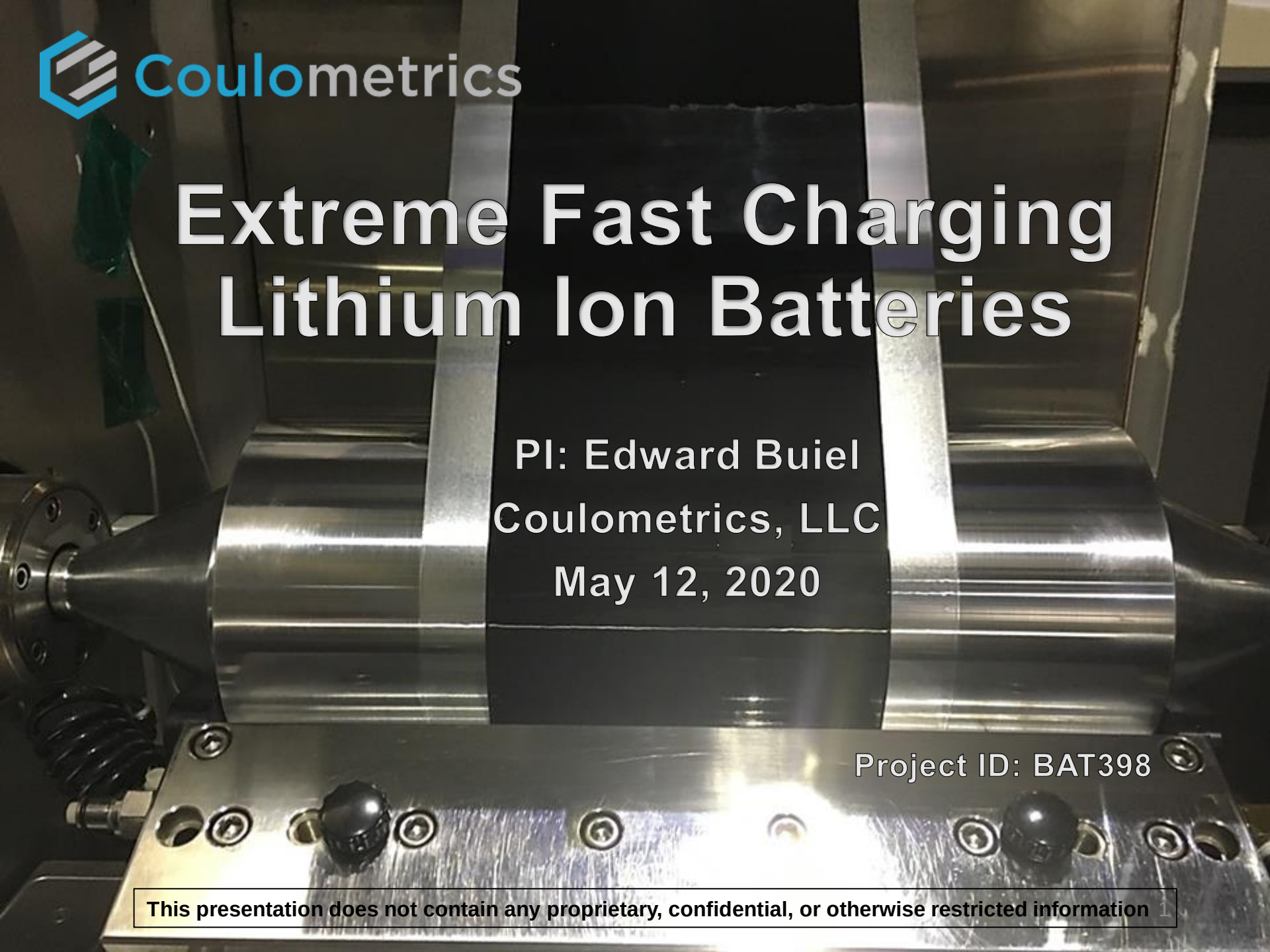

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Extreme Fast Charging Lithium Ion Batteries

PI: Edward Buiel

Coulometrics, LLC

May 12, 2020

Project ID: BAT398

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview – Coulometrics XFC Program

- Timeline
  - Start date: August 7, 2018
  - End date: August 6, 2020
  - Percent complete: 85%
- Budget
  - Total Project Funding
    - DOE share: $1,000,000
    - Coulometrics: $250,000
  - Funding:
    - FY 2018: $312,500
    - FY 2019: $625,000
    - FY 2020: $312,500
- Barriers
  - Energy/Power Density
  - Lithium Plating
  - Cost
- Partners
  - None

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Relevance

- To achieve extreme fast charging LIBs, methods to overcome lithium plating on the anode without sacrificing energy density must be found
- This program focuses on building state-of-the-art cylindrical LIBs and optimizing:
  - Anode composition
  - Electrolyte composition
  - Cell design
  - Cathode composition

Milestones:

	Milestone	Type	Description
✓	Anode Development Milestone	Technical	All anode materials listed in BP1&2 have been tested in 18650s and best materials are down-selected for XFC cell optimization.
✓	Electrode Development Milestone	Technical	All composite electrode materials from BP1&2 have been tested in 18650s and best materials are down-selected for XFC cell optimization.
✓	Electrolyte and Additives Milestone	Technical	All electrolyte and additives from BP1&2 have been tested in 18650s and best materials are down-selected for XFC cell optimization.
✓	Cell Design Milestone	Technical	All cell designs from BP1&2 have been tested in 18650s and best materials are down-selected for XFC cell optimization.
✓	DOE Cell Delivery	Technical	Produce 18 cells (>2Ah) and deliver to the DOE by M24 containing the XFC technology developed to date.
✓	Go/No Go Decision Title	Go/No Go	Cells assembly with down-selected anode, electrode, electrolyte, and cell design at end of M22. This optimized configuration must achieve the FOA objective of 144Wh/L after 500 XFC (6C/1C cycles).

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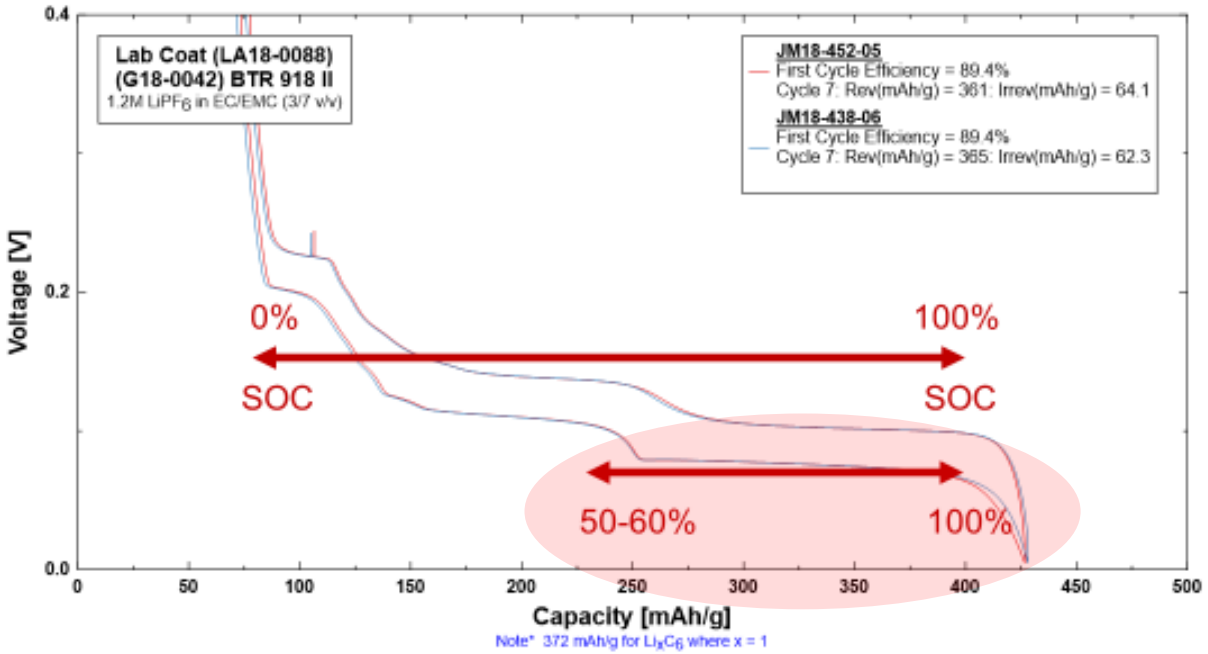
Approach

Methodology

- Focus on methods to reduce Li-plating
- Use combined strategy to optimize:
  - Anode
  - Electrolyte
  - Cathode
  - Cell design



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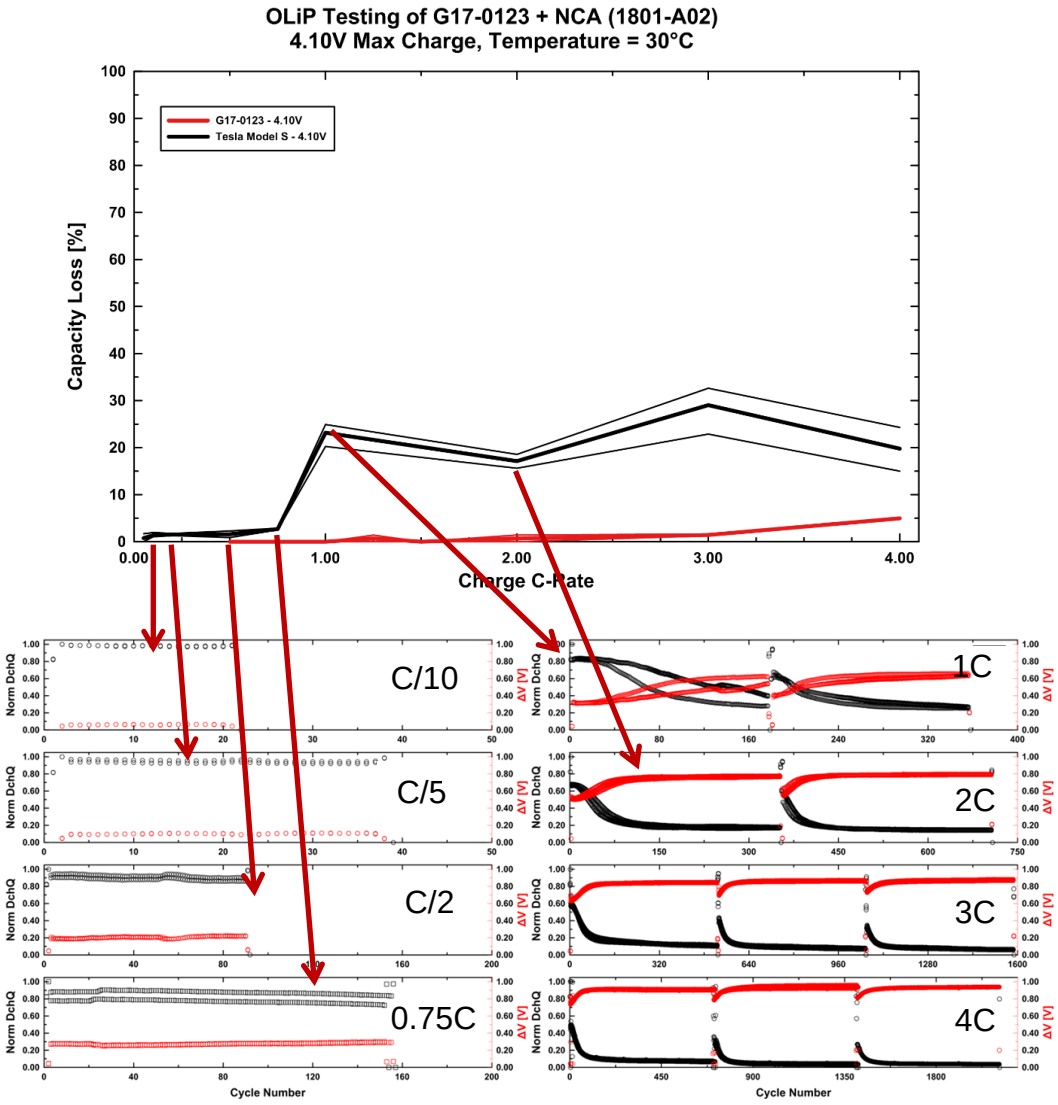
Approach

Testing Strategy

- Onset of Lithium Plating Test
  - CC charge/discharge
  - Fixed C-rate for cell group
  - Look for capacity loss after 350h and resistance change in cells
- Allows you to amplify lithium plating



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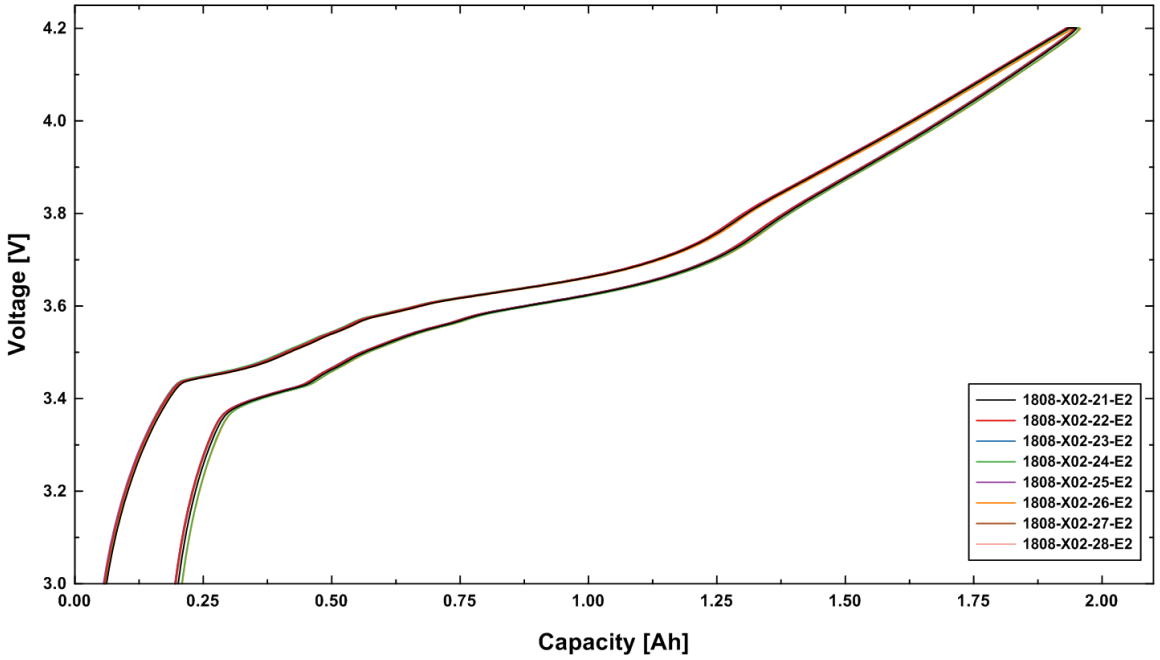
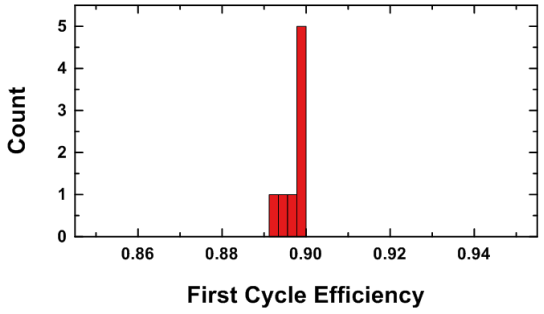
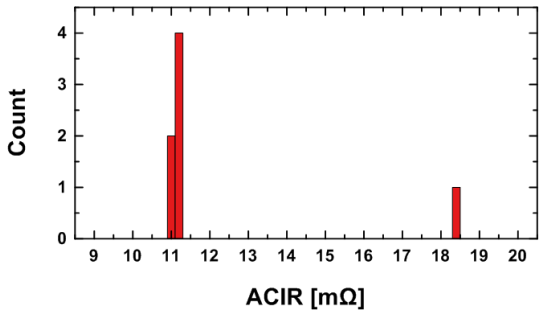
Technical Accomplishments and Progress

Example cell build quality







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Technical Accomplishments and Progress

Significant groups of cells produced with different anode compositions – limited effect on charge rate.

Cell Spec	Anode ID	Cathode Material	Anode Areal Capacity [mAh/cm^2]	Anode Density [g/cc]	Maximum Charge Rate	Capacity Loss [%]
Gen 1 Power Cells						
1801-A01	A17-0106	NCA	2.87	1.36	3.00C	2.59 @ 3C
1801-A02	A17-0123	NCA	2.88	1.36	4.00C	4.97 @ 4C
1801-A03	A17-0094	NCA	3.47	1.36	4.00C	2.06 @ 4C
1801-A03e	A17-0094	NCA	3.47	1.36	4.00C	8.43 @ 4C
1801-A04	A17-0111	NCA	3.47	1.36	3.00C	6.67 @ 3C
1803-A03	A18-0011	NCA	2.15	1.35	2.00C	7.02 @ 2C
1804-A01	A18-0019	NCA	2.00	1.35	2.00C	5.72 @ 2C
1805-A09	A18-0033	NCA	2.15	1.35	2.00C	3.18 @ 2C

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Technical Accomplishments and Progress

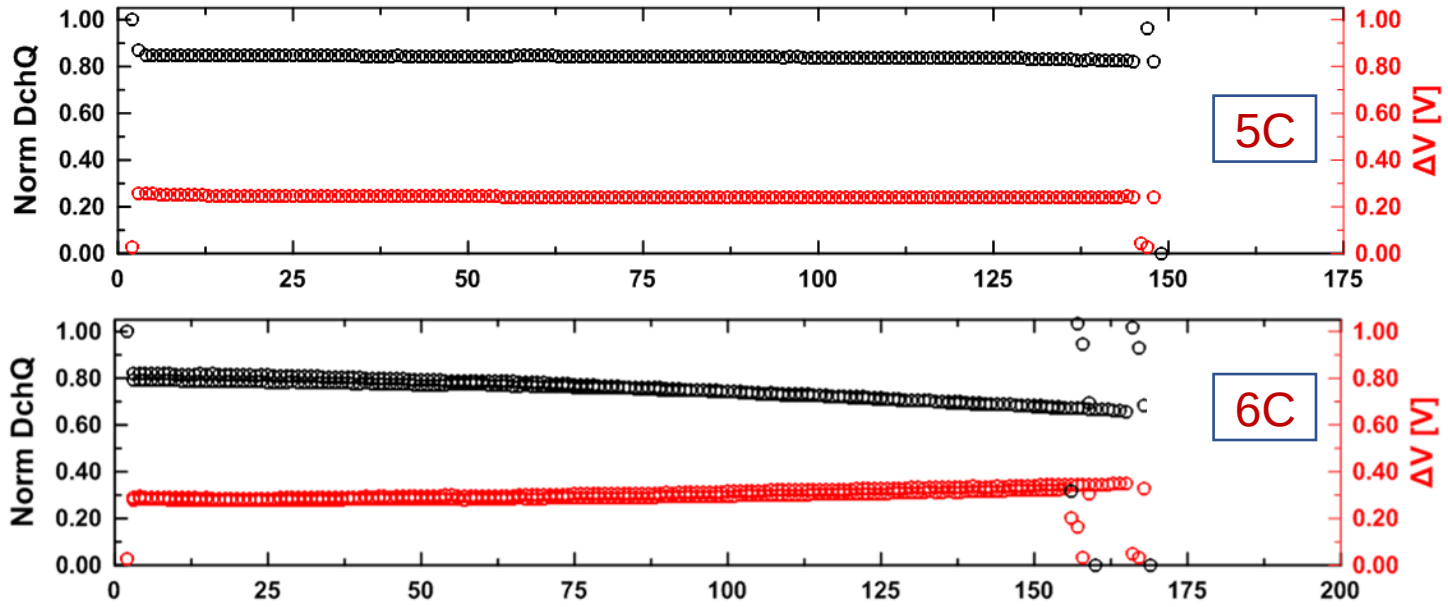
Anode coating weight reduced, and anode density increased. Anode composition showing limited impact.

Cell Spec	Anode ID	Cathode Material	Anode Areal Capacity [mAh/cm^2]	Anode Density [g/cc]	Maximum Charge Rate	Capacity Loss [%]
Gen 2 Power Cells						
1808-X01	A17-0114	NMC622 (CNT)	2.15	1.4	3.00C	5.76 @ 3C
1808-X02	A17-0114	NMC622	2.15	1.4	3.00C	4.79 @ 3C
1808-X03	A18-0069	NMC622	2.15	1.4	3.00C	7.58 @ 3C
1808-X05	A18-0057	NMC622	2.15	1.4	3.00C	4.39 @ 3C
1810-X01	A18-0102	NMC622	2.15	1.4	4.00C	5.46 @ 4C
1810-X02	A18-0106	NMC622	2.15	1.4	3.00C	7.04 @ 3C
1810-X03	A18-0109	NMC622	2.15	1.4	4.00C	2.66 @ 4C
1901-X04	A19-0009	NMC622	2.15	1.4	3.00C	5.09 @ 3C
1901-X06	A19-0010	NMC622	2.15	1.4	<4.00C	1.17 @ 3C

Technical Accomplishments and Progress

Gen 2.5 power cells reduced anode loading achieves 6C charge rate needed to Pass DOE XFC Test.

Cell Spec	Anode ID	Cathode Material	Anode Areal Capacity [mAh/cm^2]	Anode Density [g/cc]	Maximum Charge Rate	Capacity Loss [%]
Gen 2.5 Power Cells						
1902-X02	A18-0042	NMC622	1.88	1.4	6.00C	5.85% @ 6C



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Technical Accomplishments and Progress

Gen 3 power cells show reduction in anode coating weight achieves up to 9C charge rate.

Cell Spec	Anode ID	Cathode Material	Anode Areal Capacity [mAh/cm^2]	Anode Density [g/cc]	Maximum Charge Rate	Capacity Loss [%]
Gen 3 Power Cells						
1802-A01	A17-0106	NCA	2.87	1.36	9.00C	2.13 @ 9C
1802-A02	A17-0123	NCA	2.88	1.36	9.00C	2.06 @ 9C
1811-X01	A18-0042	NMC622	2.15	1.4	6.00C	TBD
1811-X02	A18-0042	NMC622	2.15	1.4	6.00C	TBD
1812-X01	A18-0042	NMC622	2.23	1.4	6.00C	TBD

Technical Accomplishments and Progress

Cell design.

- Tabs cause issues
  - Current density and voltage
    - Non-uniform through electrode with position from tab
  - Tabs are heat transfer path
    - Leads non-uniform heat distributions
- New electrode design eliminates tab issues
  - Causes a few new ones
    - No production equipment
    - Different production equipment
    - Still learning

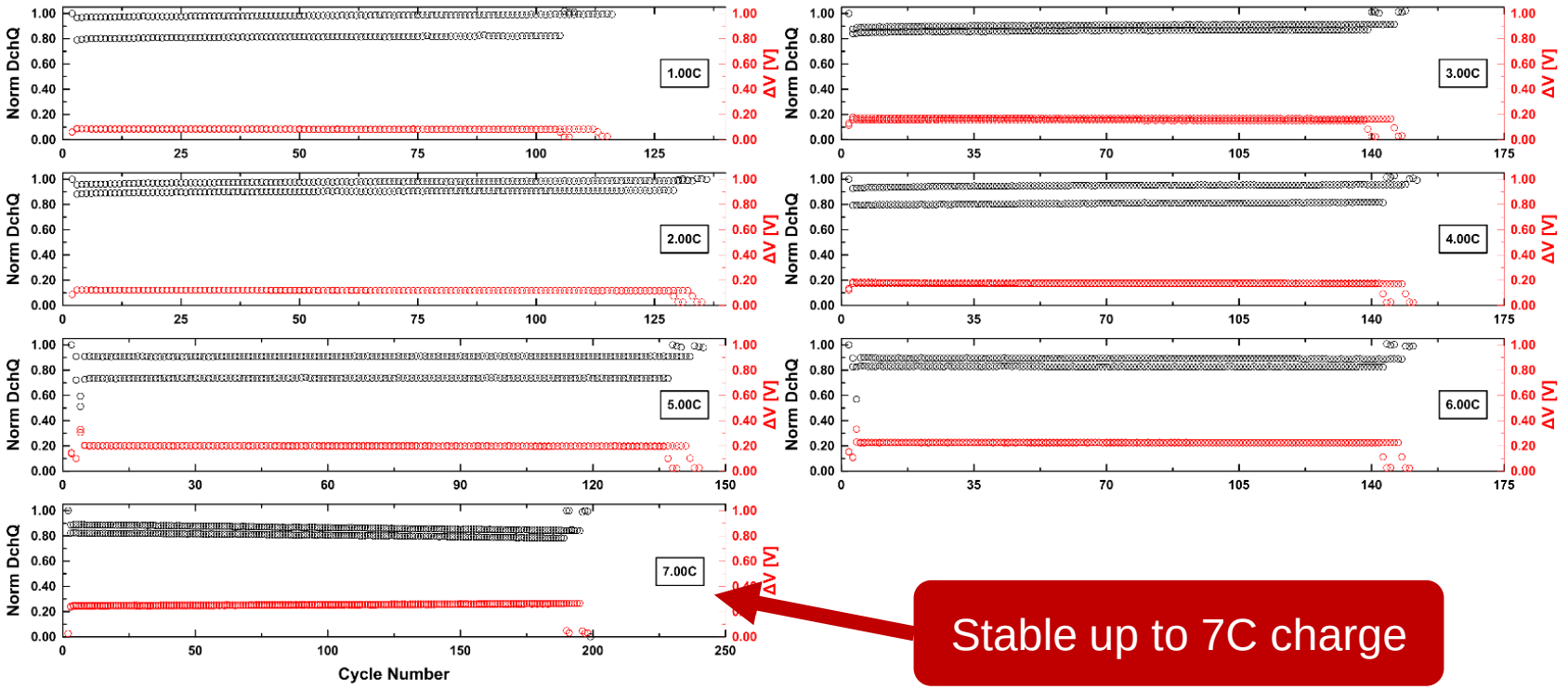
Technical Accomplishments and Progress

Continuous tab anode and cathode

Anode Tabs	Cathode Tabs	ACIR [mΩ]
2	1	13.0
New Design Anode	1	**9.1**
2	**New Design Cathode**	**10.9**
New Design Both	**New Design Both**	**7.6**

Technical Accomplishments and Progress

Gen3 – Power cell featuring continuous tabs.



Stable up to 7C charge

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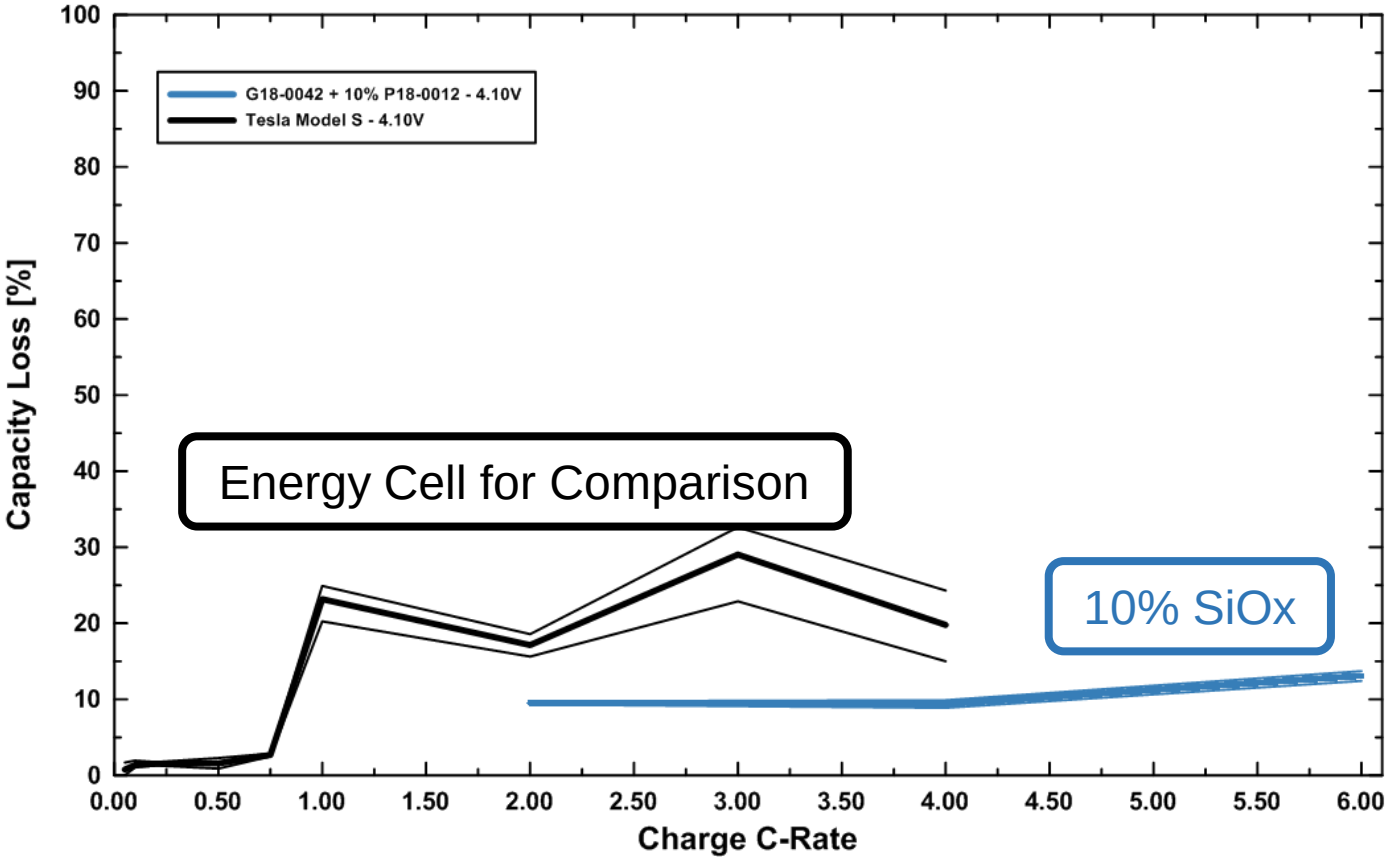
Technical Accomplishments and Progress

Gen3 – with 10% SiOx (no significant improvement)



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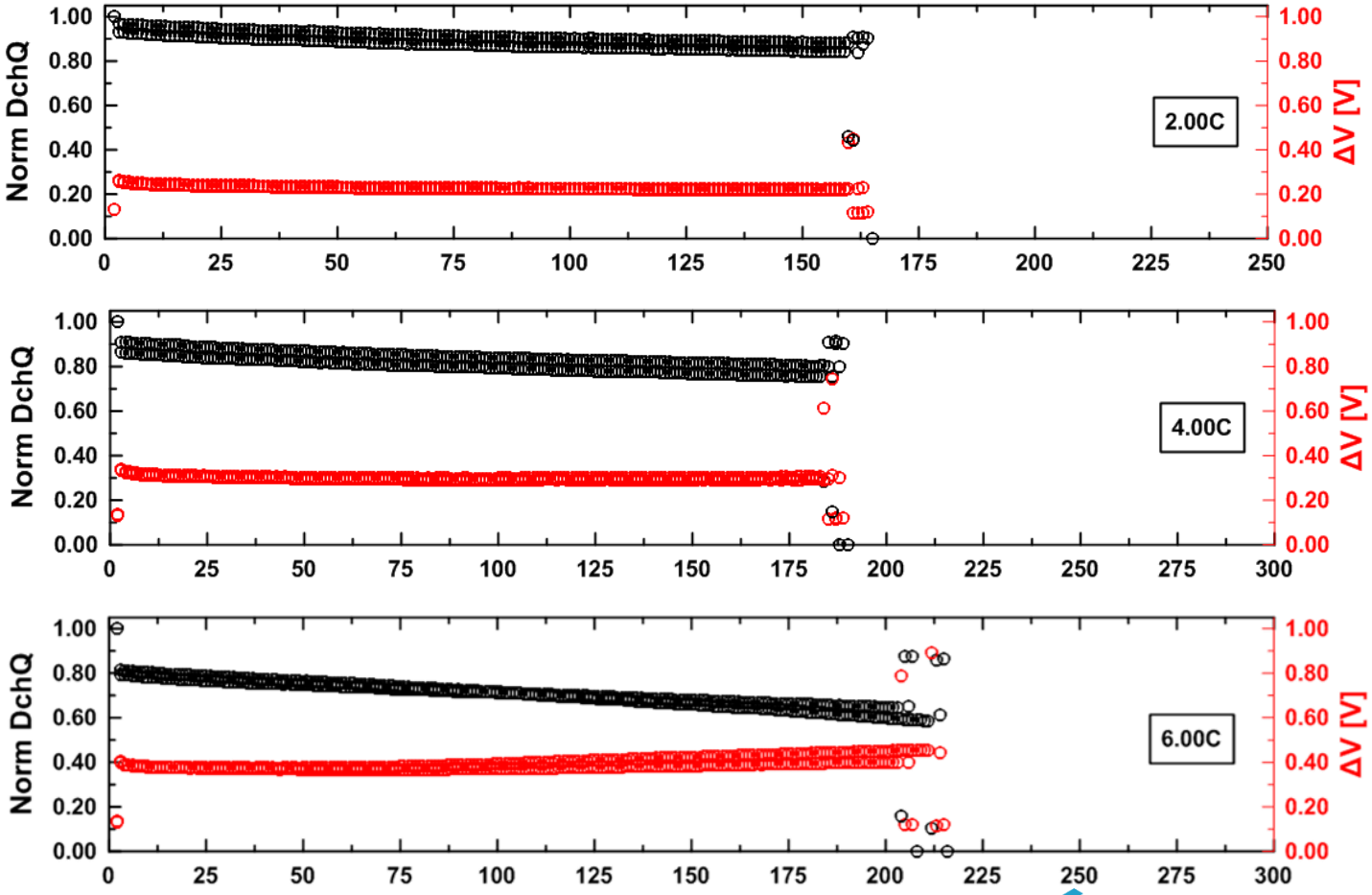
Technical Accomplishments and Progress

Gen3 – with 10% SiOx (no significant improvement)



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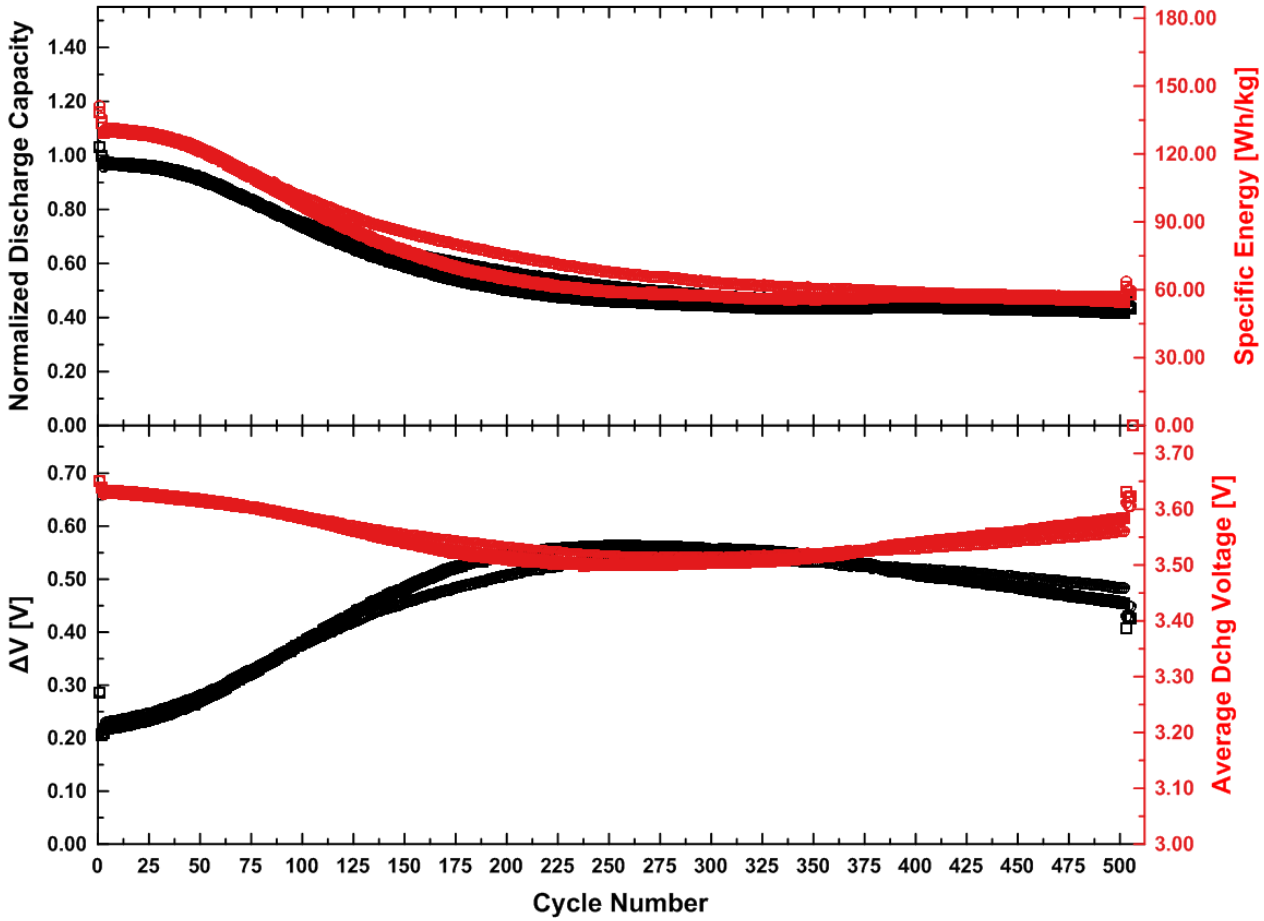
Technical Accomplishments and Progress

XFC Testing

Cell Spec	Anode ID	Cathode Material	Anode Areal Capacity [mAh/cm^2]	Anode Density [g/cc]	Weight [g]	Initial DchgQ [Ah]	Initial Energy [Wh]	Specific Energy [Wh/kg]	Energy Loss [Avg %]
Gen 2 Power Cells									
1904-X05 Procedure 0	G19-0005	NMC622	2.19	1.4	41.925	1.449	5.237	125.048	46.74
1904-X05 Procedure 1	G19-0005	NMC622	2.19	1.4	41.925	1.276	4.556	108.675	36.86
1904-X05 Procedure 2	G19-0005	NMC622	2.19	1.4	41.925	1.359	4.871	116.048	40.54

Technical Accomplishments and Progress

XFC Testing: 1904-X05 P0 (Gen 2 Power Cell)



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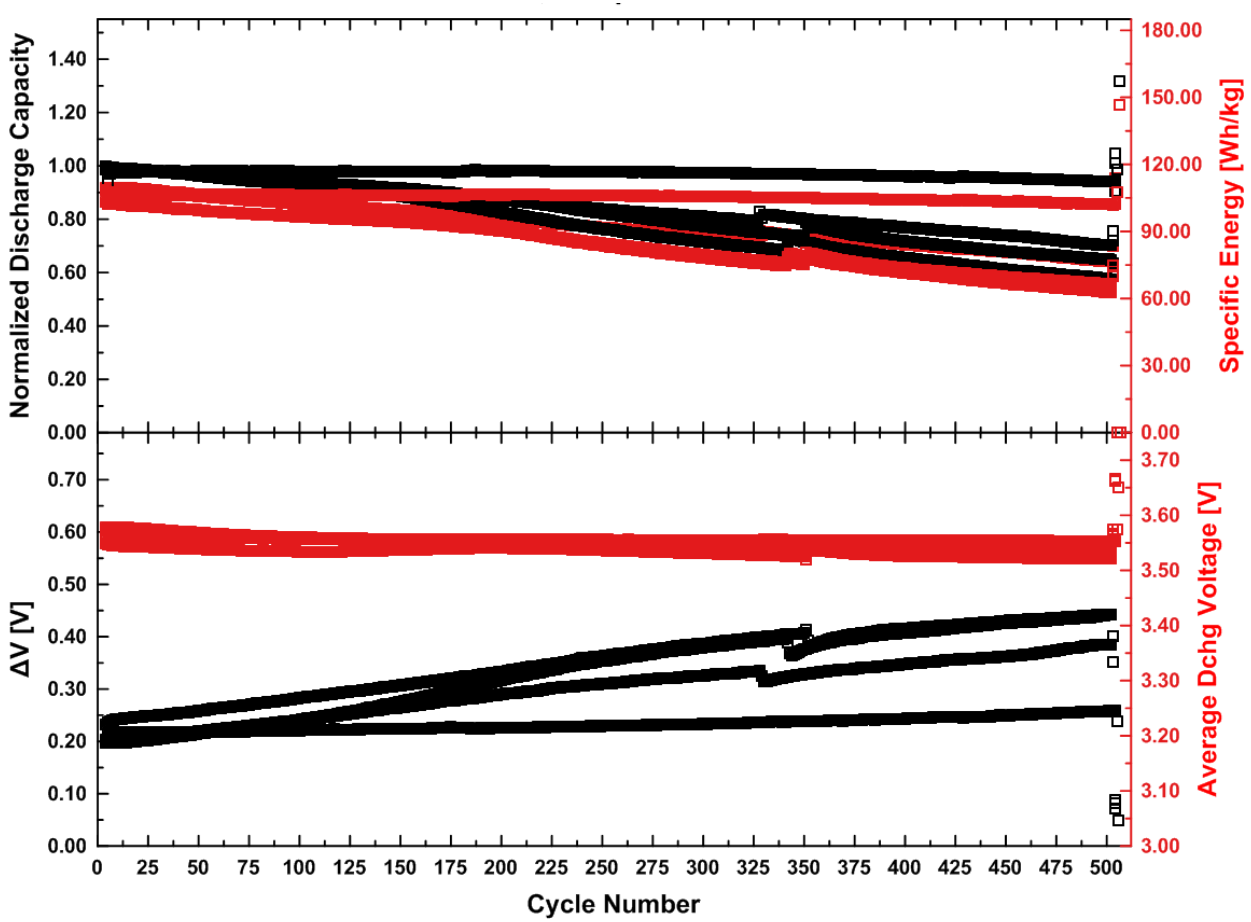
Technical Accomplishments and Progress

XFC Testing: 1904-X05 P1 (Gen 2 Power Cell)



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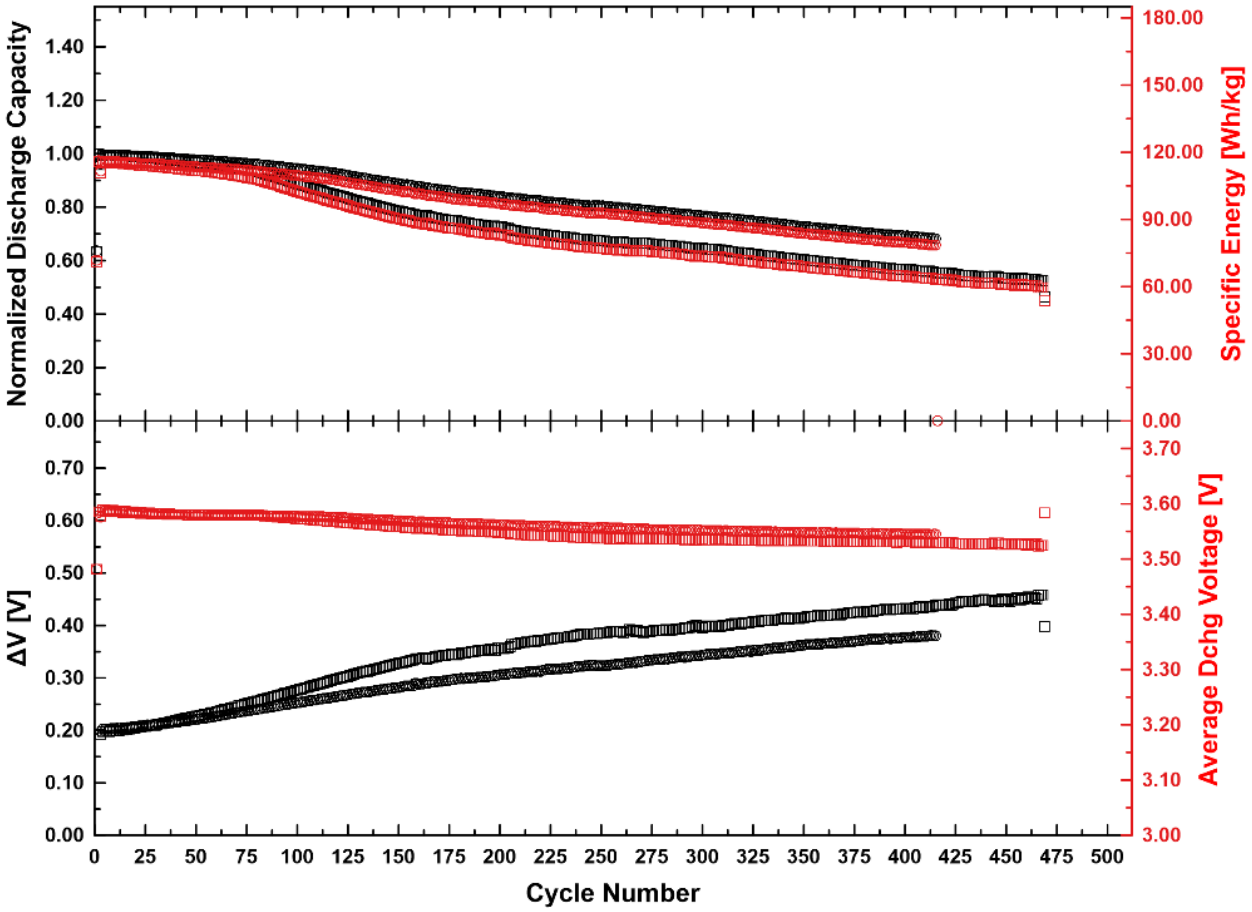
Technical Accomplishments and Progress

XFC Testing: 1904-X05 P2 (Gen 2 Power Cell)



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Future Work

- FY20 Final Work (Underway):
  - Complete full cell homologation of proven design improvements for final report and cell deliverable milestone for DOE.