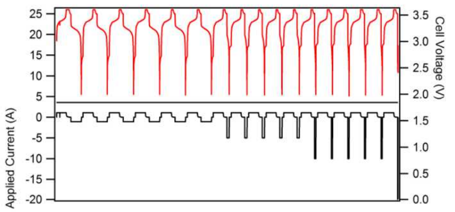
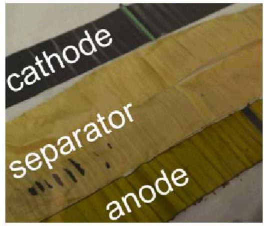
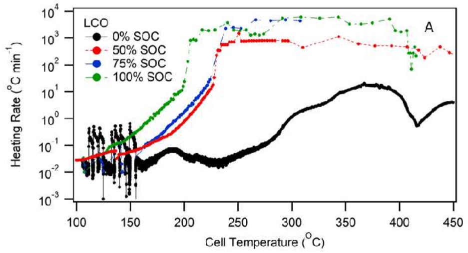
SAND2019-5905C

Thermal stability study of commercial lithium-ion batteries as a function of cathode chemistry and state-of-charge







PRESENTED BY

Summer Ferreira

235th ECS
May 27--Dallas TX

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System selection should be informed by safety

Problem:

Performance and safety data

- Primarily manufacturer-provided data

Chemistry Selection for an ESS installation must consider

- Cost
- Size
- Safety
- Application
- Reliability
- Oversizing
- Manufacturer reputation
- Performance
- Pack management

Approach:

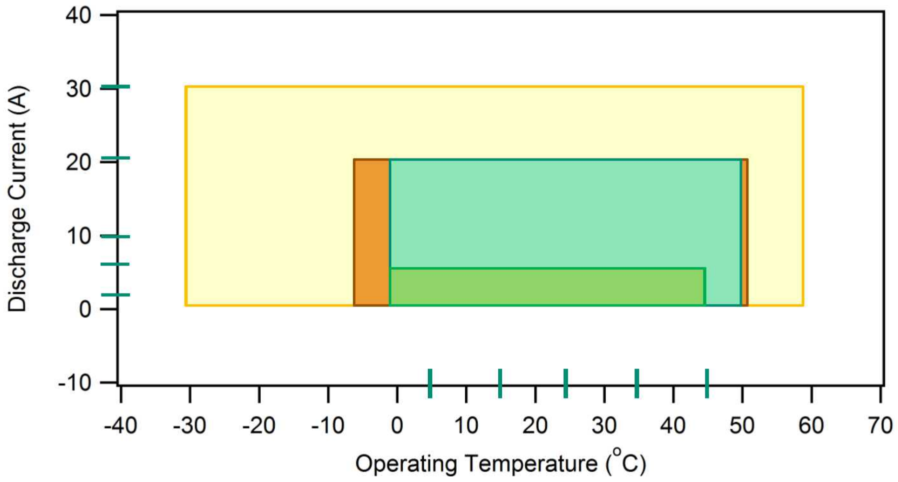
Quantify performance with uniform methodology

Evaluate fundamentals of material stability and abuse response

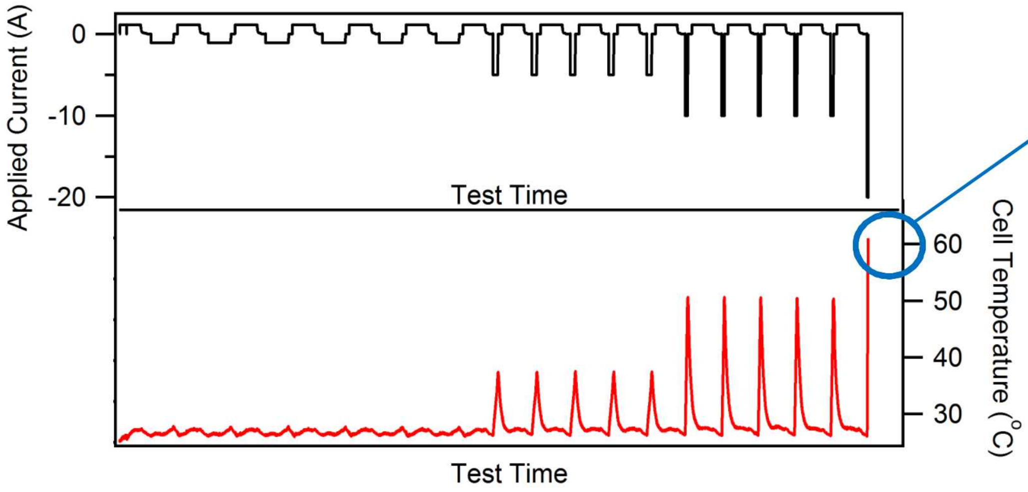
Cells and Manufacturer Specs.

Cathode Chemistry	AKA	Specific Capacity (Ah)	Average Potential (V vs Li°/Li+)	Max Discharge Current	Acceptable Temperature (°C)
$LiCoO_2$	LCO	2.5	3.6	20	0 to 50
$LiFePO_4$	LFP	1.1	3.3	30	-30 to 60
$LiNi_xCo_yAl_{1\text{-}x\text{-}y}O_2$	NCA	2.9	3.6	6	0 to 45
$LiNi_{0.80}Mn_{0.15}Co_{0.05}O_2$	NMC	3.0	3.6	20	-5 to 50

LCO LFP NCA NMC

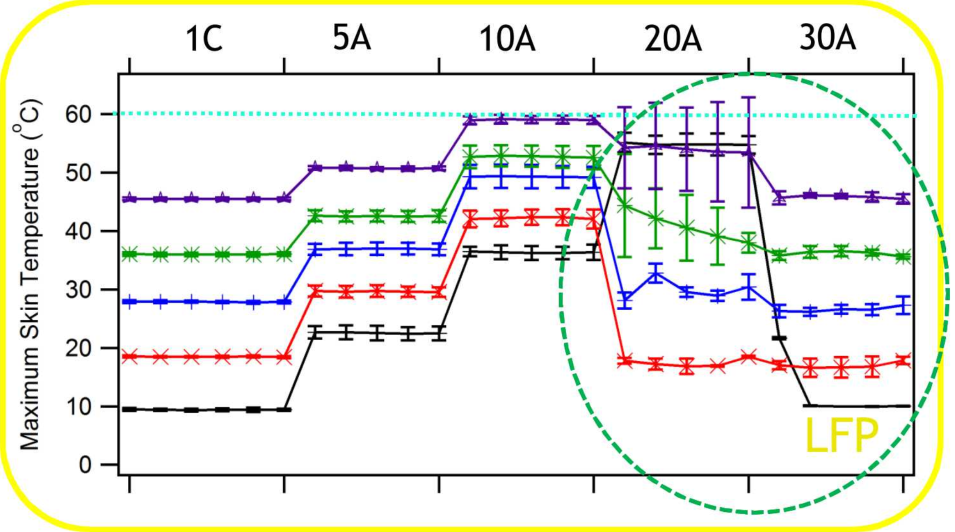


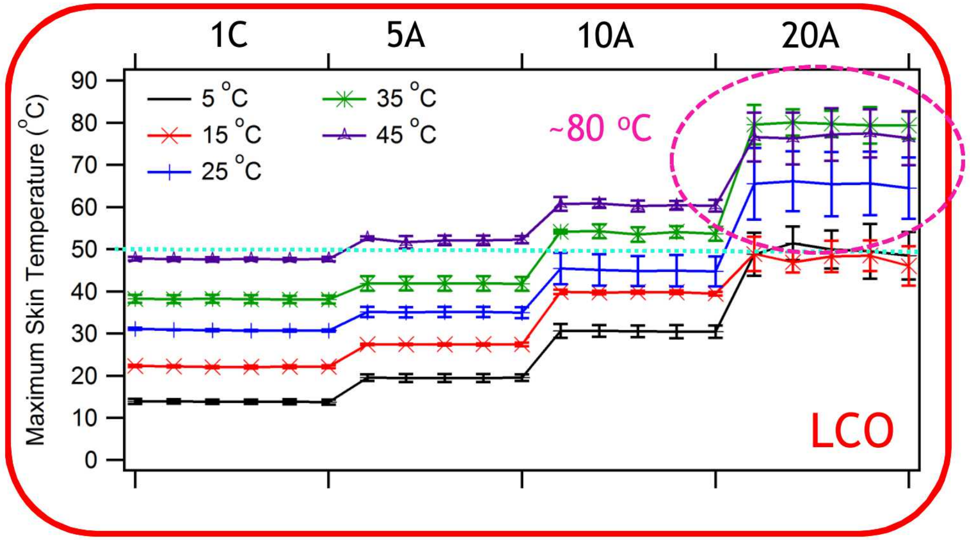
Avoiding accelerated aging or abuse by assessing performance under varied conditions for commercial chemisties



Current = 20 A (max = 30 A)
Environment = 25 ^oC
Cell skin Temp = 60 ^oC

Most packs don't monitor individual cell skin temperatures.
Unintended abuse condition under 'normal' operation.





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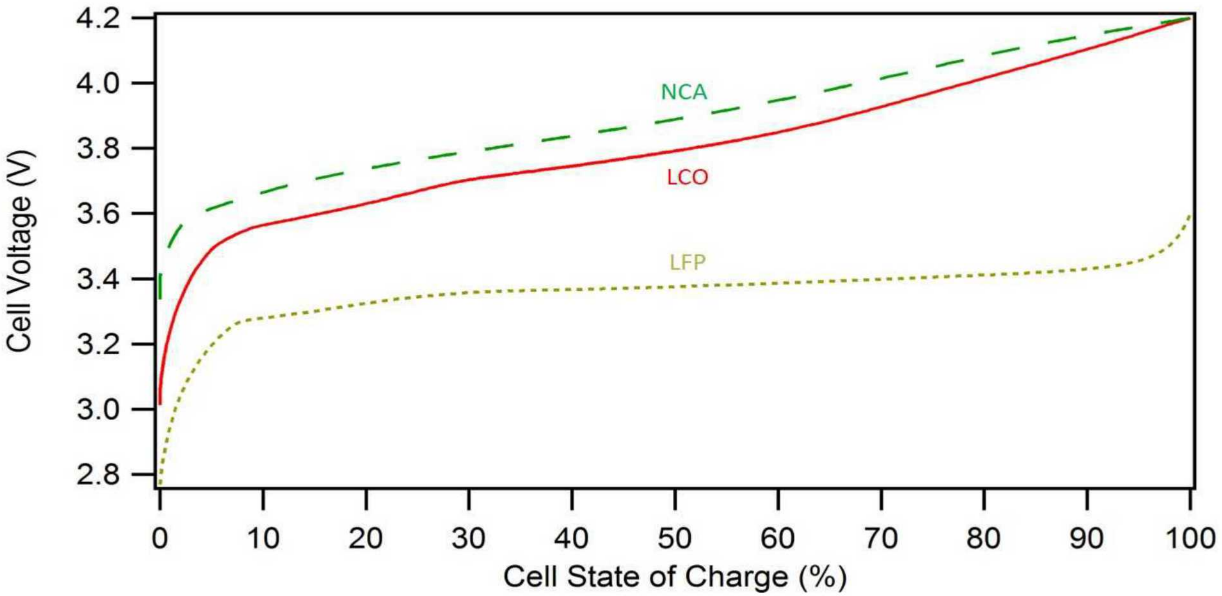
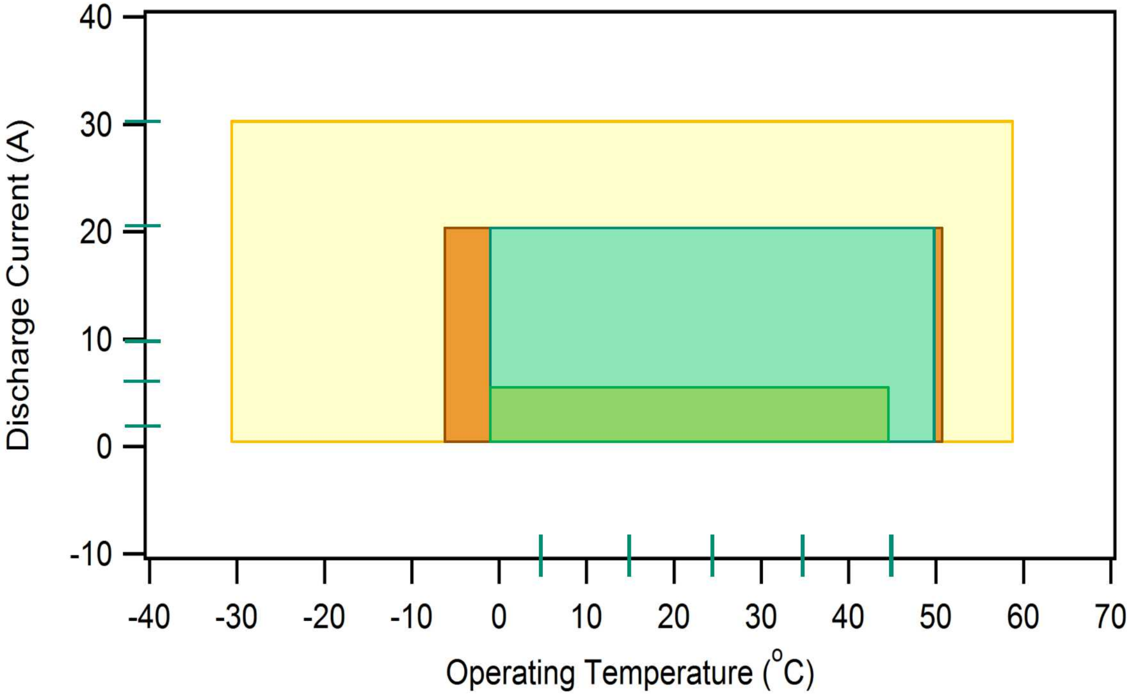
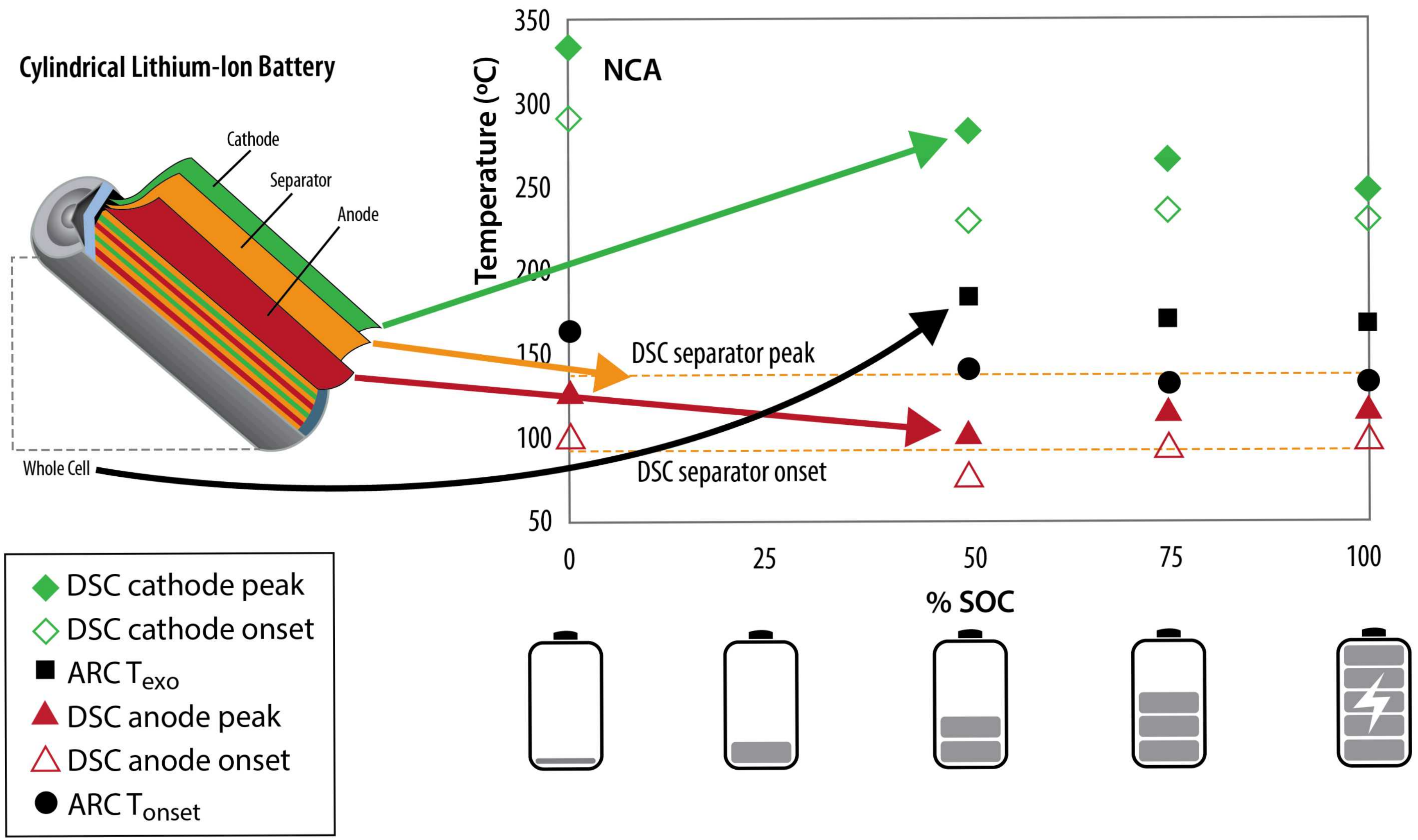
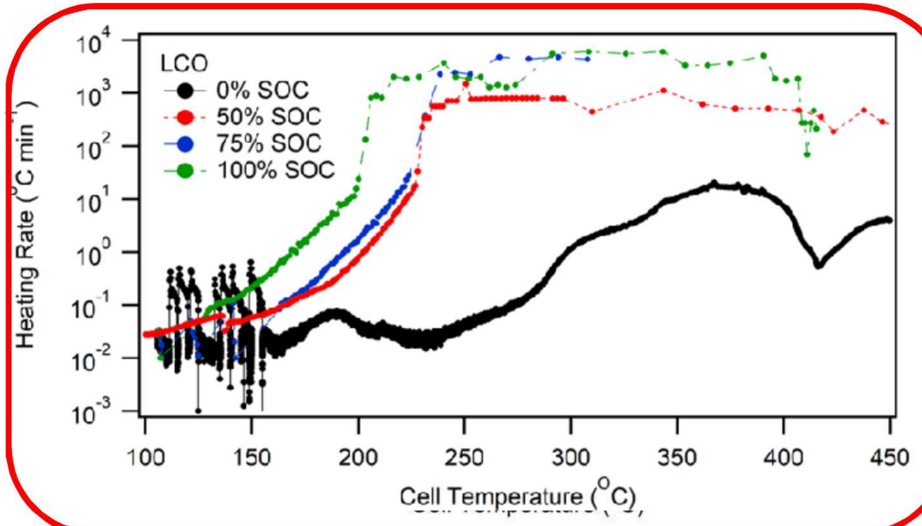


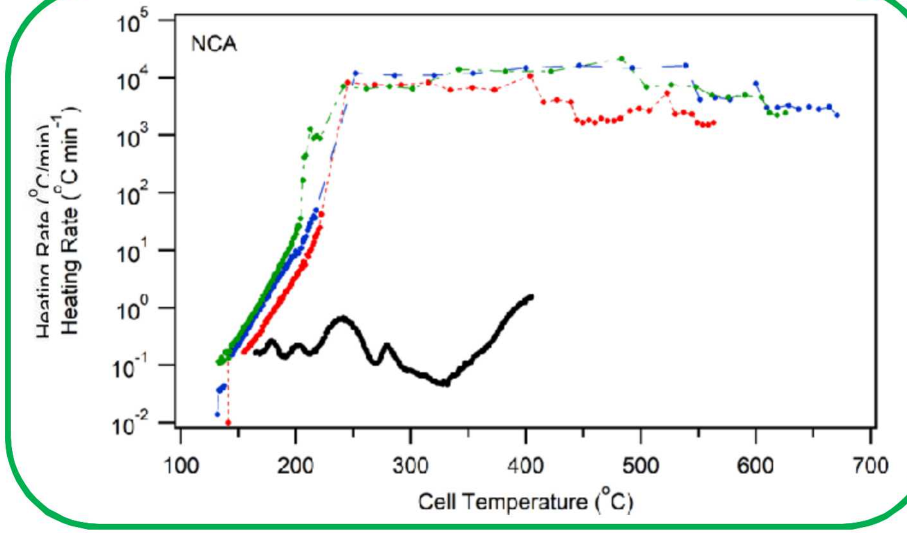


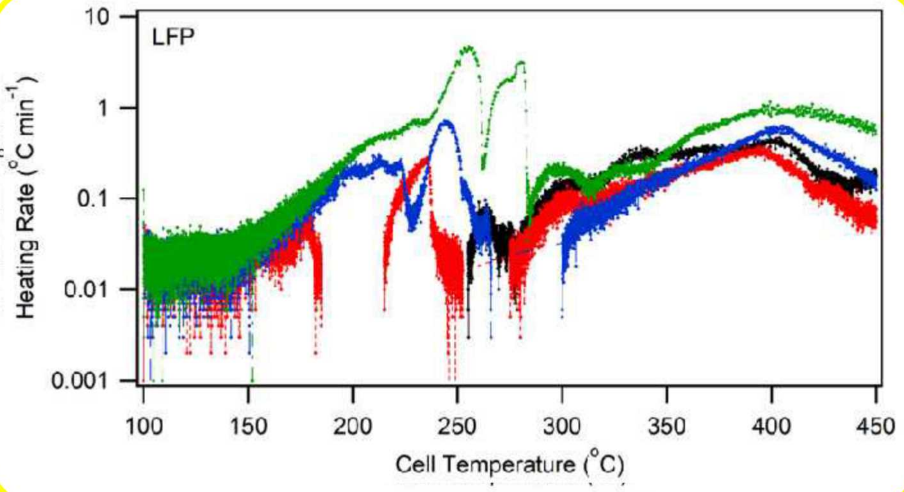
Component and whole cell thermal response



SOC dependence of heating



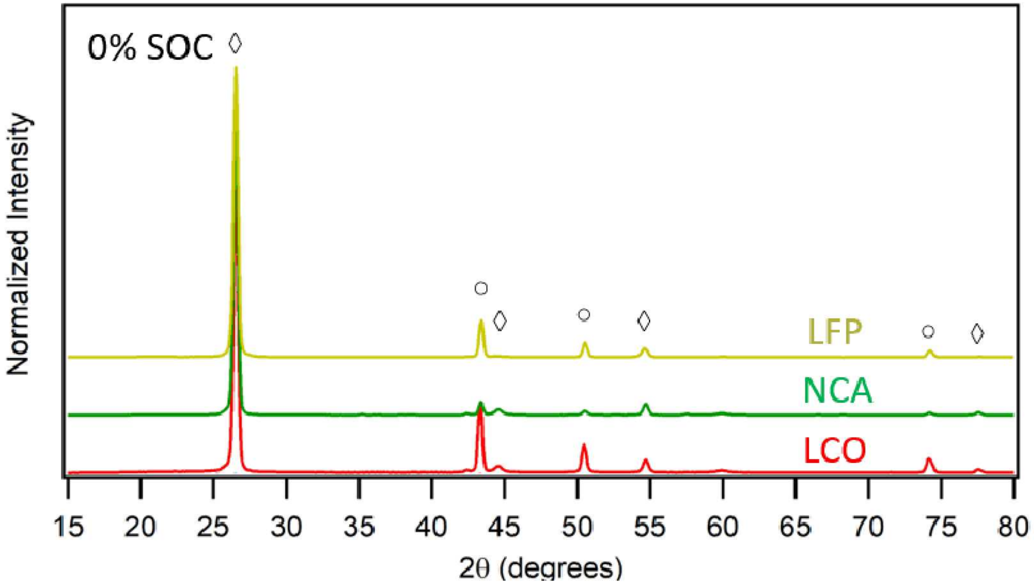


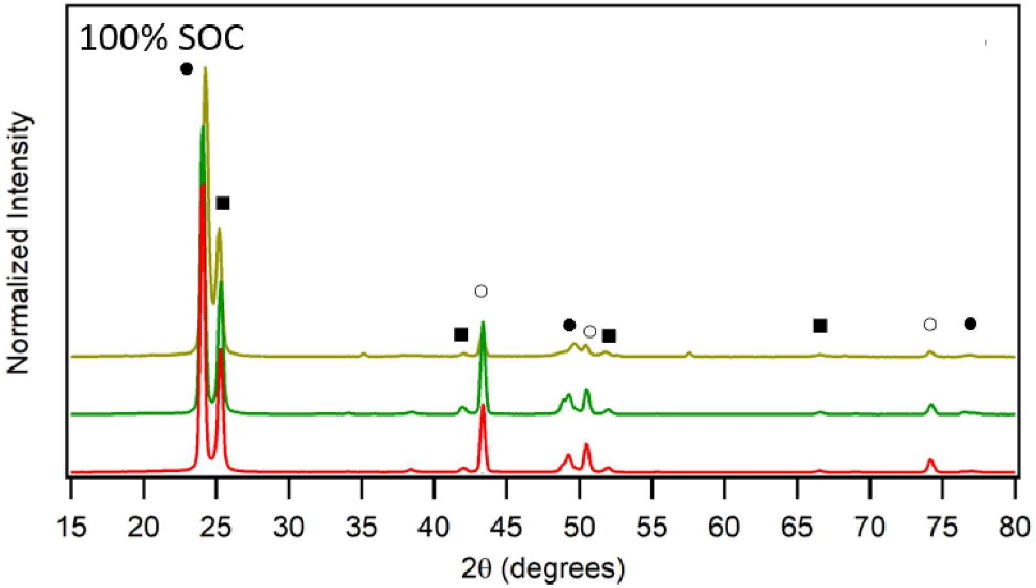


Observations

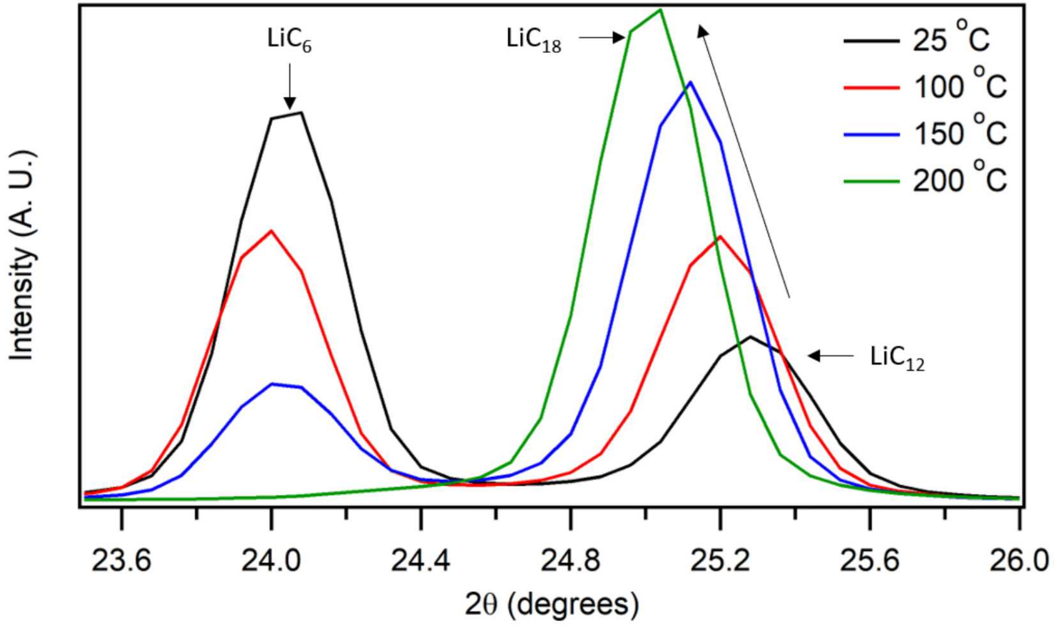
1) *LFP most stable, but still sensitive to SOC*
2) *LCO onset is SOC dependent*

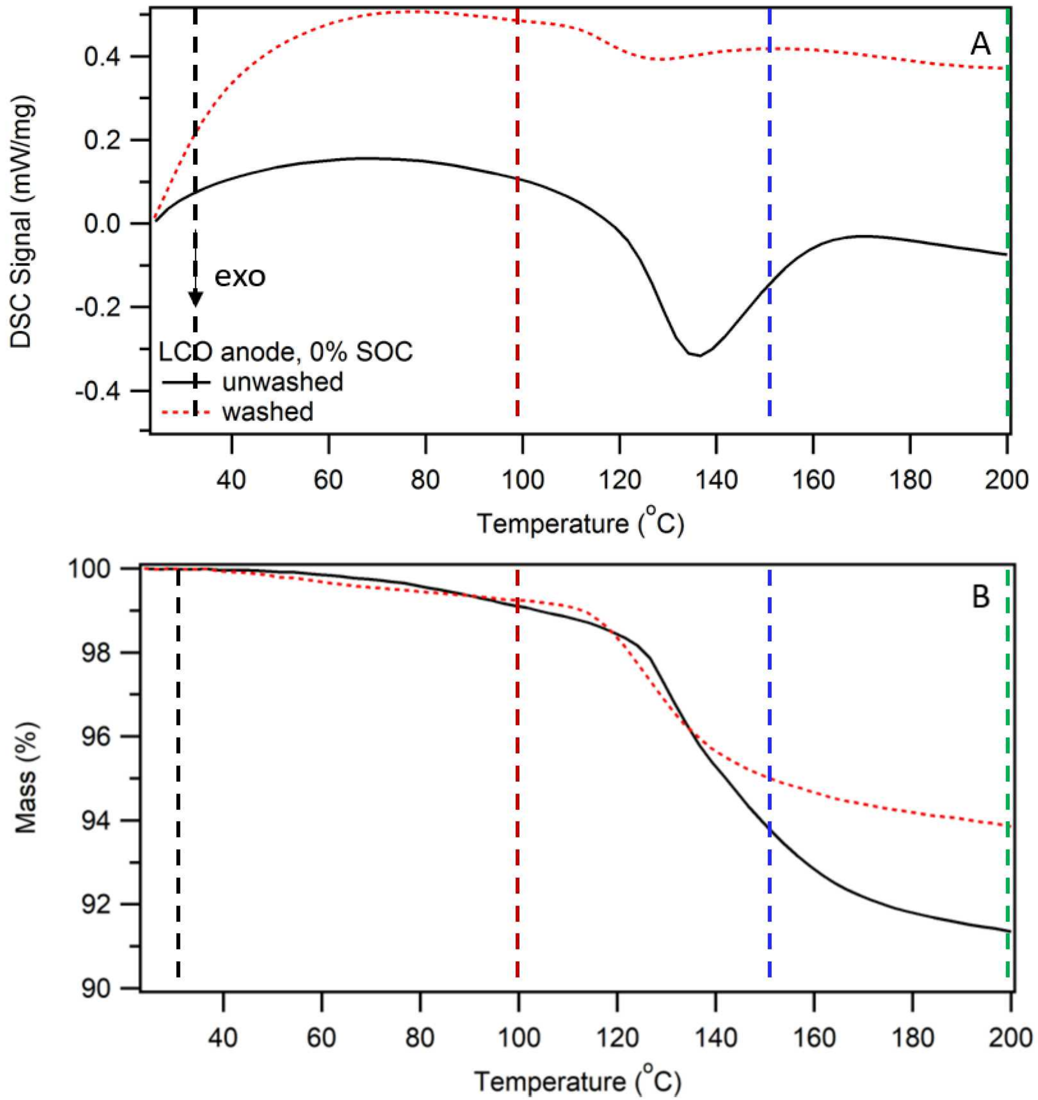
Anode phase composition similar between cells



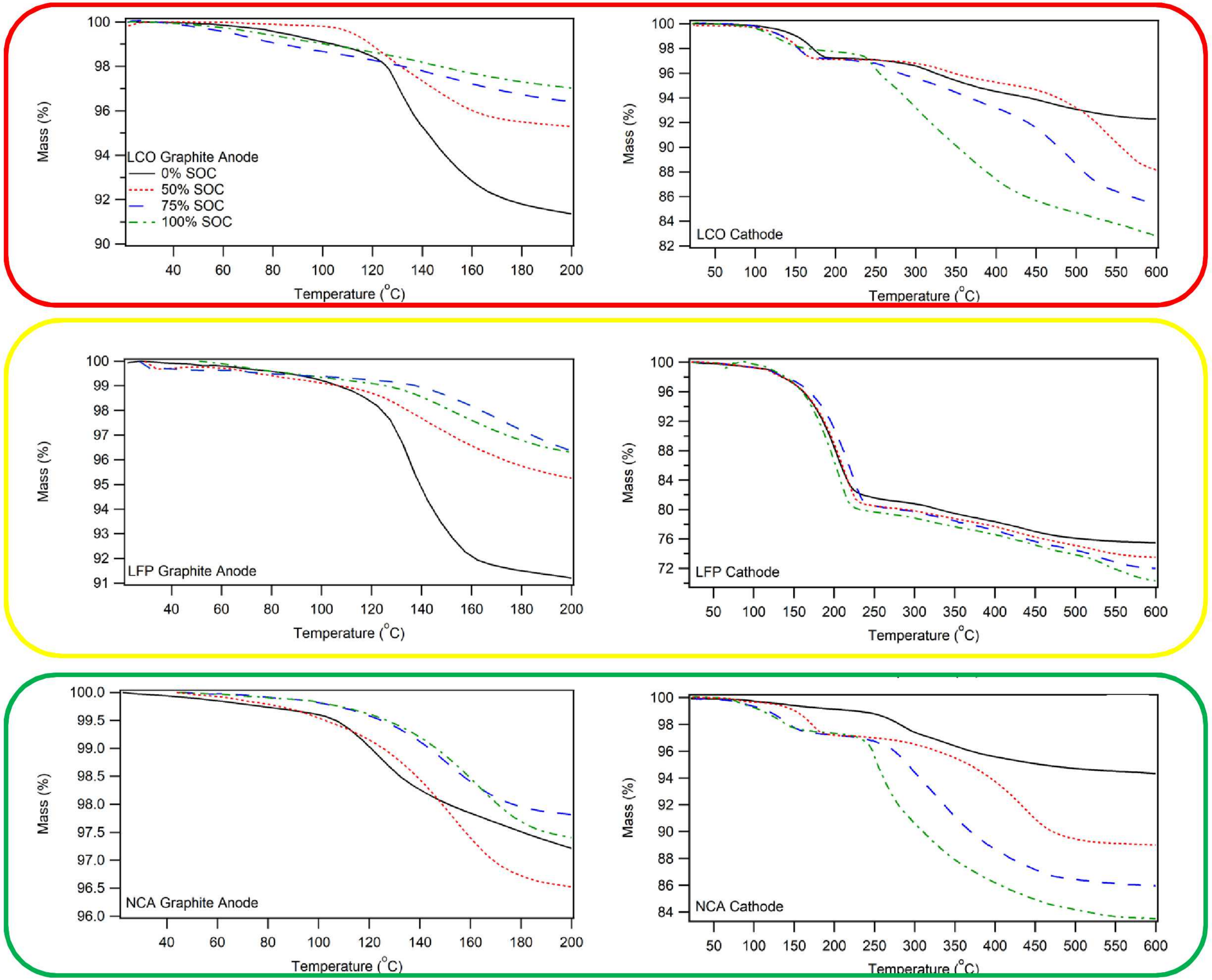


Anode behavior similar across commercial cells upon heating

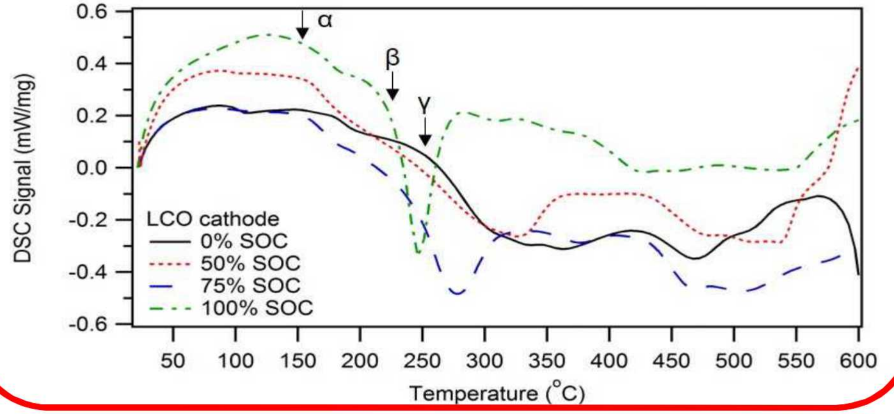


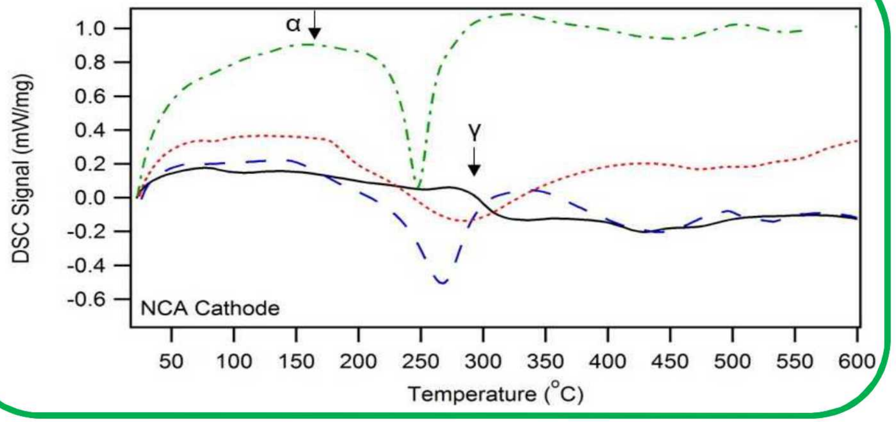


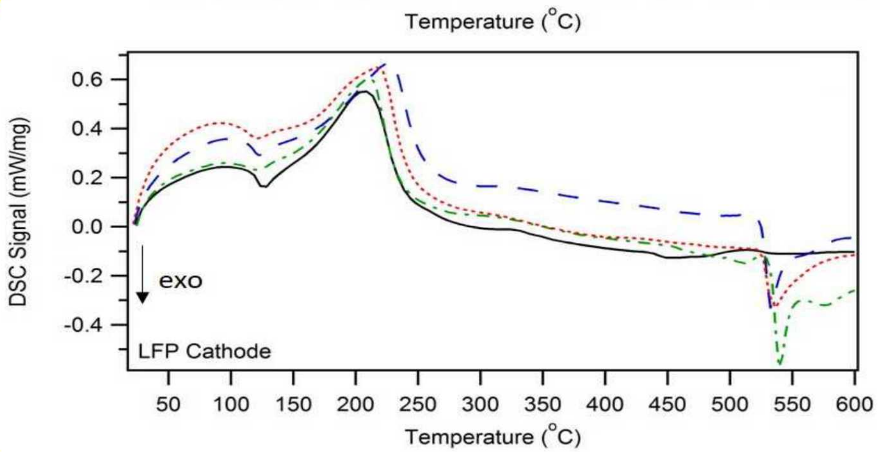
Mass loss similar in anodes; higher temperature in cathodes



Cathode exhibit exotherms above anode temperature

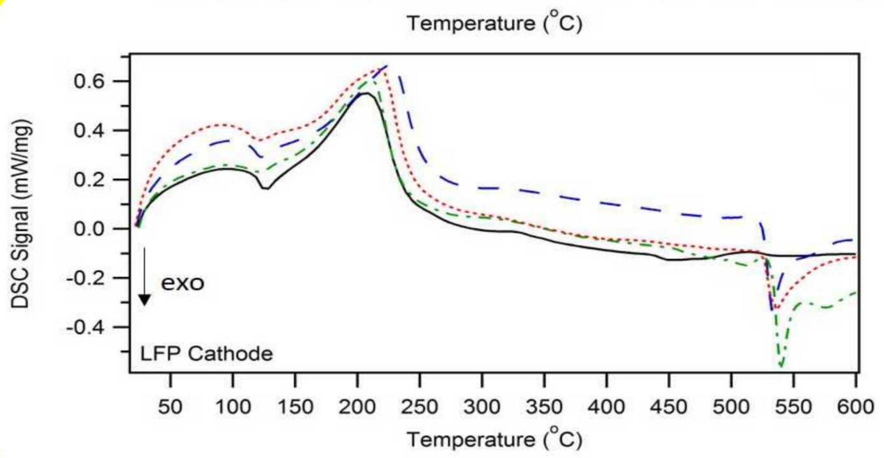


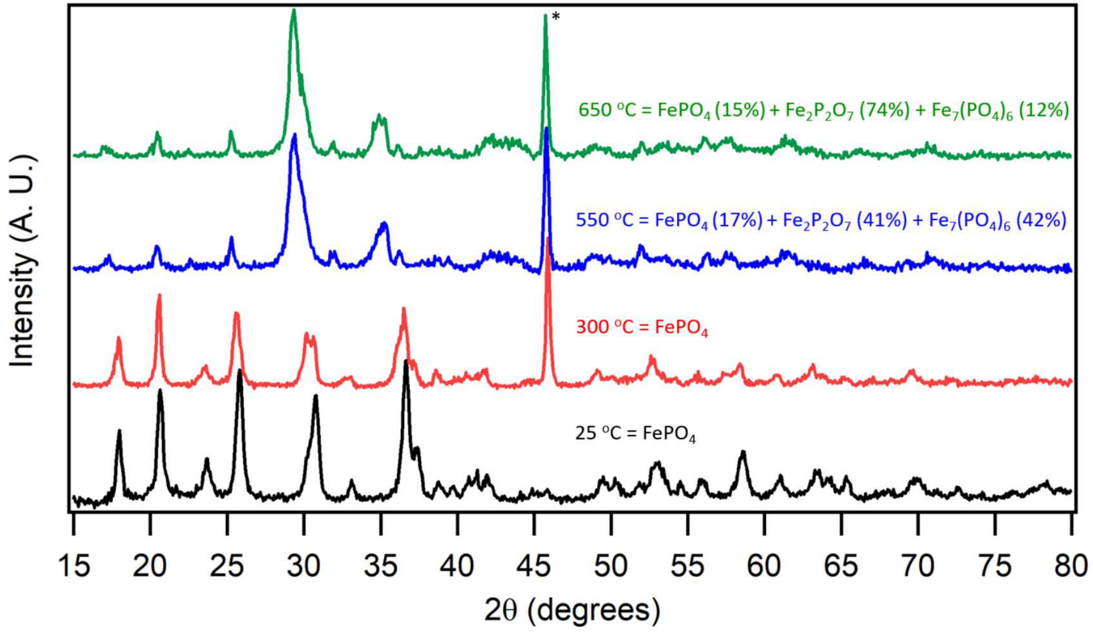




- LCO and NCA have exotherms around 250 °C
- LFP has exotherm above 500 °C

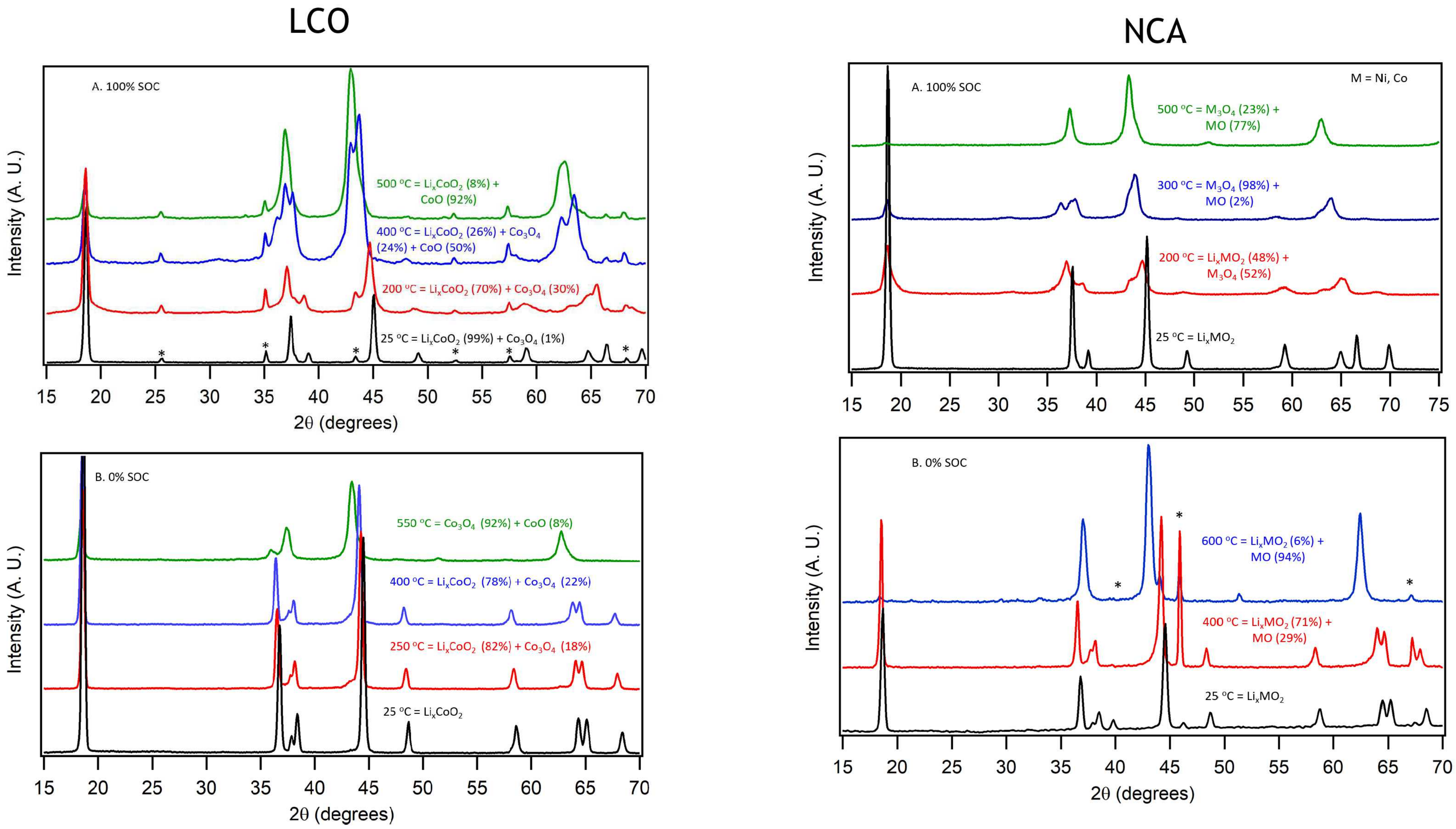
LFP Cathode Thermally Stable





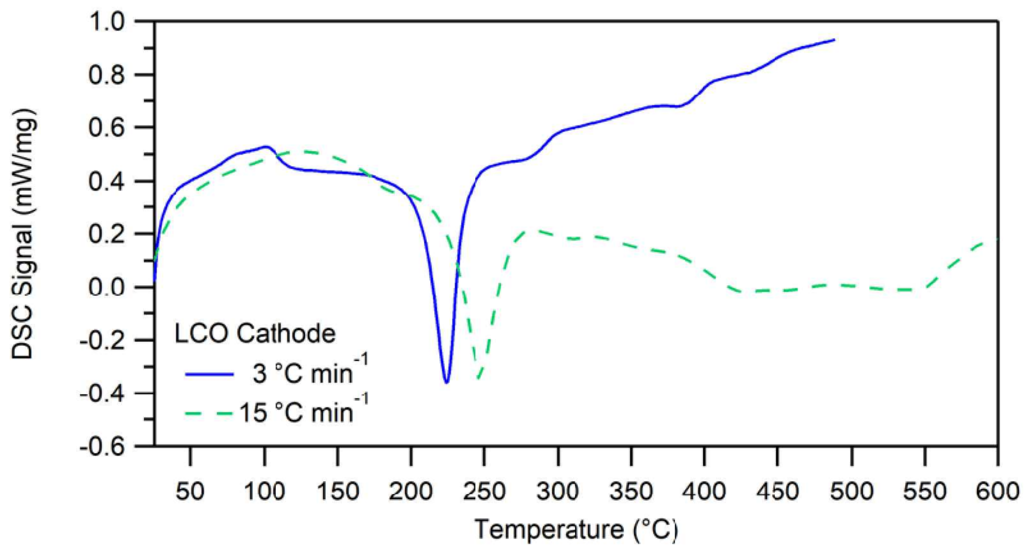
Endotherm at 200 °C likely from electrolyte burn off

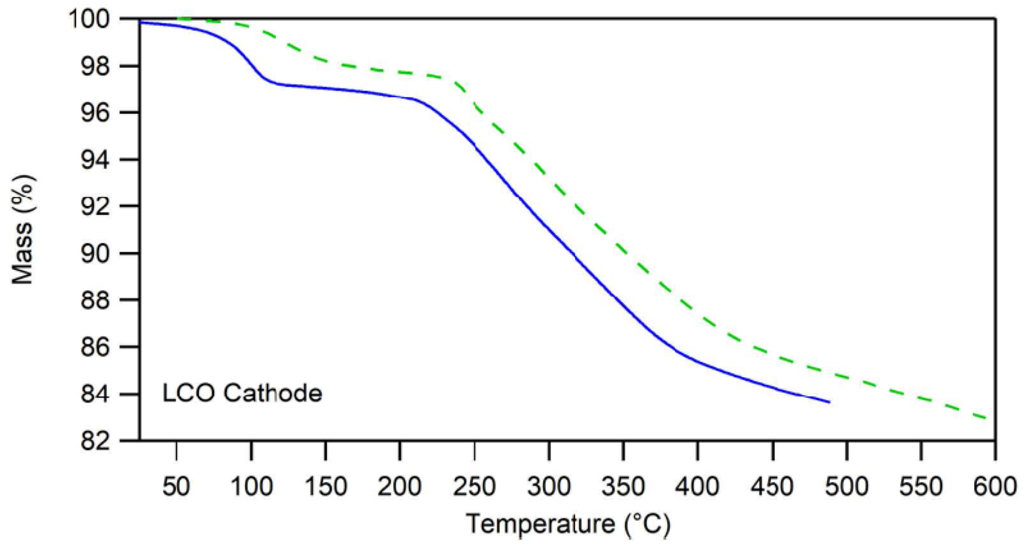
Cathode Phase Composition as a Function of Temperature



Cathode Li content impacts phase behavior on heating

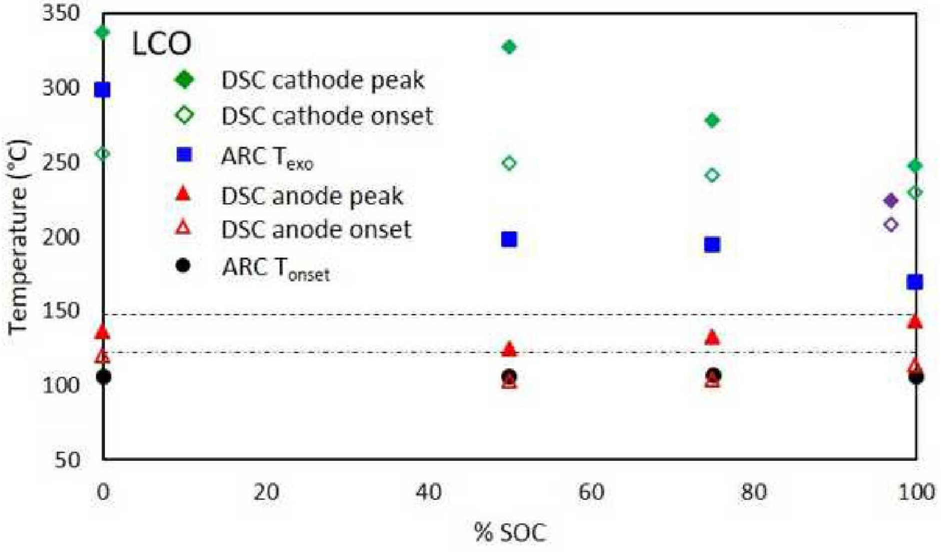
Scan rate dependence

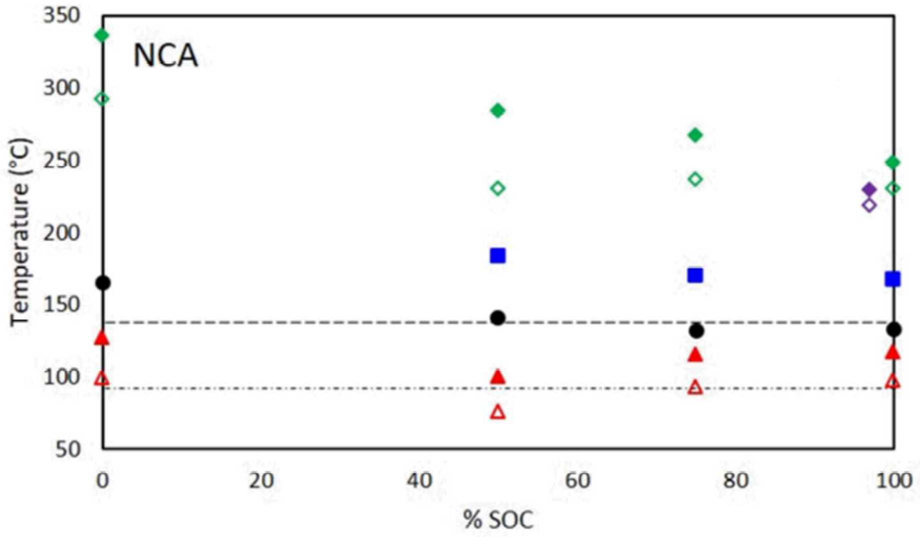


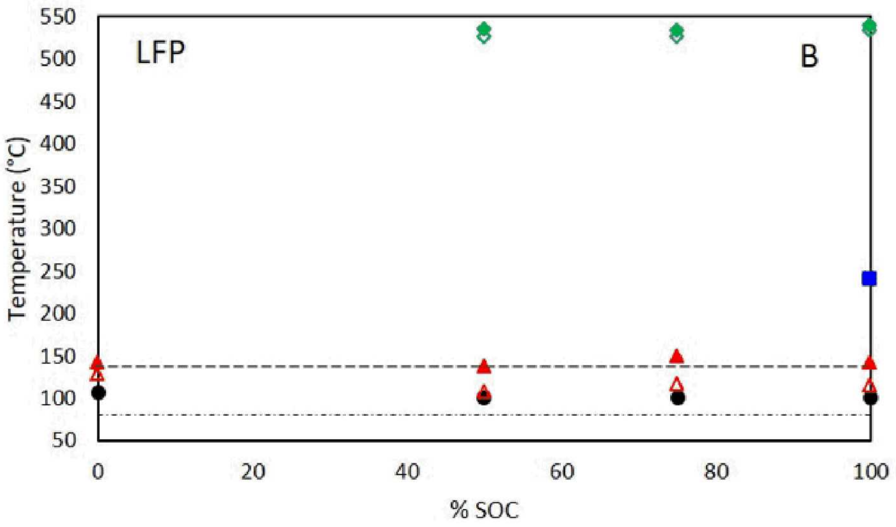


- The rate of data collection impacts the temperatures of significance
- To achieve mechanistic understanding, and scale to expected outcomes at varied scales kinetics must be understood

Multiscale view of thermal events

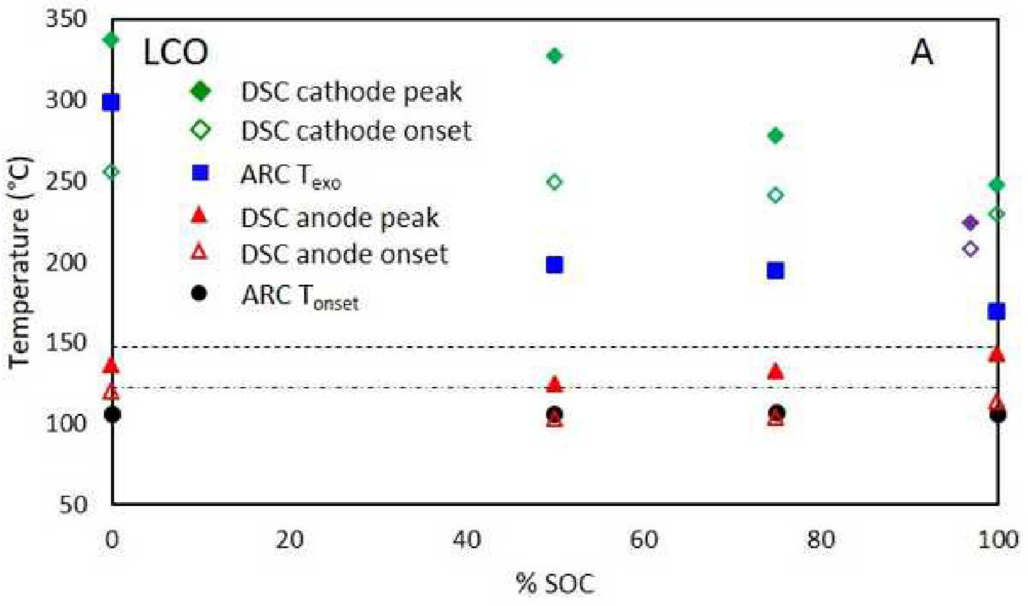






Conclusions

- Whole cell thermal runaway onset temperature decreases and peak heating rate increases with SOC due to cathode destabilization
- LCO and NCA cathodes are metastable, with NCA cell exhibiting the highest thermal runaway rates
- LFP cathode is stable to > 500 °C, even when charged.
- For anodes, the decomposition and whole cell self-heating onset temperature is generally independent of SOC.
- DSC exotherm onset temperatures of the anodes were generally within 10 °C of the onset of self-heating in whole cell ARC.
- Onset temperatures of the cathodes were typically observed above the ARC onset of whole cell runaway.



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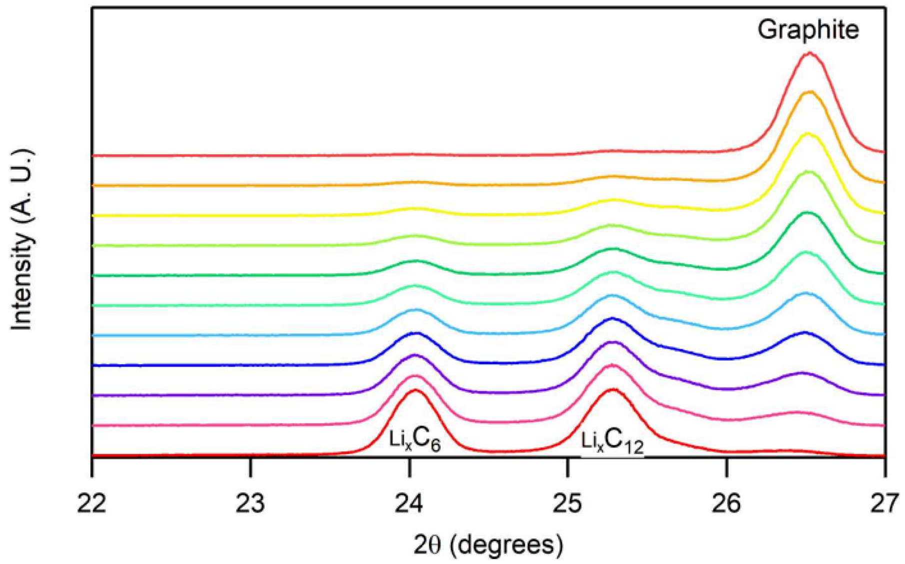
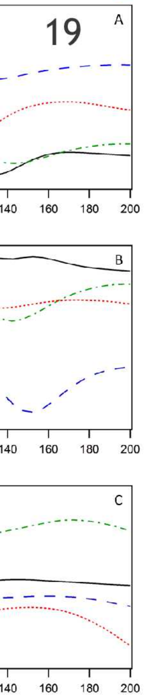
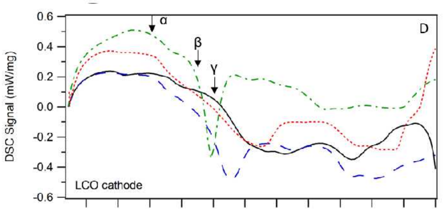
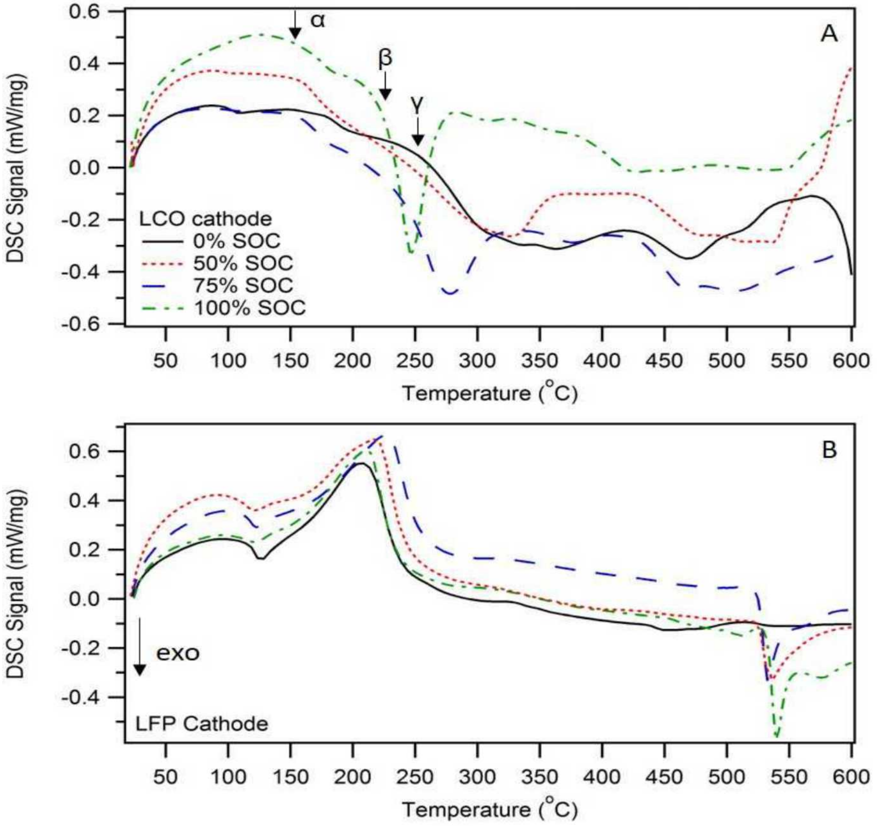
Air impacts on anode XRD




A
140
160
180
200
B
140
160
180
200
C
140
160
180
200

F


0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
DSC Signal (mW/mg)
α
β
γ
D
LCO cathode


0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
DSC Signal (mW/mg)
α
β
γ
A
LCO cathode
0% SOC
50% SOC
75% SOC
100% SOC
50
100
150
200
250
300
350
400
450
500
550
600
Temperature (°C)
0.6
0.4
0.2
0.0
-0.2
-0.4
DSC Signal (mW/mg)
B
exo
LFP Cathode
50
100
150
200
250
300
350
400
450
500
550
600
Temperature (°C)

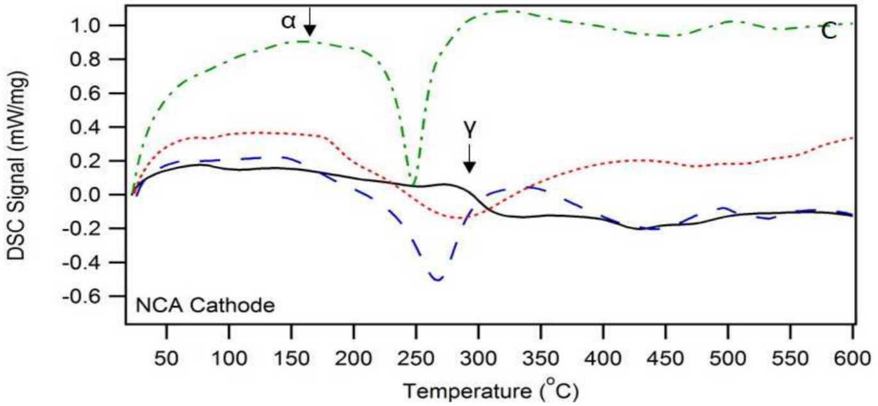
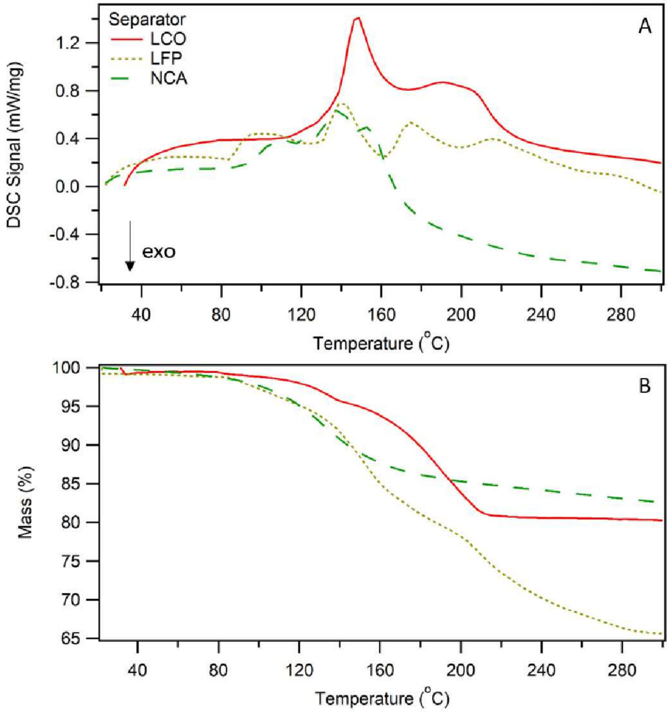
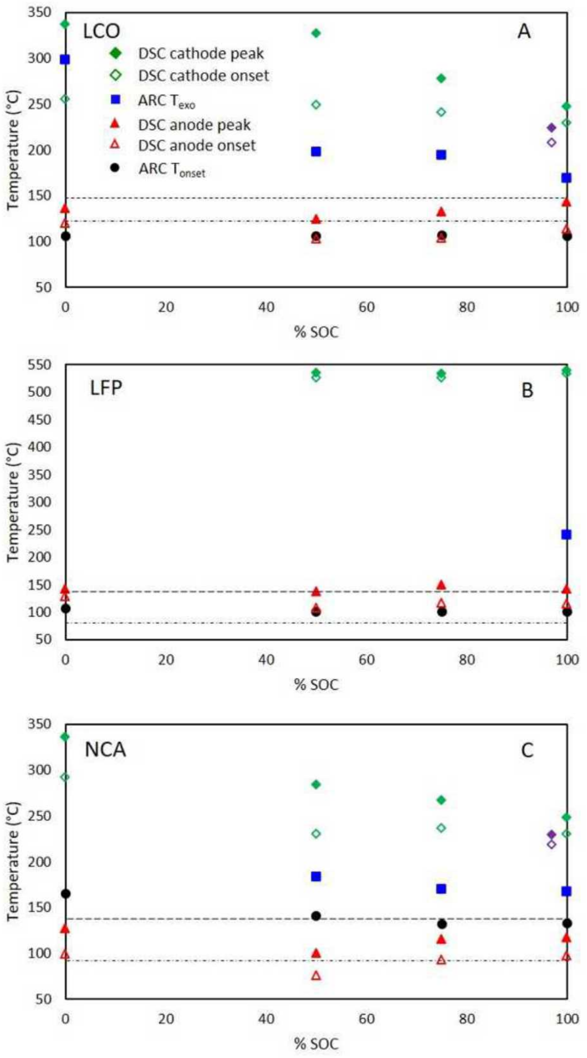

1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
DSC Signal (mW/mg)
α
γ
C
NCA Cathode
50
100
150
200
250
300
350
400
450
500
550
600
Temperature (°C)

Fig 2 separator





Cell	SOC (%)	T_{onset} (°C)	T_{exo} (°C)	HR_{max} (°C min^{-1})	$HR_{max,norm}$ (°C min^{-1} Ah^{-1})
LCO	0	105.8	298.1	18.4	7.4
	50	106.2	197.8	1361.1	544.4
	75	106.5	169.4	4822.3	1928.9
	100	106.4	168.4	6053.5	2421.4
LFP	0	105.9	---	0.4	0.4
	50	100.8	---	0.3	0.3
	75	100.7	---	0.7	0.6
	100	100.9	240.5	4.5	4.1
NCA	0	164.9	391.8	1.5	0.5
	50	140.7	182.2	10810.3	3603.4
	75	131.7	169.4	16107.4	5369.1
	100	132.5	165.9	21480.4	7160.1