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Electric Vehicle Battery Cell Testing

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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 durability of EVs, especially as they concern extended low temperature operation.
- Performance losses of batteries with respect to temperature are well known, but durability studies are not well characterized.

Framework

- How does Battery Durability of an EV/PHEV over its lifetime affect predicted and extrapolated GHG emissions over their lifetime?

- What affects lifetime – cold weather, hot weather, fast charging, poor thermal management, cell construction, ever changing material supplier choices, etc…

- Our previous work focused on 18650 cells and now the focus is on EV cells that have much higher capacity and lifetimes

Areas of Investigation 1 – EV Cell Analyses Test Matrix

Test Variable	Configurations								
Cell types	OEM 1 (2013)			OEM 2 (2013)			OEM 3 (2014)		
History*	"Fresh" and high mileage**			"fresh"			"Fresh" and high mileage***		
Cell format	Pouch			Prismatic			Pouch		
Rated Capacity (Ah)	15			21.5			33		
Voltage limits (V)	3.0 – 4.1			3.0 – 4.1			2.5 – 4.2		
Charge/discharge current (C-rate)	C/4	C/2	C	C/4	C/2	C	C/4	C/2	C
Charge/discharge current (A)	3.75	7.5	15	5.375	10.75	21.5	8.25	16.5	33
Environment Temperatures (°C)	For each configuration above								
	-15	-5	5	~~15~~	25	35	45		

* "fresh" cells are extracted from EV battery packs that have less than 2000 accumulated kilometers

** OEM 2 "high mileage" cells have been extracted from vehicles that have greater than 150,000 kilometers. One has higher "EV mileage" than the other

*** After completion of ACLV2 vs DCFC study; cells will be tested here

Low temperature testing

- Testing EV sized cells at low temperature present a number of issues especially if controlled temperature is required (it is!)
- Batteries absorb and give off heat (especially at high rates) and thus stable temperature readings are very difficult
- Extended testing at low temperature presents safety issues that have to be dealt with especially with the size of these EV cells
- NRC has built a new low temperature testing system that safely permits accurate EV cell level testing at low temperature.

Low temperature EV cell chambers

Fire-proof enclosure

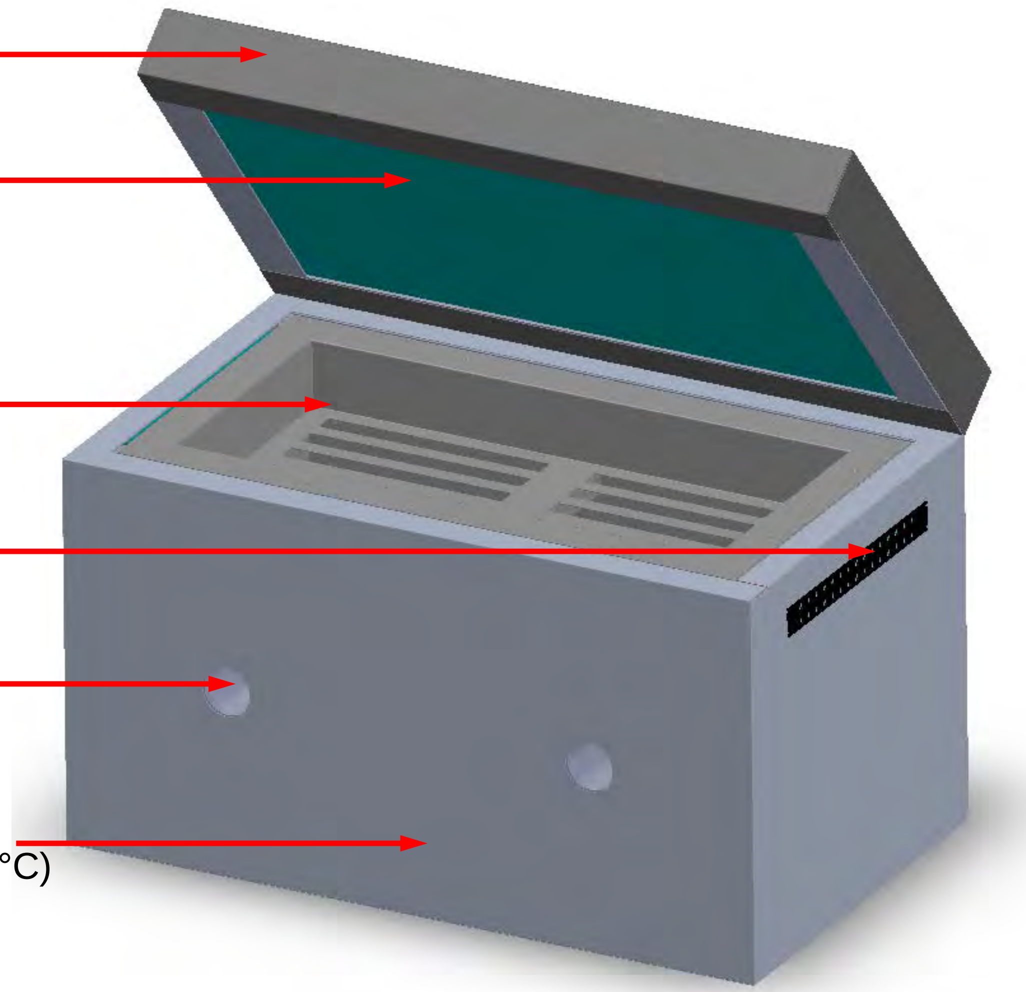
R-20 insulation
(~70W losses at -30°C)

12 flexible cell “sleeves”
submersed in isothermal fluid

Electrical connections
to test cells

Heat transfer fluid cooled by
external process chiller
(500W at -30°C)

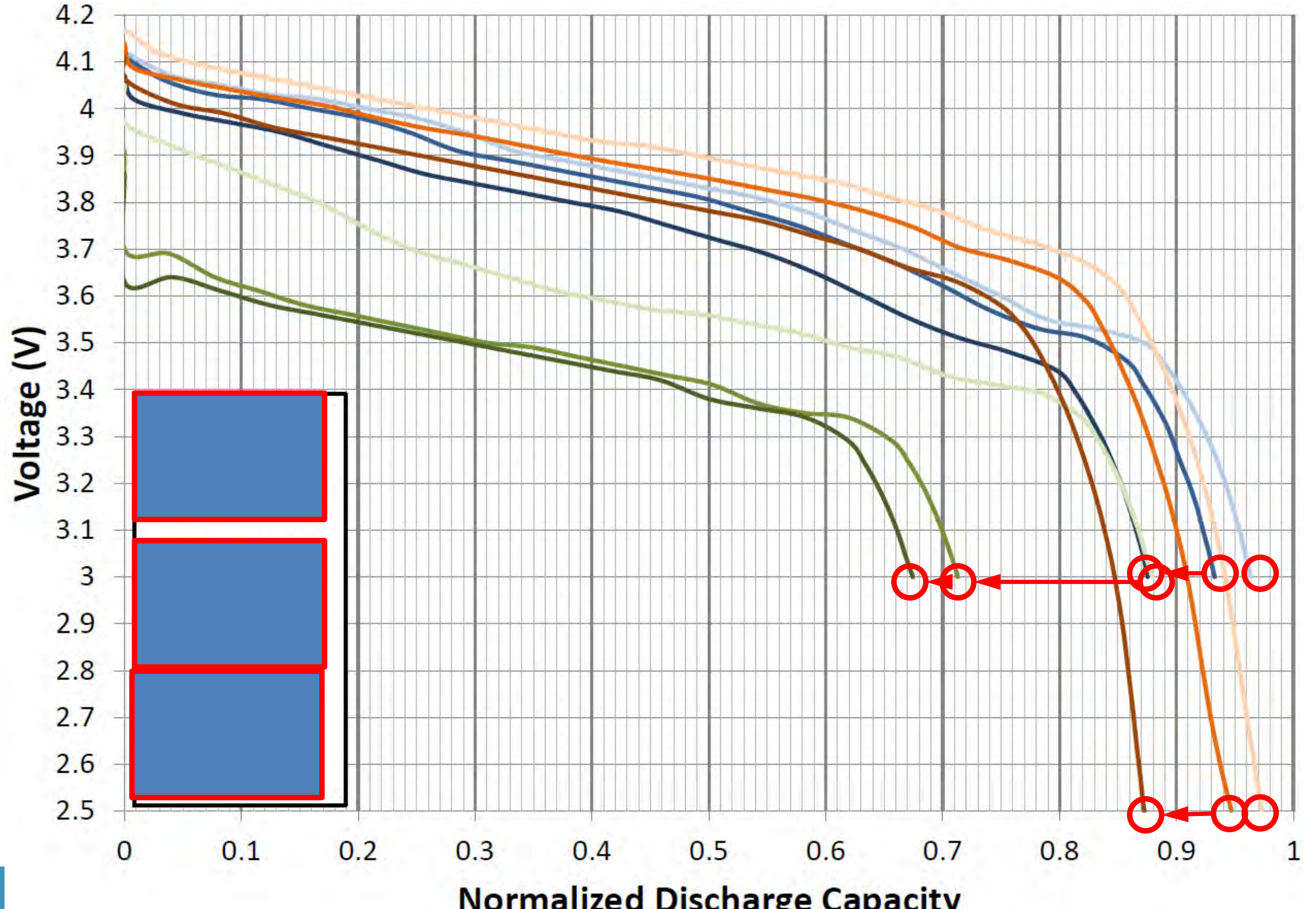
60L liquid reservoir
(Thermal capacitance = 220kJ/°C)



Low temperature EV cell chambers

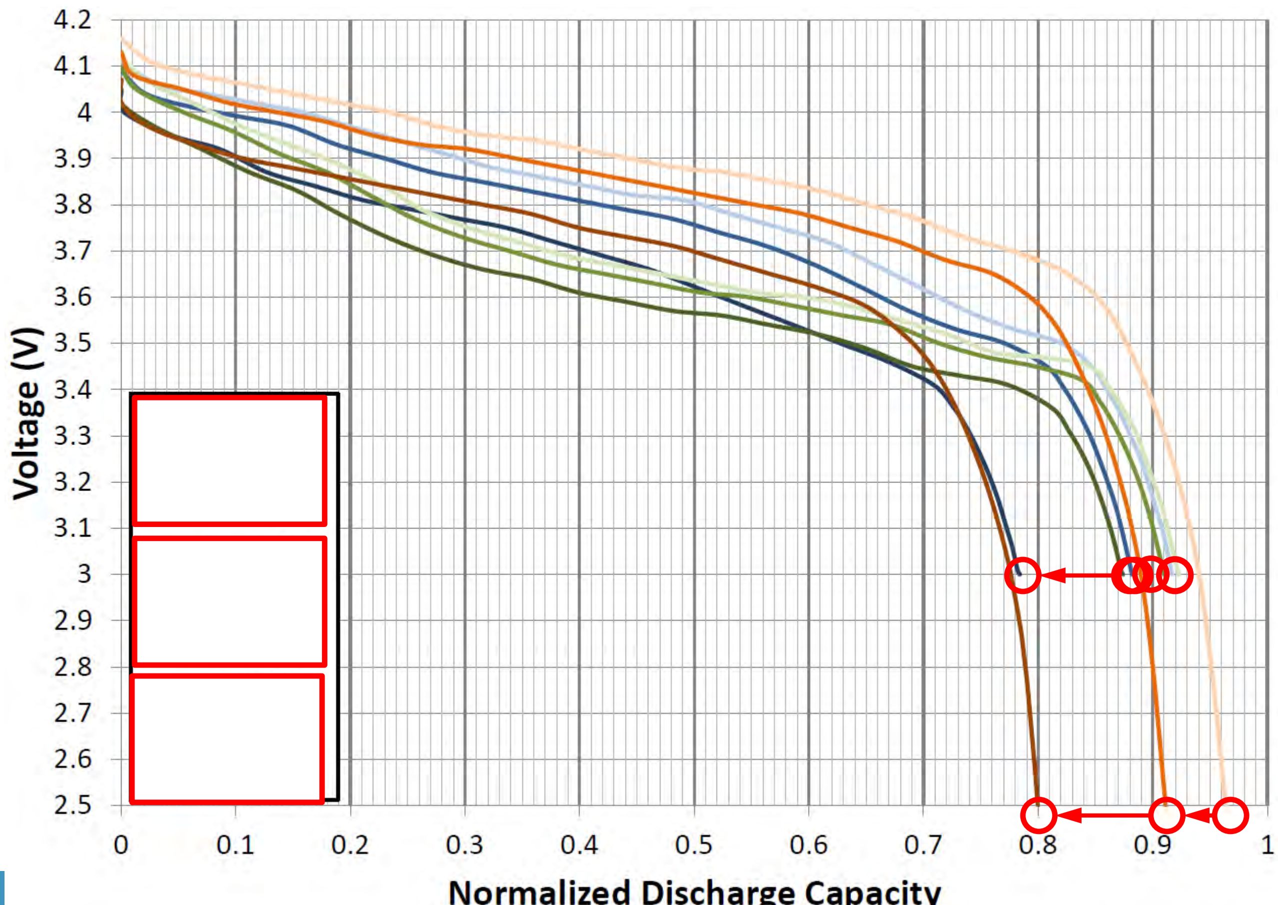
Areas of Investigation 1 – EV Cell Analyses
Rate Performance 1

- Voltage vs. normalized discharge capacity for 3 cell types at 3 charge/discharge rates (the 20th cycle shown for each test)
- Environment temperature 45°C [Cell temperature +/- 0.75°C]



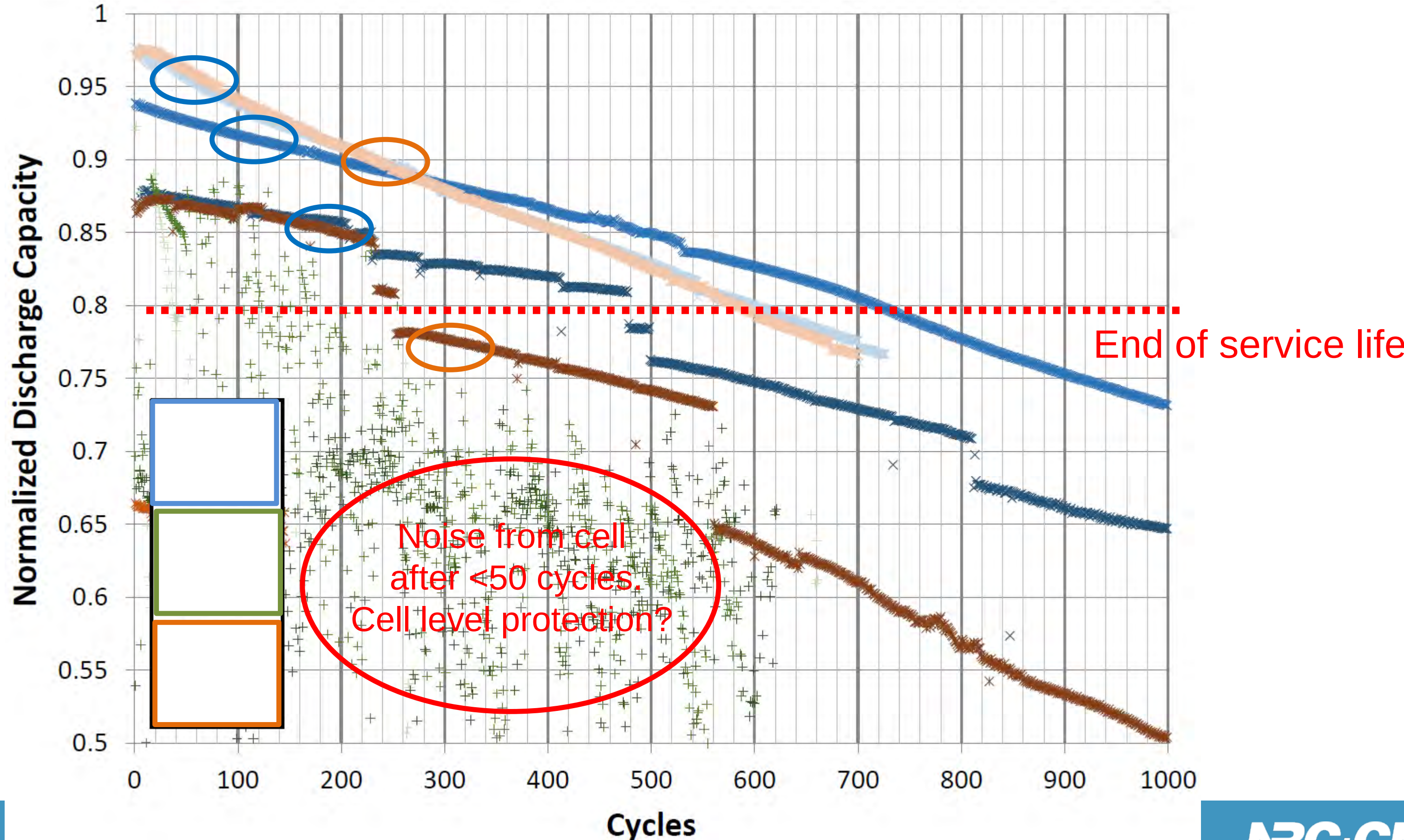
Areas of Investigation 1 – EV Cell Analyses Rate Performance 2

- Voltage vs. normalized discharge capacity for 3 cell types at 3 charge/discharge rates (the 20th cycle shown for each test)
- Environment temperature 25°C   [Cell temperature +/- 0.75°C]



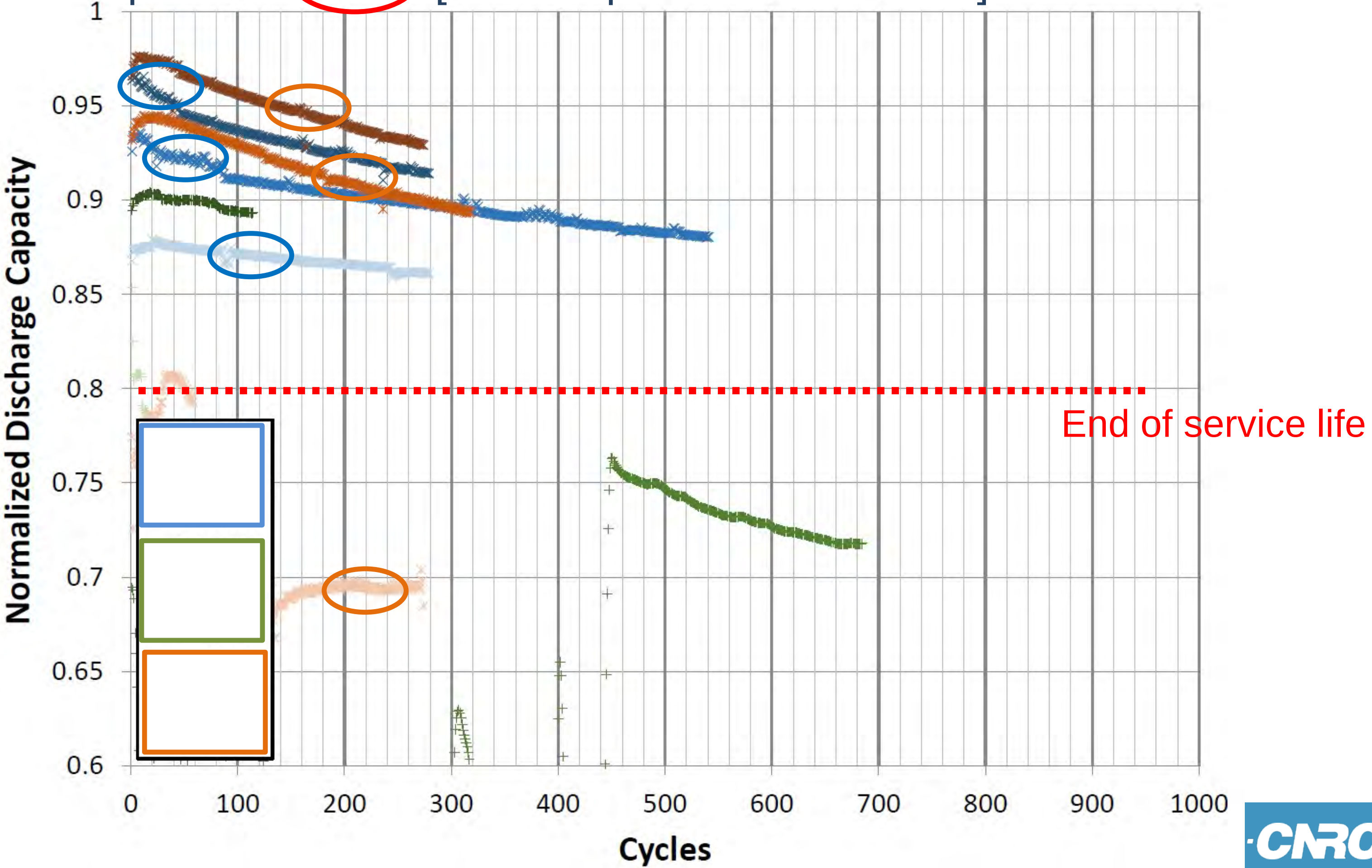
Areas of Investigation 1 – EV Cell Analyses Lifetime 1

- Normalized discharge capacity vs. cycle number for 3 cell types at 3 charge/discharge rates (normalized by the cell's rated capacity)
- Environment temperature 45°C [Cell temperature +/- 0.75°C]



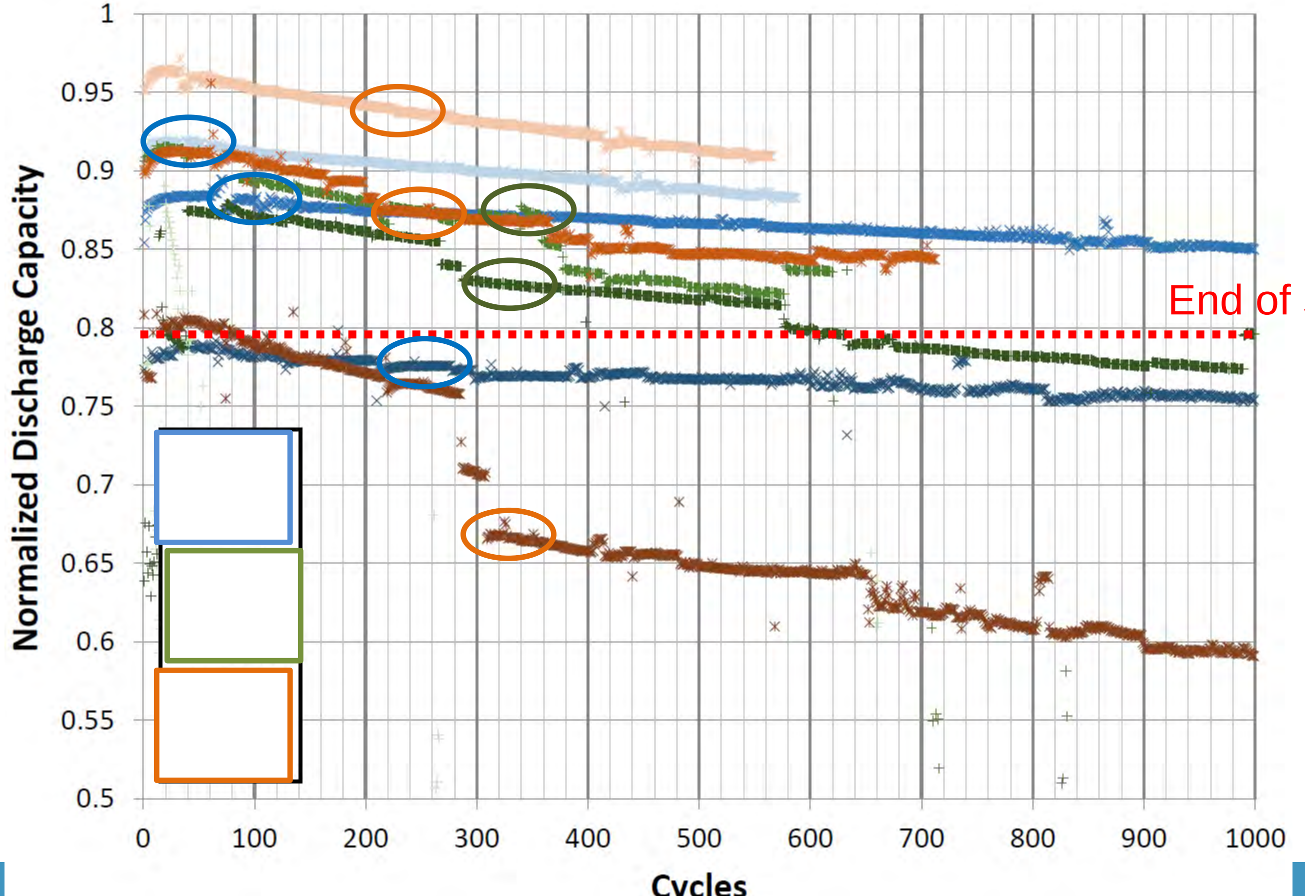
Areas of Investigation 1 – EV Cell Analyses Lifetime 1

- Normalized discharge capacity vs. cycle number for 3 cell types at 3 charge/discharge rates (normalized by the cell's rated capacity)
- Environment temperature 35°C [Cell temperature +/- 0.75°C]



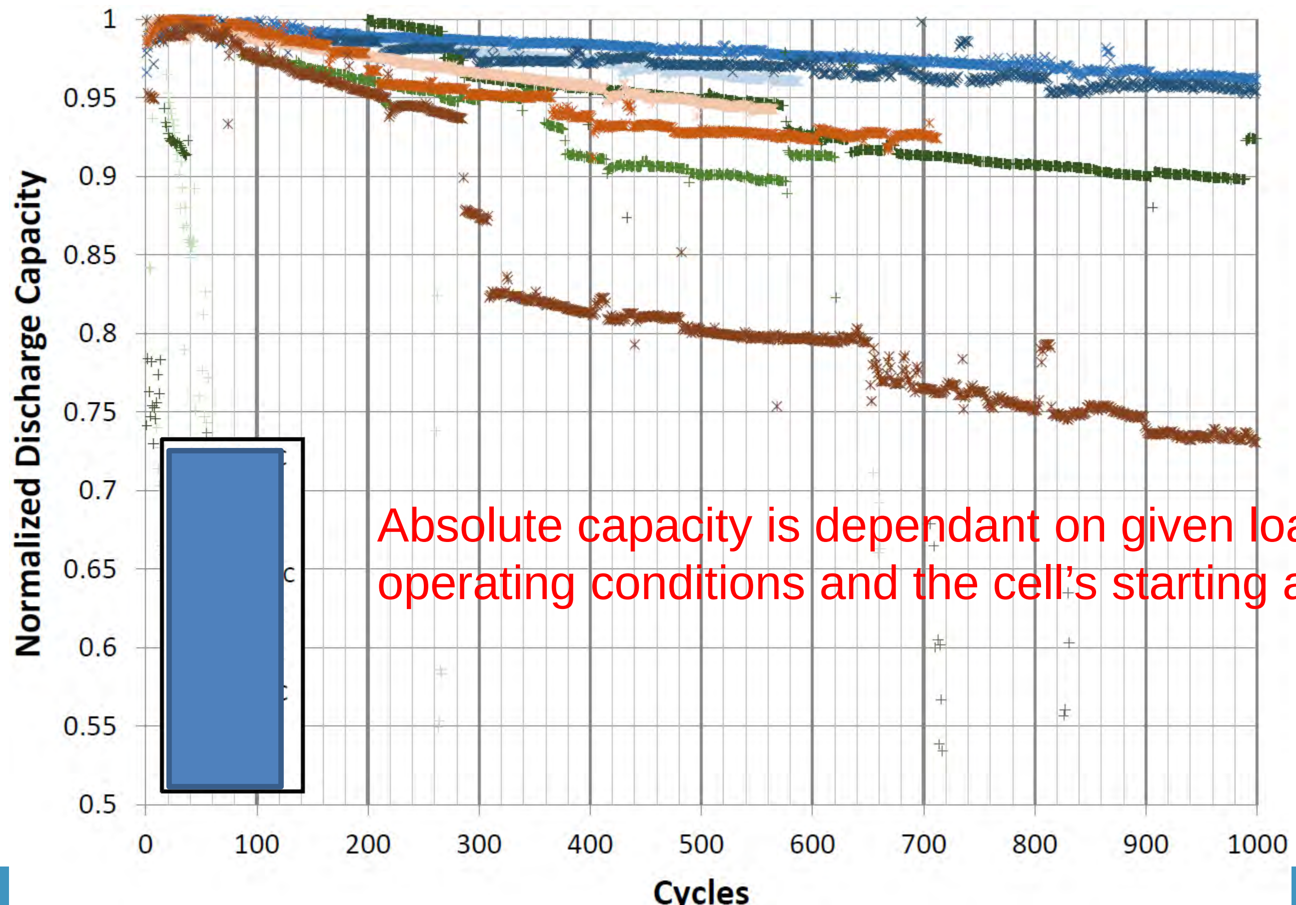
Areas of Investigation 1 – EV Cell Analyses Lifetime 2

- Normalized discharge capacity vs. cycle number for 3 cell types at 3 charge/discharge rates (normalized by the cell's rated capacity)
- Environment temperature 25°C [Cell temperature +/- 0.75°C]



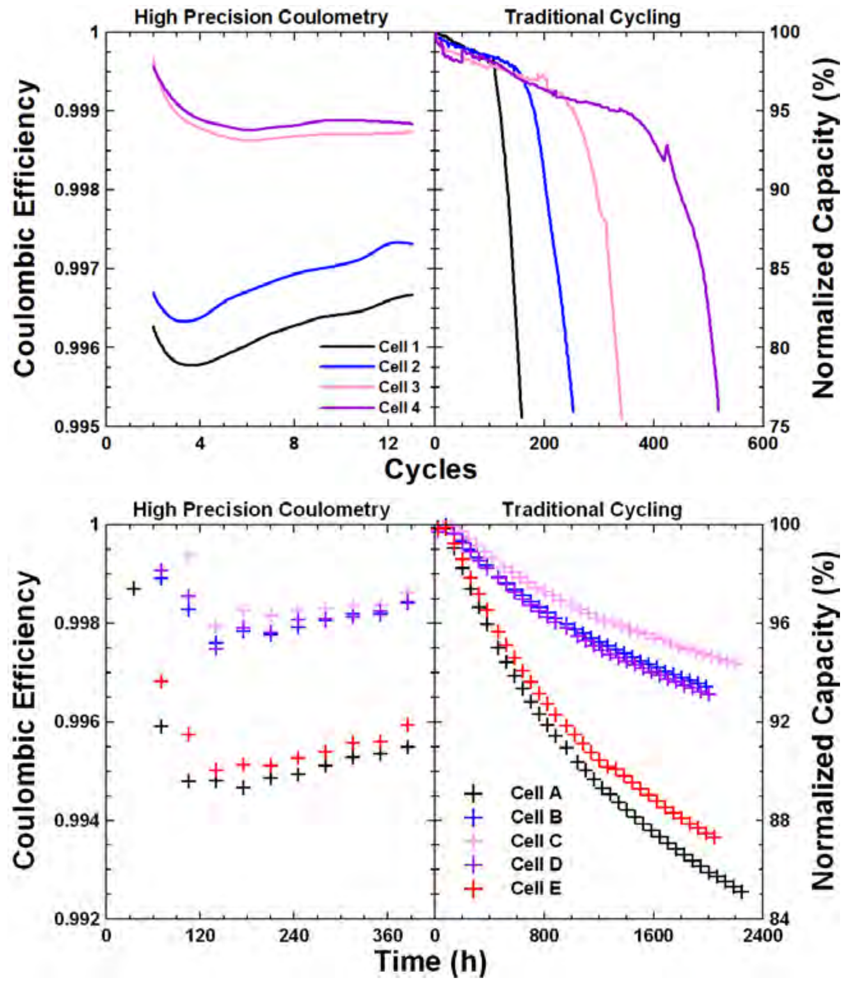
Areas of Investigation 1 – EV Cell Analyses Lifetime 3

- Normalized discharge capacity vs. cycle number for 3 cell types at 3 charge/discharge rates (**normalized by initial discharge capacity of each test**)
- Environment temperature 25°C [Cell temperature +/- 0.75°C]



Absolute capacity is dependant on given loading case, operating conditions and the cell's starting age.

Methodology – High Precision Testing Sample



Lifetime prediction of cells that show only drastic failure

Lifetime prediction of cells that show gradual capacity loss

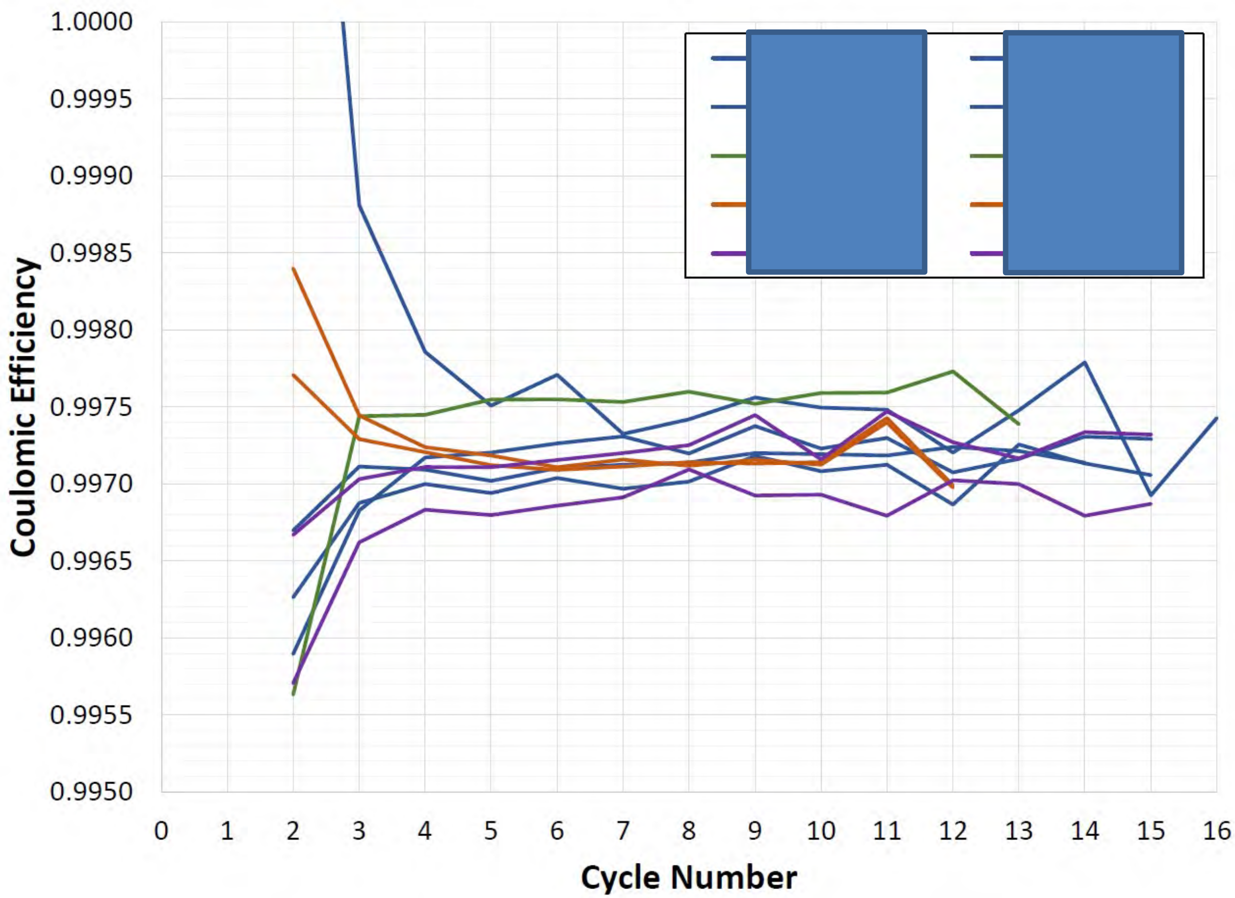
From Burns *et. al.* J. Electrochem. Soc. **160**, A1451 (2013).

Methodology – High Precision Testing

- Comparison of High Precision cycling of EV cells to Standard battery cycling methods
- Can we estimate durability in a shorter timeframe
- Requires very stable temperature environments and low cycling rates
- Compare “fresh” and “high mileage” EV cells

Areas of Investigation 1 – EV Cell Analyses
New Method for Durability 2

- CE measurements for 3 cell types at C/40 and environment temperature 45˚C
- CE cycle variance depends on temperature stability
- CE cell-to-cell variance depends on cell manufacturing and pack uniformity



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Areas of Investigation 1 – EV Cell Analyses New Method for Durability 3

Cell type	CE measurement at C/40 and 45˚C	Cycles to 80% at at 1C and 45˚C
OEM 1	0.997327	813
OEM 2	0.997560	? (CID)
OEM 3	0.997136	562

Areas of Investigation 1 – EV Cell Analyses Real World Comparison

- EV Cell Analysis from cells extracted from USED high mileage EVs
- The concept is to compare predicted performance with actual remaining performance
- Currently performing a comparative teardown and performance analysis

Areas of Investigation 2 – New Cell Chemistries

Opening positive end of 18650

- Only positive side is opened up with mills to collect electrolytes

Centrifugation of 18650

- To collect electrolytes
- 4000 rpm for 20 min
- Collected electrolytes are analyzed with GCMS

Opening the negative end and cylinder

- Inner materials are separated, measured and analyzed

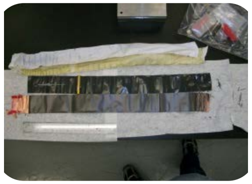
Material characterization

- SEM and EDX

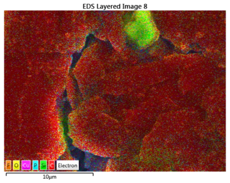
LG18650MJ1

Opened 18650s

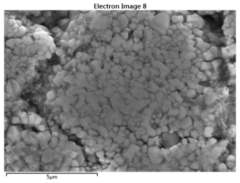
Inner materials, anode, cathode, and separator



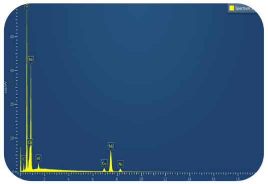
Unrolled anode, cathode, and separator



SEM&EDX mapping of anode



SEM of cathode



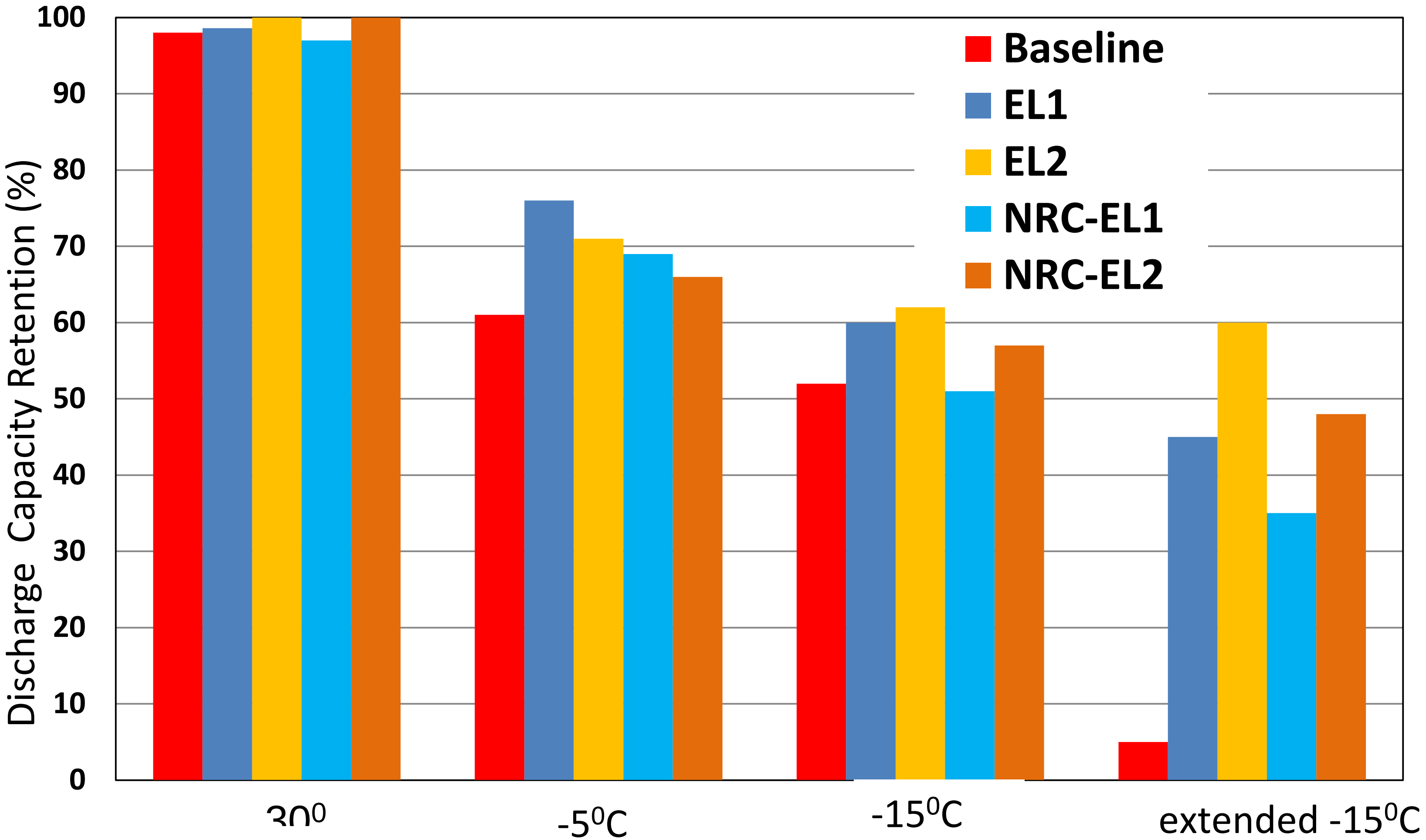
EDX of cathode

Areas of Investigation 2 – New Cell Chemistries

Company	Model	Cathode	Anode	Electrolyte
LG	ICR18650S3	NMC111	Graphite	EC:DMC, 3:7
	INR18650MJ1	NMC532	SiO_x/Graphite	EC:DMC:EMC, 3:6:1
	18650HG2	NMC532	SiO_x/Graphite	
Samsung	INR18650GA			
	INR18650-35E	NCA	Si/Graphite	EC:DMC:EMC, 2:6:2
Sanyo	NCR18650GA	NCA	SiO_x/Graphite	EC:DMC:EMC, 3:6:1
	NCR20700B			
Panasonic	NCR18650B	NCA	Graphite	EC:DMC:EMC, 2:7:1

NMC*xyz* – $Li(Ni_{x/10}Mn_{y/10}Co_{z/10})O_2$
NCA – $LiNiAlO_2$
EC – Ethylene carbonate
DMC – Dimethyl carbonate
EMC – Ethyl methyl carbonate

Areas of Investigation 3 – New Electrolytes



Capacity dropped with T with EL2 showing best capacity retention

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Thank you for your kind attention!

Any Questions, Suggestions or Comments