Low Temperature Durability of Electric Vehicle Batteries

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Introduction

- Environment and Climate Change Canada (ECCC) and Transport Canada (TC) are leading Canada's efforts towards the UNECE-EVE.
- An area requiring further investigation is cold weather durability of EVs.
- Performance losses of batteries at low temperature are well known, but durability studies are not well characterized.
- Typically, to improve low temperature performance and durability specially designed electrolytes/battery materials or manufacturing processes are introduced, but these come at a high cost and issues at higher operating temperatures.
- This presentation summarizes our initial study in the area and described the soon to be funded follow up project.

Scope and Objectives

- Overall Scope – evaluate the durability of batteries for EV under low temperature conditions.
- Specific Objectives – investigate and determine the reasons behind the loss in durability.

Approach and Methodology

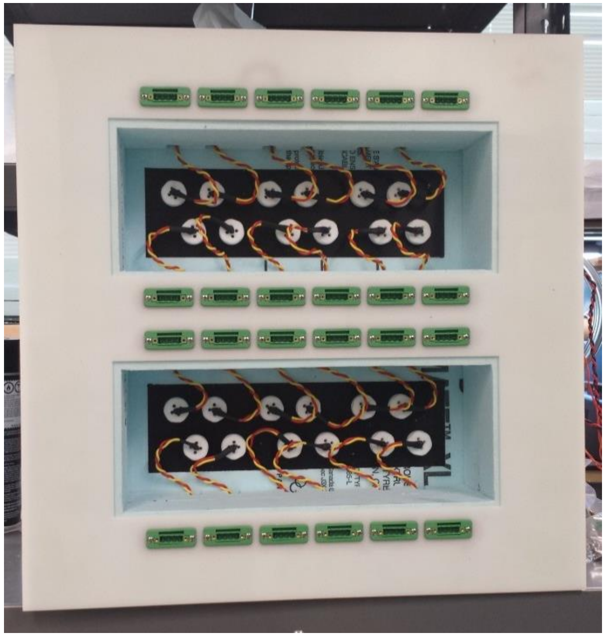
- Focus is on EV batteries, but wide variety of rapidly changing products (pouch, prismatic, 18650) all with different sizes, chemistry, capacity etc..
- For this initial project due to equipment requirements, safety issues of testing large cells at low temperature for extended periods the focus was on commercially available 18650 cells.

Approach and Methodology cont.

- Teardown analysis of a selection of currently available EV cells to identify an equivalent 18650 cell for testing.
- NRC in-house built high precision thermal management system for 18650 is used to control the battery temperatures.
- Rate mapping – 18650 cells are tested at different temperature and C-rates.
- Durability testing – Different temperature and C-rate until failure (80% of the initial capacities) using standard CC-CV cycling.
- Characterization – High Pulse Power Characterization and Electrochemical Impedance Spectroscopy testing (before, after and during testing).
- Teardown analysis – Cycled cells are torn down and characterized.

Approach and Methodology cont.

- High Precision Thermal Management



Approach and Methodology cont.

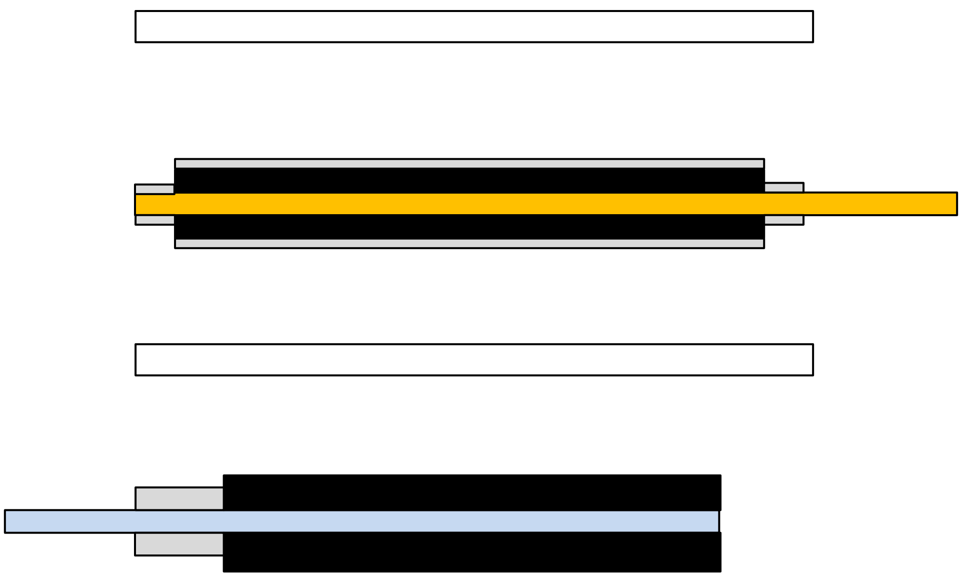
Temperature stability/precision results

Environment	T_{SET} (°C)	Avg. temp. offset (°C)	Std. Dev. (°C)	Temp. var. over 1 hour (°C)	1W Heater 1hr ΔT_{S-E}* (°C)
Free convection in room	23.0	0.78	0.37	+/- 0.72	+21.0
Forced convection in oven #1	30.0	0.09	0.36	+/- 0.75	+12.1
Forced convection in enviro. chamber #1	0.0	0.65	0.75	+/- 1.27	+5.2
Reco18650	**0.00**	**0.04**	**0.01**	**+/- 0.04***	**+0.6**

*A temperature variance of +/- 0.75°C around 60°C can lead to:

- 5% error on cycle performance
- 50 cycle difference to end of life

Results – Teardown (Thickness Sample)



Thicknesses in Microns (um)

(*) values measured directly are in **bold**

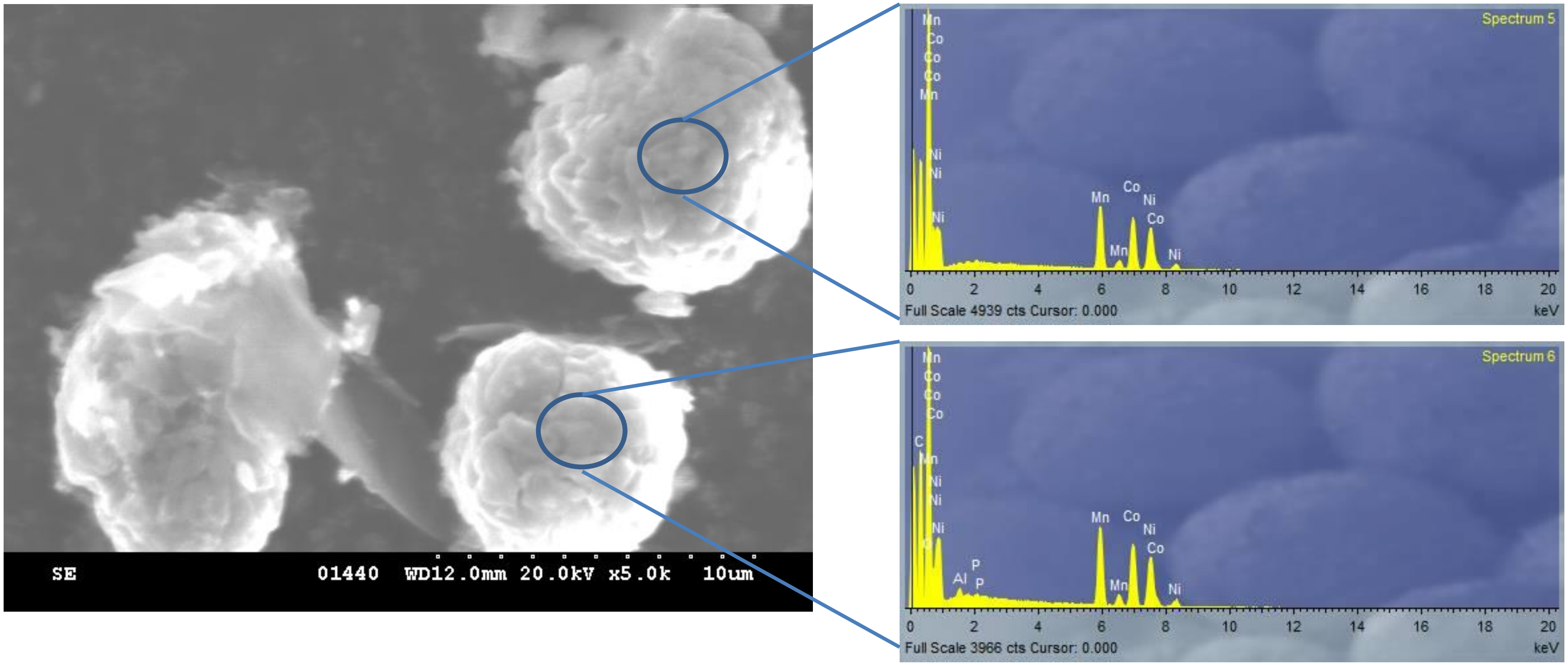
Anode	Total	Side 1	Side 2
Bare Copper	**10**	8	8
Ceramic and Foil	**22**	11	11
Active and Foil and Ceramic	**80**	40	40
Active	58	29	29
Ceramic	6	3	3

Cathode	Total	Side 1	Side 2
Bare Aluminum	**20**	10	10
Ceramic and Foil	**60**	30	30
Active and Foil	**78**	39	39
Active	58	29	29
Ceramic	40	20	20
Cathode Tape (both I&T)	**80**	40	40

	Total
Separator 1	**23**
Separator2	**23**
Separator and JR tape	**70**

Drawings are conceptual and not precisely to scale

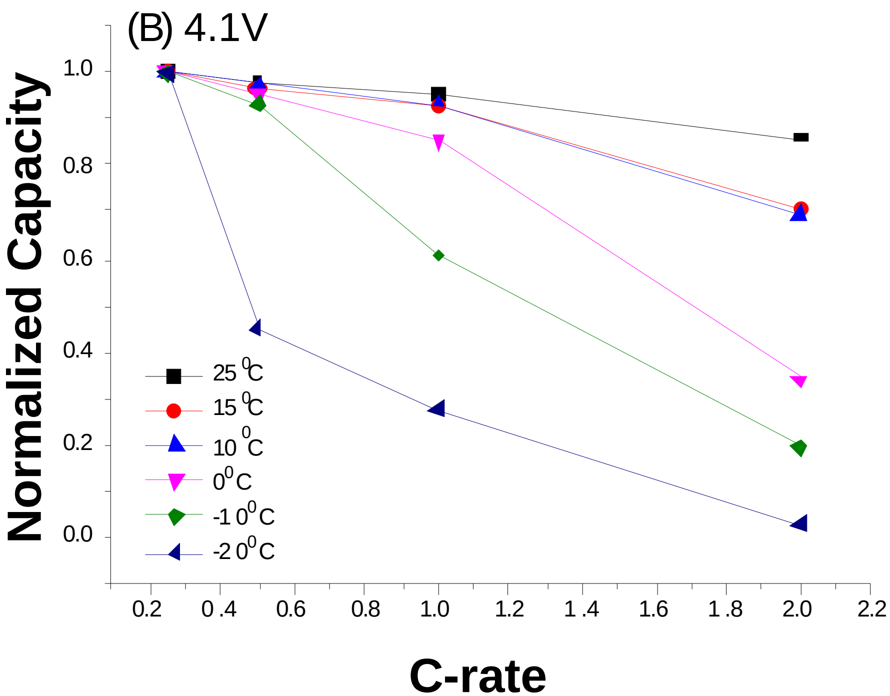
Results – Teardown (Cathode SEM/EDX sample)

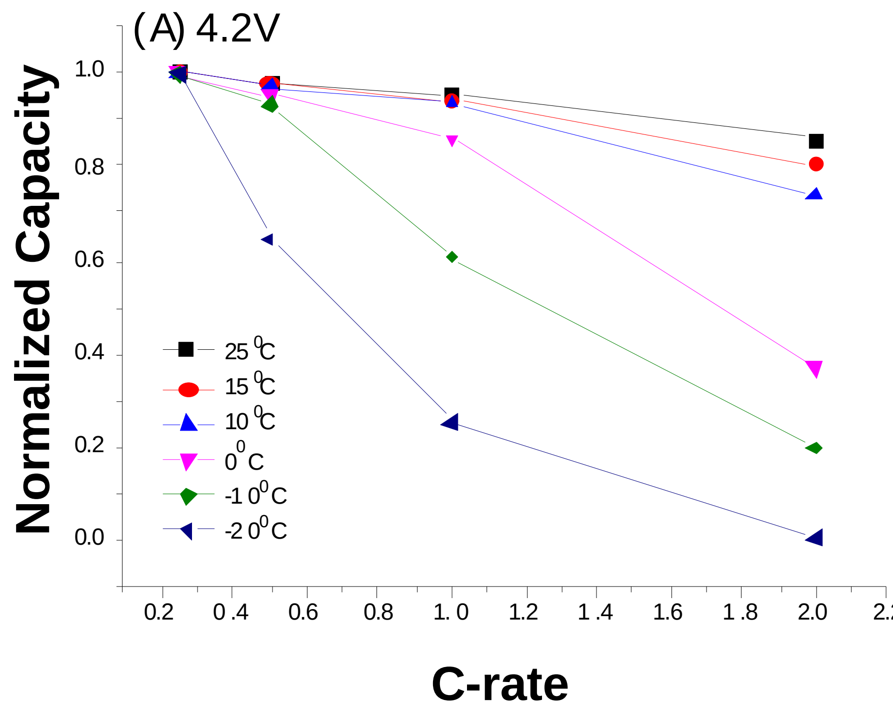


❖ Observations: Single Grain Analysis

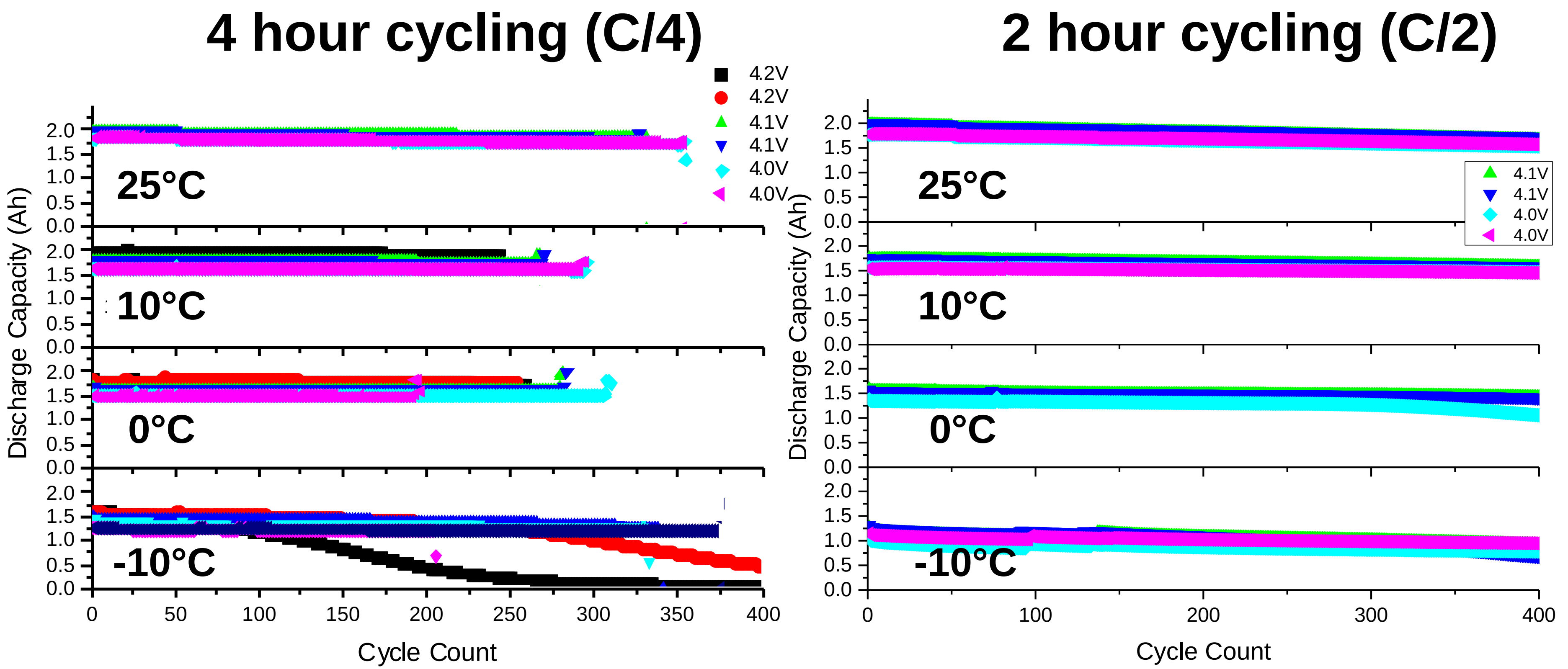
- Spherical morphology with high surface area
- Single Grain EDX confirms NMC; i.e. not a blend
- At%: Ni 36.5, Mn 29.0, Co 34.5 | $LiNi_{(0.36)}Mn_{(0.29)}Co_{(0.34)}O_4$

Results – Rate mapping at various temperatures



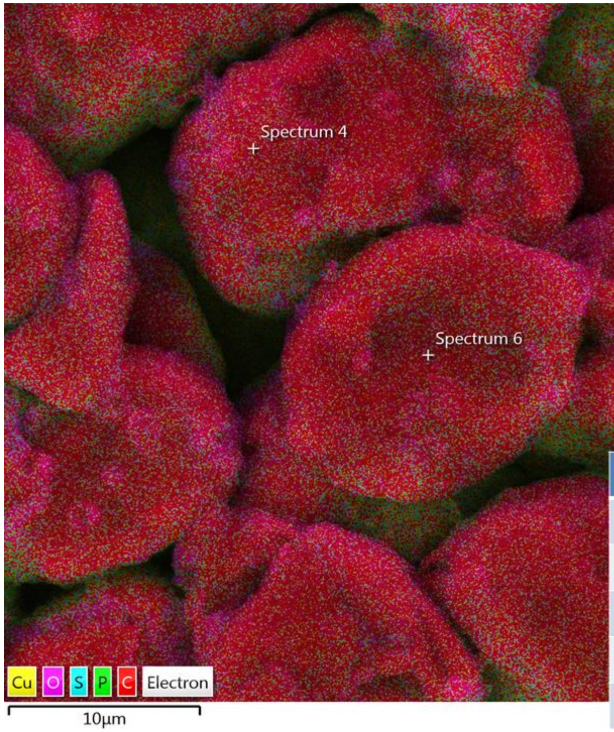


Results – Durability at C/4 and C/2



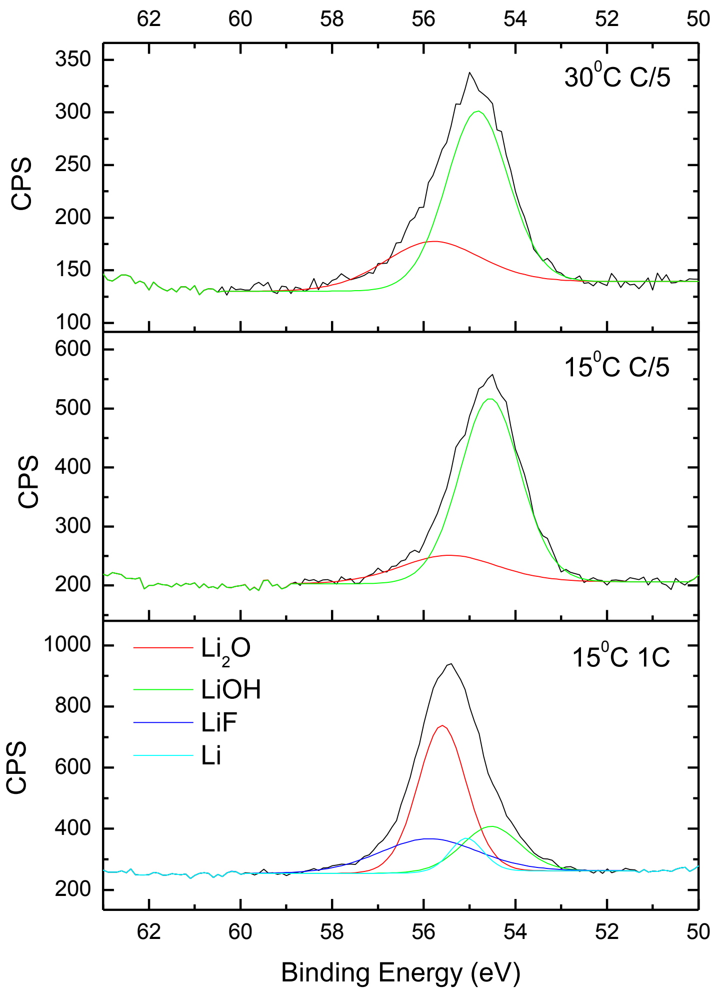
CC-CV cycling, CV cut-off rate drops to <80 mA or 2 hours
Small increase in absolute capacity at lower cycling rates.
Small increase in capacity loss over time at higher cycling rates and lower temperatures.
Higher voltages show higher capacity loss at lower temperature.

Results - Teardown Analysis After Cycling - Anode



Elements	At%
C	93.4
O	19.1
S	0.1
P	0.1
Cu	0.0

Results - Teardown – XPS of Anode



Chemical analysis of the surface of the anode after cycling shows that the higher rate, lower temperature samples indicate a higher concentration of residual Li species on the surface of the graphite. Indicating the possible presence of Li dendrites or thicker SEI. Further analyses are being performed on lower temperature cells.

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Next Phase 2017-2018
Approach

- Previous phase of project looked only at 18650 cells and they were not optimized for use in EVs.
- Current phase will examine cells extracted from EV battery packs obtained from Transport Canada vehicles.
- We will also maintain a technology watch activity looking at the next generation of battery technologies (materials, separator, electrolytes), specifically low temperature performance and durability.
- Due to the safety, equipment and time required to test these large cells, testing methods/equipment used previously needs to be adjusted and/or new ones investigated.

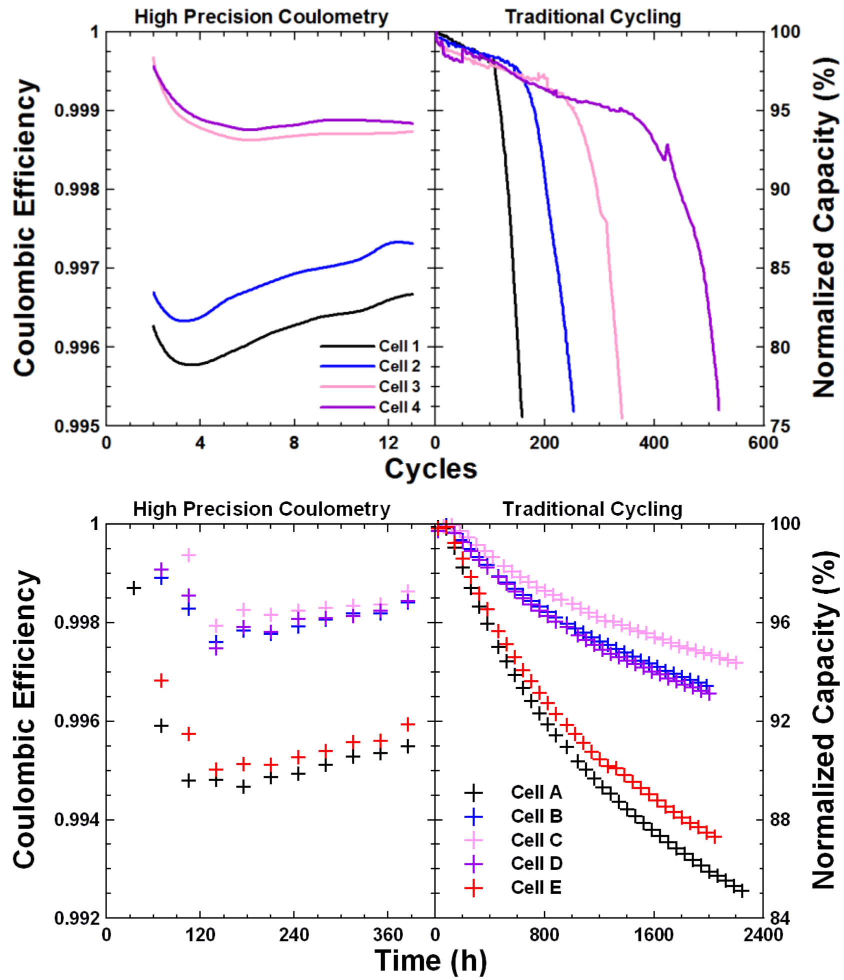
Next Phase 2017-2018 Methodology

- All testing will be performed on cells extracted from previously crash tested electric vehicles (no visible sign of a compromised REESS) by Transport Canada.
- As before, rate mapping of three chosen EV cell choices will be performed at four temperatures (-15, -5, 5, 15°C) and voltages (4.0, 4.1, 4.2, 4.3V). The results will be used to determine the limits of each cell's operating range.
- Long term durability testing on standard battery chargers will be performed at two temperatures.

Next Phase 2017-2018
Methodology

- Researcher in Canada have been pioneering the use of High Precision Cycling (HPC) to test batteries and to determine whether a proposed change is beneficial to the durability of a cell at a much shorter timeline than traditional battery testing protocols.
- NRC has a HPC and will investigate whether it can be used with large format EV cells in conjunction with our high precision thermal management cell testing system.
- The goal is that the HPC in combination with precision control of temperature will permit the identification of important parasitic reactions that may be temperature driven.
- A comparison of the HPC results with standard cycling tests may lead to a potential protocol for low temperature durability in a much shorter timeframe.

Next Phase 2017-2018 Methodology



Lifetime prediction of cells that show only drastic failure

Lifetime prediction of cells that show gradual capacity loss

From Burns *et. al.* J. Electrochem. Soc. **160**, A1451 (2013).

Next Phase 2017-2018 Deliverables

- Deliverable #1 – A report on the benefits and comparison of using a High Precision Cycler (HPC) to test large EV cells in comparison to standard battery cycling methods. The focus here will be mainly on low temperature test results.

- Deliverable #2 – A report on the follow up of Phase 1 report that will concentrate on the low temperature performance/durability of 18650 cells containing new technologies or materials.

- Deliverable #3 – Can a preliminary test procedure be proposed for the testing the durability of EV batteries at low temperatures.

Acknowledgements

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Thank you for your kind attention!

Any Questions, Suggestions or Comments