Li-ion Pouch Cell Designs; Are They Ready for Space Applications?

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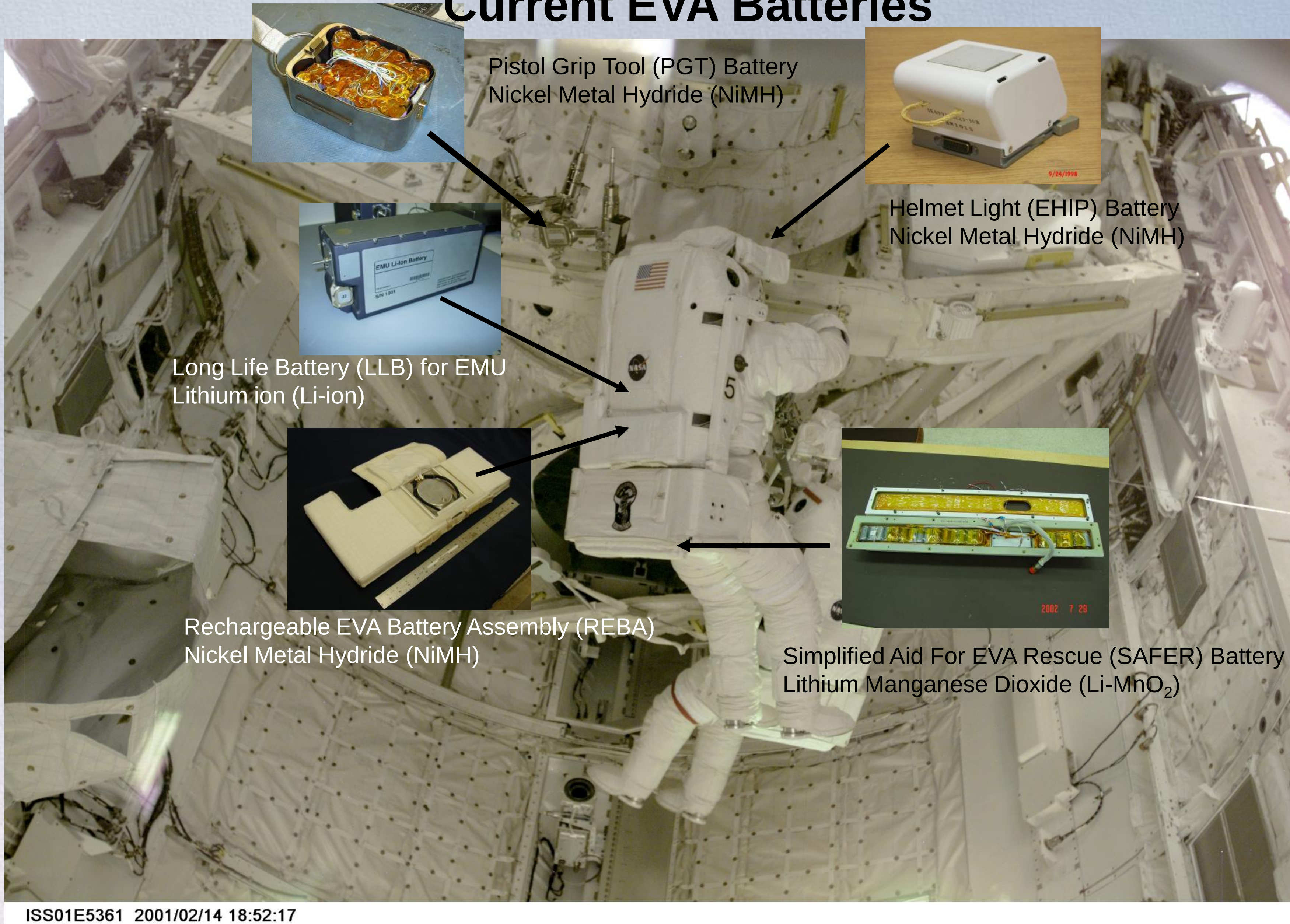
For the
Large Li-ion Battery Technology and Application Symposium
of the
Advanced Automotive Battery Conference
8 Feb 2012
Orlando, FL

Outline

Li-ion Pouch Cells

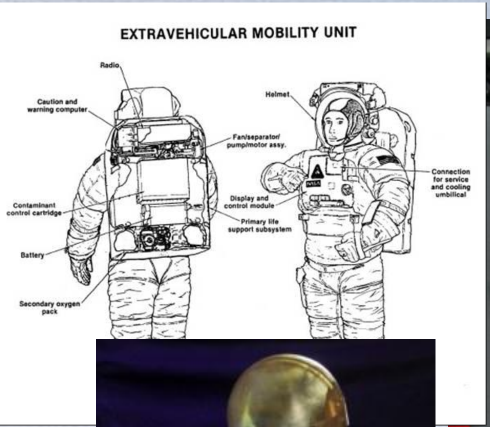
- Various Space Applications
- Pouch cell design evaluation
- Cell lot uniformity, why that’s important
  - Soft Short Screening
- Performance at 4C Discharge Rates
- Pouch Corrosion
- Forward plans
  - Cycle life durability
  - Seals
  - Manufacturing quality
- Conclusions

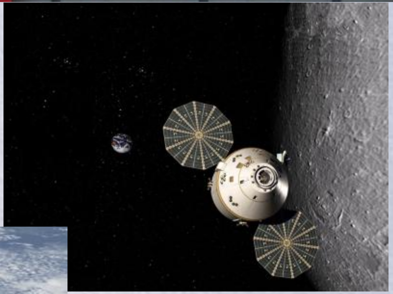
Current EVA Batteries

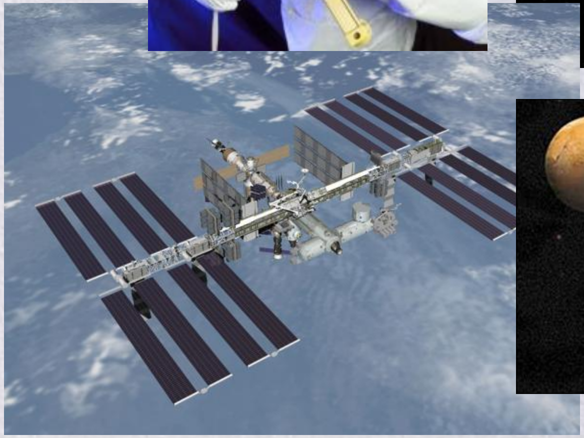


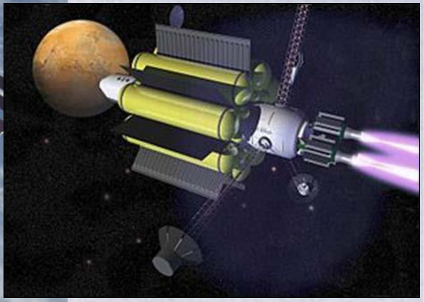
Critical Manned Spacecraft Batteries

- Spacesuit (Li-ion first flight in 2011)
  - 20V, 35Ah, 50 cycle, 5 yr life
  - Power all life support systems of the spacesuit
- Robonaut (proposed)
  - 96V, 26Ah, few cycles, 5 yr life
  - Eventually operates side-by-side with spacewalkers
- Orion Crew Exploration Vehicle (201?)
  - 120V, 30Ah, 3000 cycles, 3 yr life
  - 6-man capsule
- International Space Station (Li-ion planned for 2017)
  - 120V, 120 Ah, 38,000 cycles, 6.5 yr life
  - Main power source during LEO eclipses
- VASIMR (proposed)
  - 425V, 50 kWh discharged in 15 minutes
  - Main power for RF generator firings
- Safety Requirements
  - Two-fault tolerant to most catastrophic hazards
  - Electrolyte leakage and cell internal shorts hazards controlled by a defined process that applies all reasonable mitigating measures









Assessment of Cell Designs

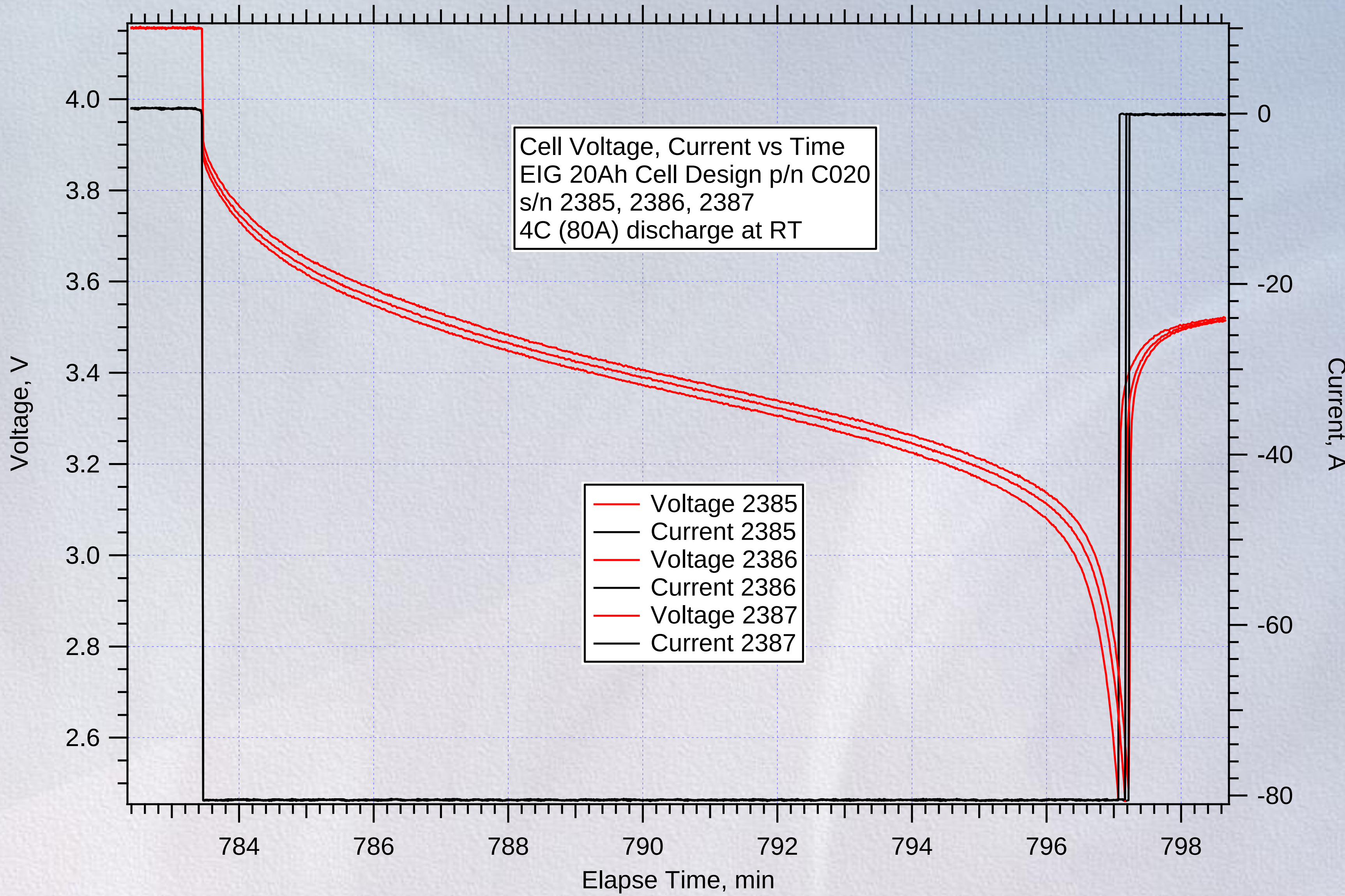
#	Vendor	P/N	Mass (g)	Rated Discharge Capacity (Ah)	Standard Charge Regime	Max Discharge
1	A123	PHEV	480	20	3.6V at C/2 with C/50 taper current limit	80A to 2.0V
2	Dow Kokam	SLPB75106100	165	8	4.2V at C/2 with C/50 taper current limit	32A to 2.7V
3	EIG	C020	425	20	4.15V at C/2 with C/50 taper current limit	80A to 2.5V
4	LG Chem	P1	383	15	4.15V at C/2 with C/50 taper current limit	60A to 2.8V

- All 4 are mature cell designs, made in high volume production lines
- All 4 provide a blend of high power and energy density capability

Test Plan for Assessment of Cell Designs

- Acceptance Testing
  - Visual, OCV, AC Impedance, mass, dimensional
  - Pouch isolation resistance
  - Soft short (OCV bounce back after deep discharge)
- Capacity performance
  - Capacity/Energy vs rate
    - at ambient T, C/5, C/2, C, 2C, 4C with 3 cells per design,
    - all charging at manufacturer recommended rate
- Cycling performance
  - Capacity/Energy vs cycle number
    - 4C discharge, C/2 charge at ambient T for >100 cycles
- Evaluate cell design and manufacturing quality
  - Seal leak rate and compare to 18650 crimp seal rates
    - Seal cells in Al laminate bag with dual element impulse heat sealer
    - Then thermally cycling (vs not) for 3 weeks
    - Sample gas trapped in outer bag
    - Measure trace concentrations of electrolyte components via GC/MS to calculate leak rate in volume/time
      - Compare leak rates per Wh, seal perimeter
  - Corrosion susceptibility
  - Destructive Physical Analysis (Tear down)

EIG Cell Discharging at 80A



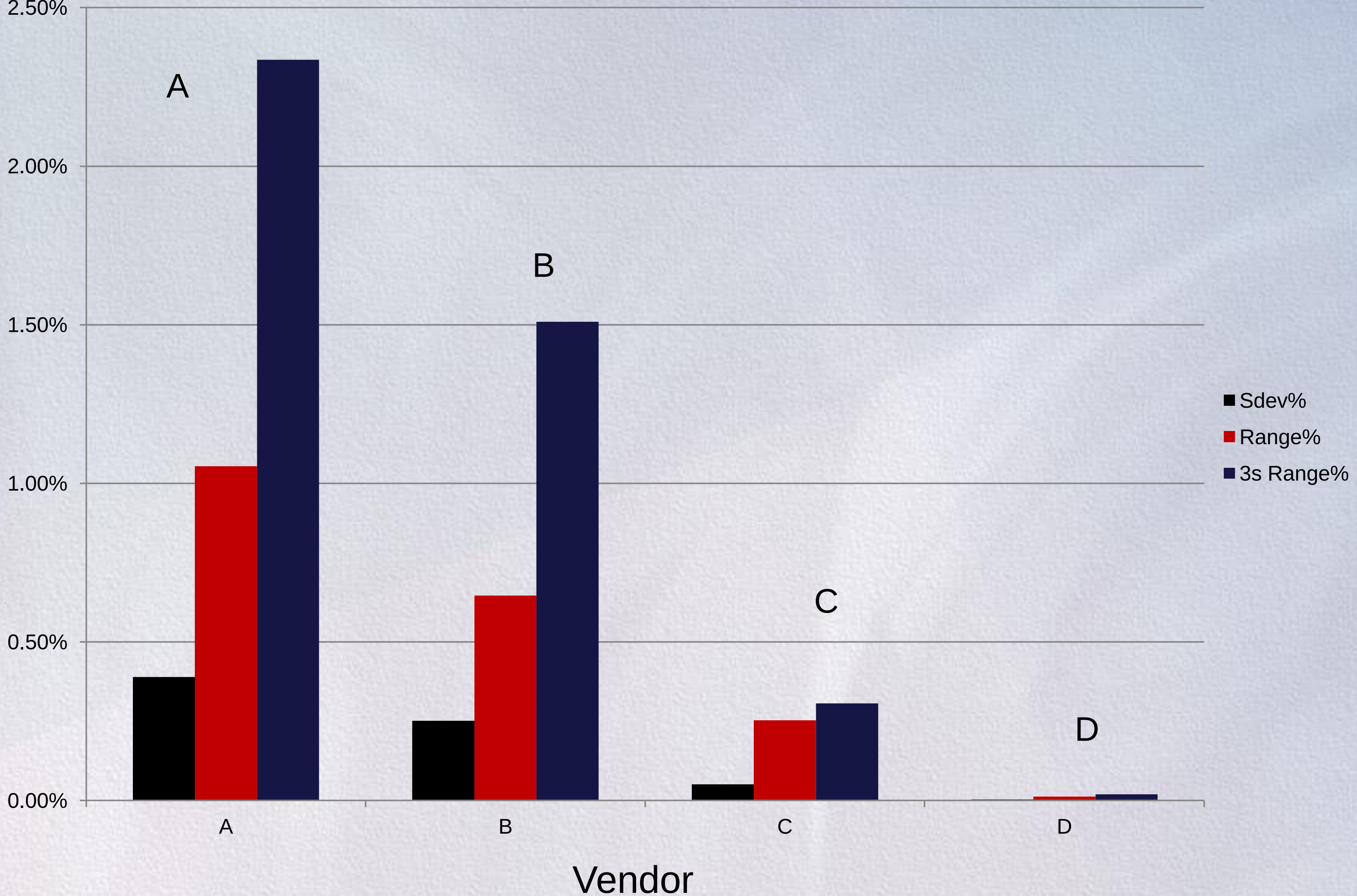
Comparisons of Demonstrated Performance

4C specific energy and energy density comparison

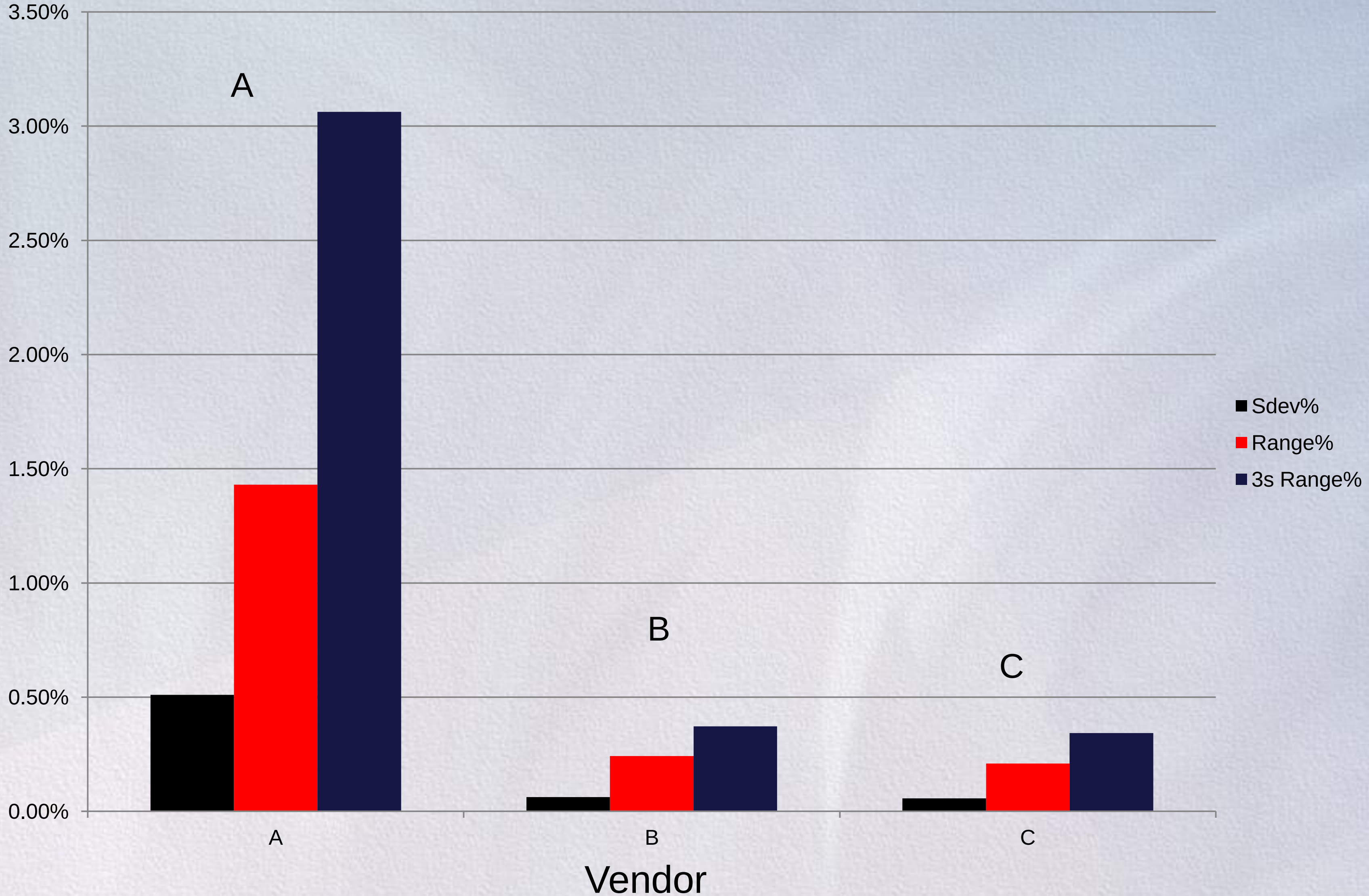
Vendor	PN	4C rate Energy	Average mass	Specific Energy	Length	Width	Thickness	Volume	Energy Density
		Wh	g	Wh/kg	mm	mm	mm	L	Wh/L
A123	PHEV	55.01	509.6	107.9	227	161	7.2	0.26314	209.1
DK	SLPB75106100	26.34	165.0	159.6	102	106	7.8	0.08433	312.3
EIG	C020	64.48	429.4	150.2	216	130	7.2	0.20218	318.9
LG	P1	51.62	382.5	135.0	226	165	5.5	0.2051	251.7

- DK has highest specific energy (~160 Wh/kg) at the 4C-rate
  - However, also has highest temperature rise (28 C)
- EIG has highest energy density (~319 Wh/L) at the 4C-rate
  - 2nd highest specific energy (~150 Wh/kg)

Variations in as Received OCVs

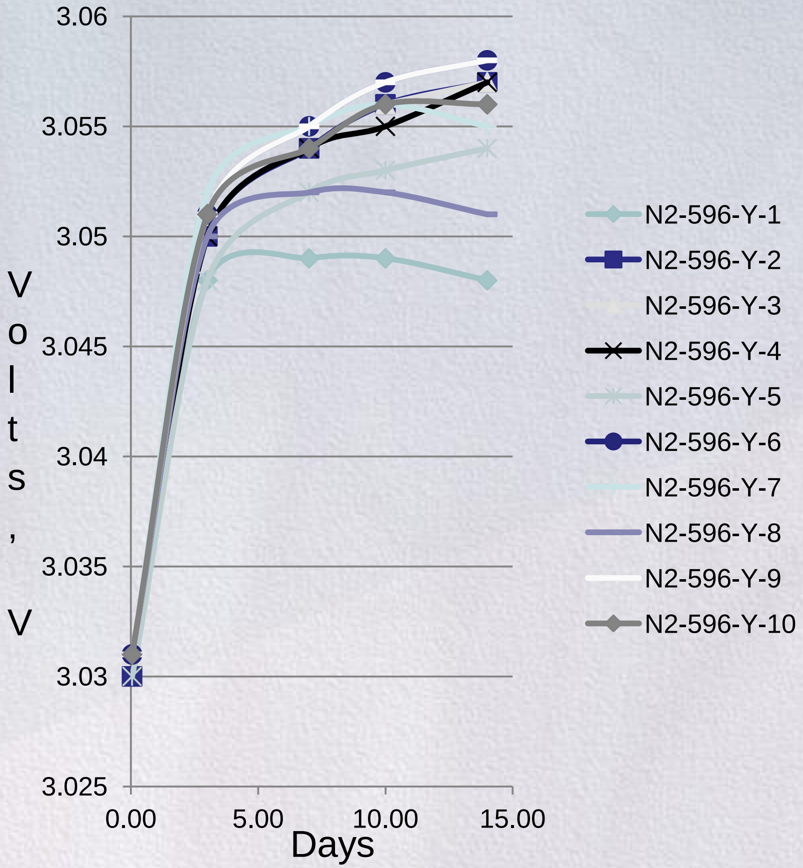


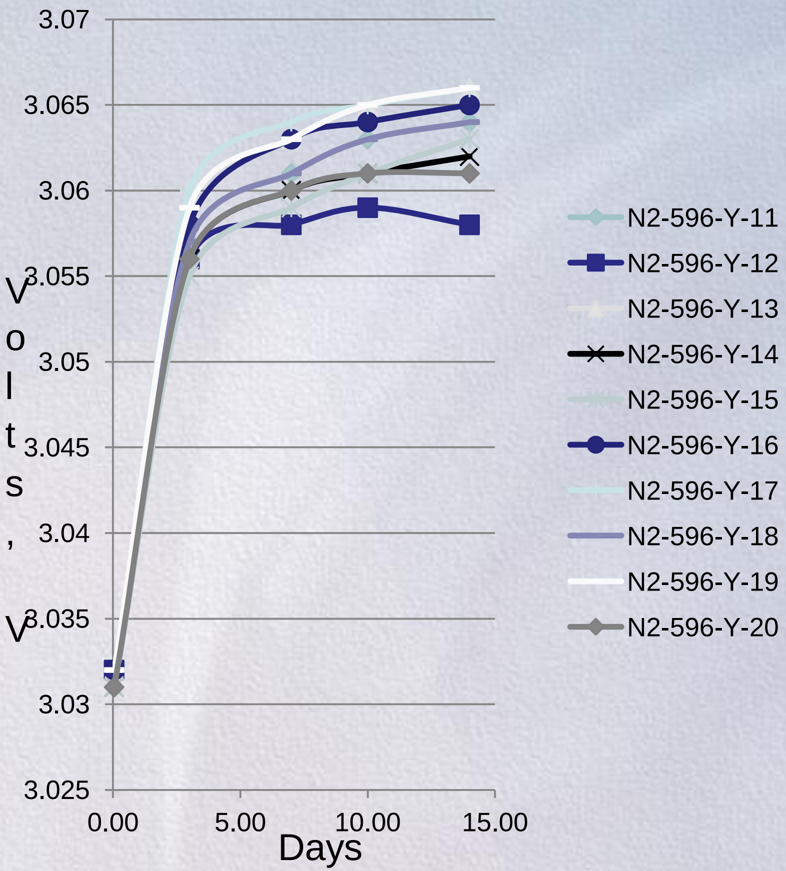
Variations in as received Mass



Soft Short (Large Cell Design)

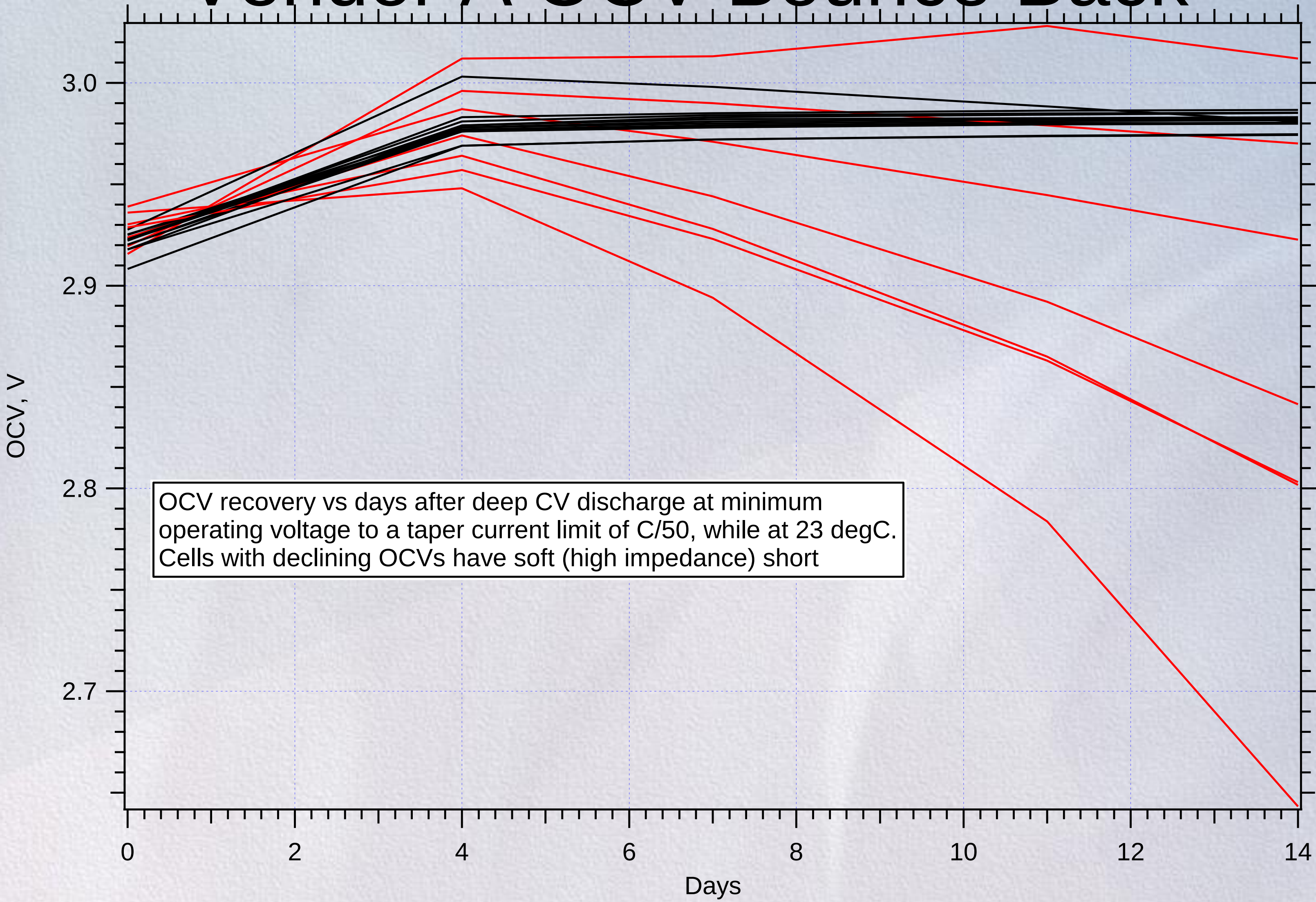
14-day OCV bounce back after deep discharge (constant voltage to 3.0V)



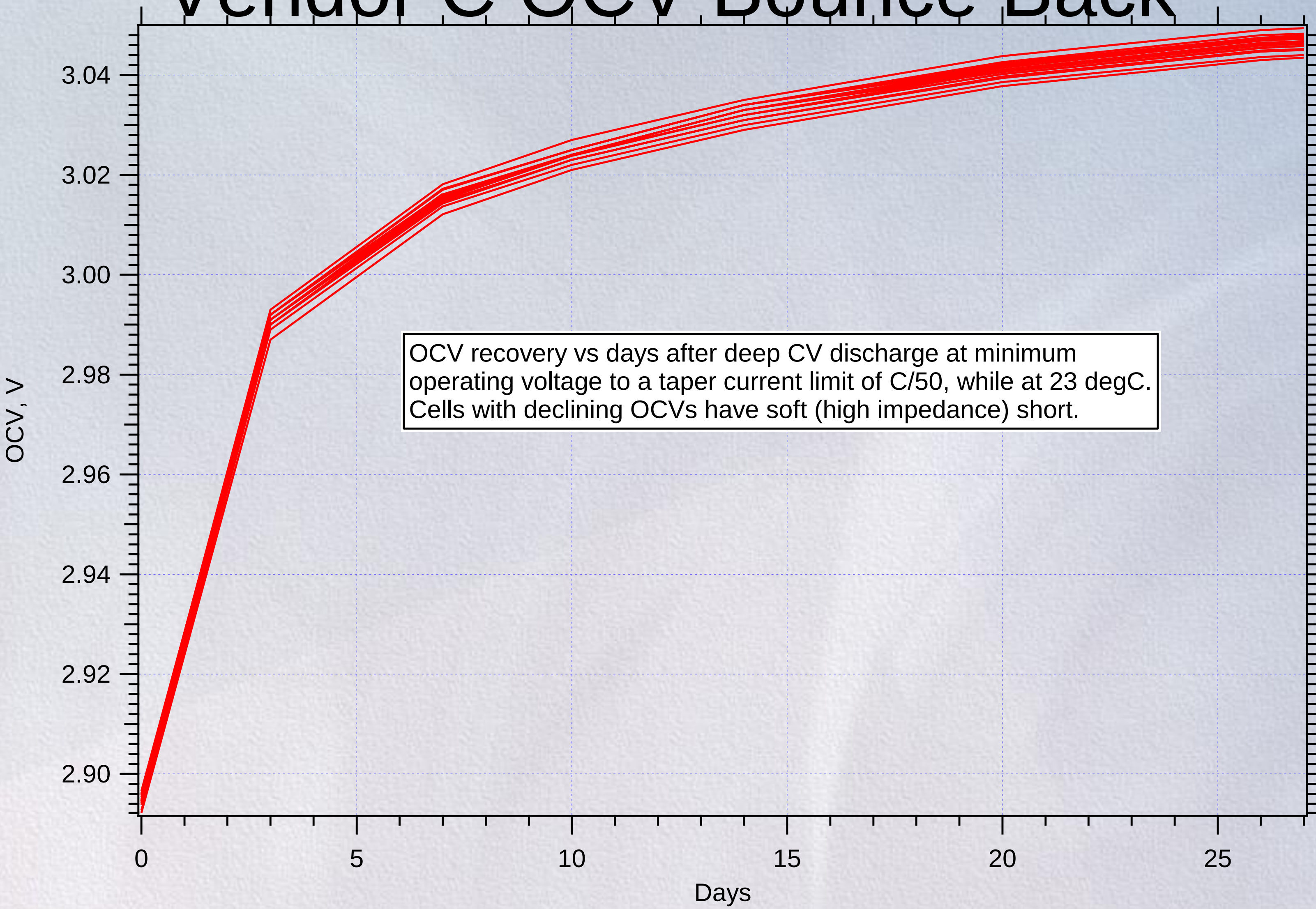


4 cells out of 20 had declining OCV between days 10 and 14

Vendor A OCV Bounce Back



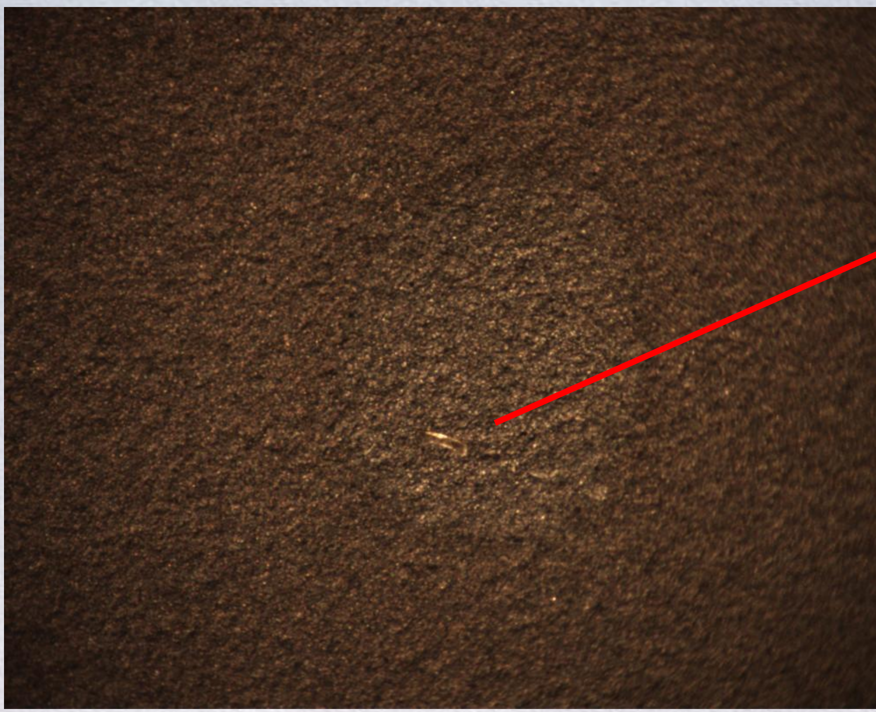
Vendor C OCV Bounce Back

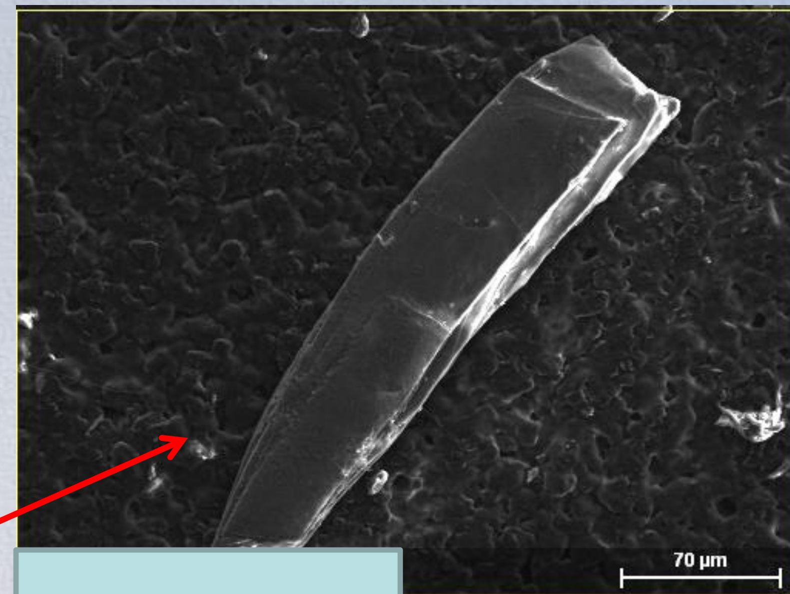


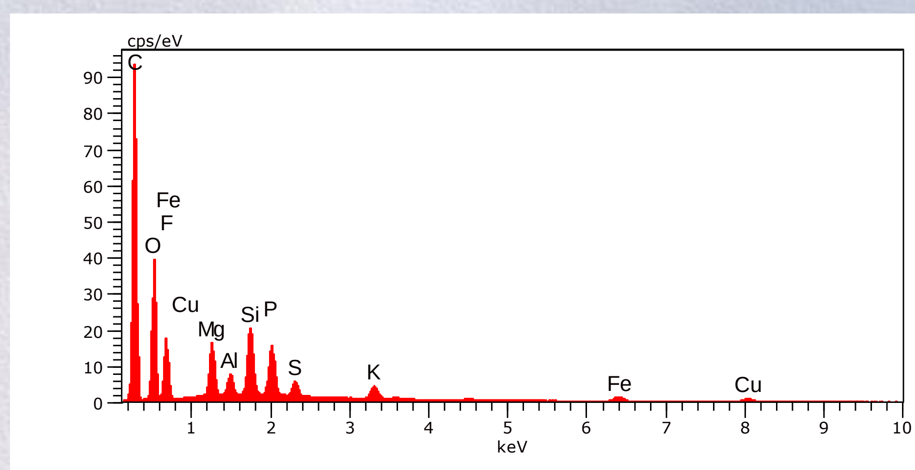
DPA Results of Failing Cells

- Cells failing the OCV bounce back test were from lots made on consecutive days
  - Cells made on other dates passed all acceptance tests
- OCV bounce back test after deep discharge (soft short test) was effective at non-destructively identifying cells with defects (in case of worst performing cell, defect was confirmed by DPA)
  - 2 large halos detected on one anode,
    - one with a crystalline piece of FOD consisting of Fe, Mg, Si, Al
    - And with a small piece of Al NOD

SEM/EDS



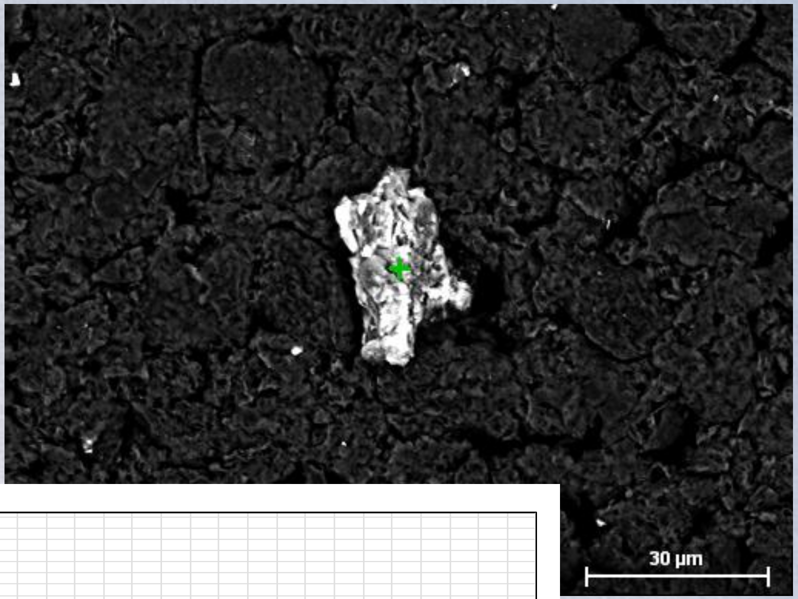


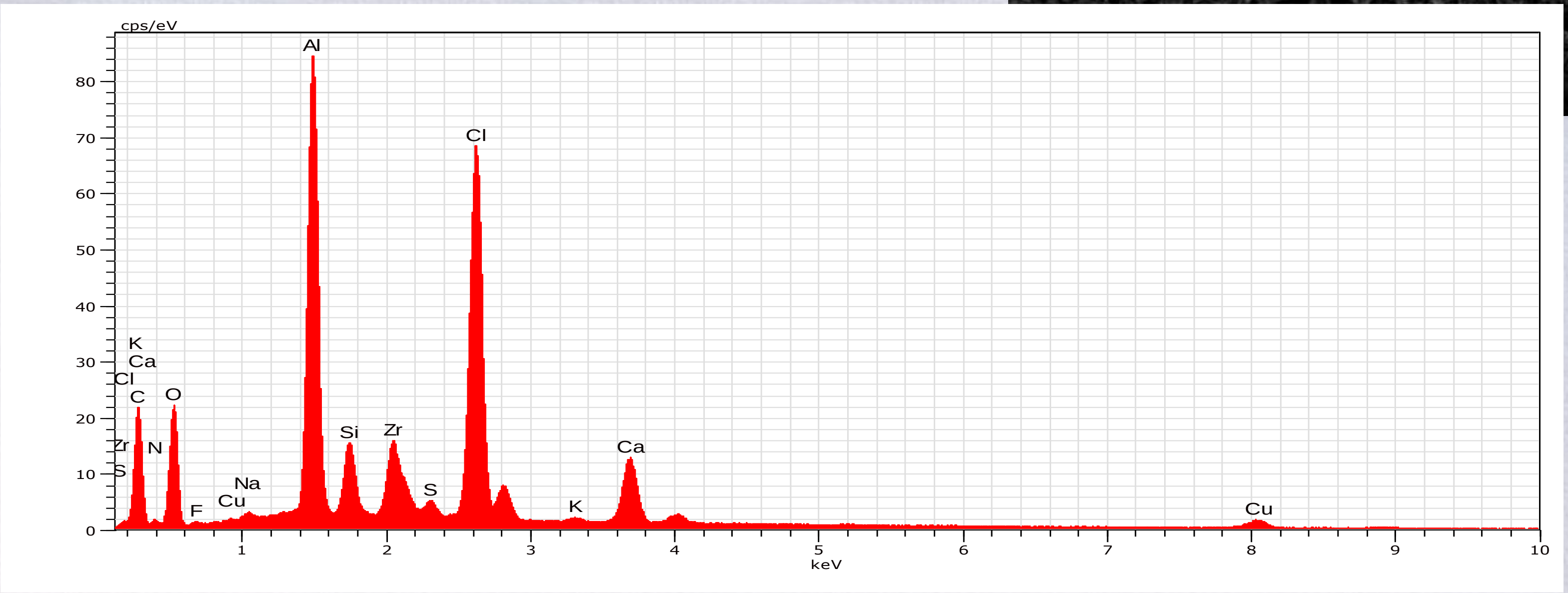


Crystalline FOD consists of Fe, Mg, Al, and Si

SEM/EDS of NOD

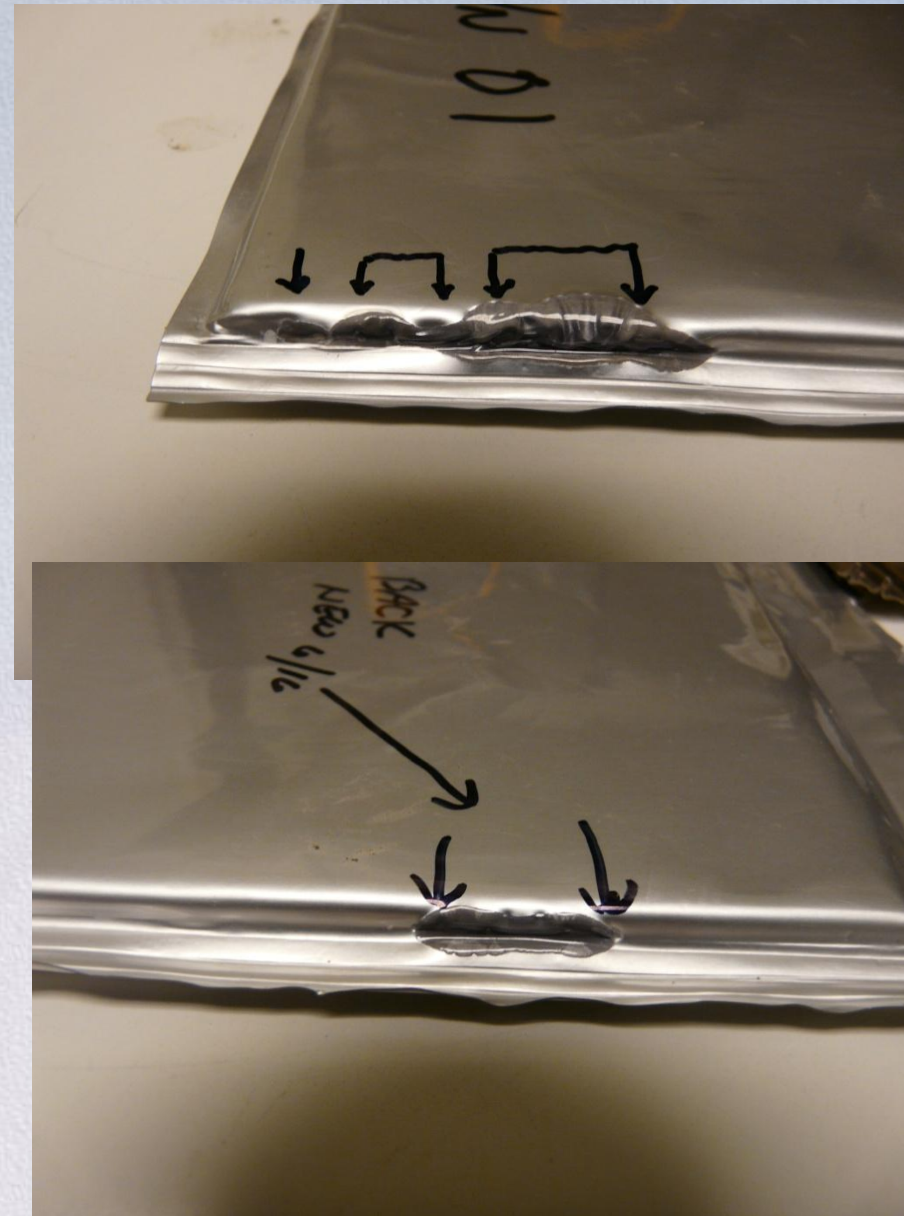
- Piece of Al debris on anode
- Found near the bigger FOD





Pouch Corrosion

- Procedure
  - Polarize Al layer of pouch to the negative potential of the cell
  - All four cell designs tested for up to 2 months
- Results
  - Within 2 weeks, the pouch corrosion sites on Vendor D cell developed several wide, black blisters
  - The cell pouch no longer appeared tightly fitted around the cell electrode stack



Pouch Corrosion (cont)

- Vendor C Results
  - Within 4 weeks, the pouch corrosion sites on cell developed, one black and one small, gray blister, both on the corners
  - The cell pouch no longer appeared tightly fitted around the cell electrode stack
- Results on the other 2 designs
  - No evidence of pouch corrosion after 2 months
- What cell design attributes do pouch corrosion resistant cells have that the others don’t?

Other Examples of Pouch Corrosion

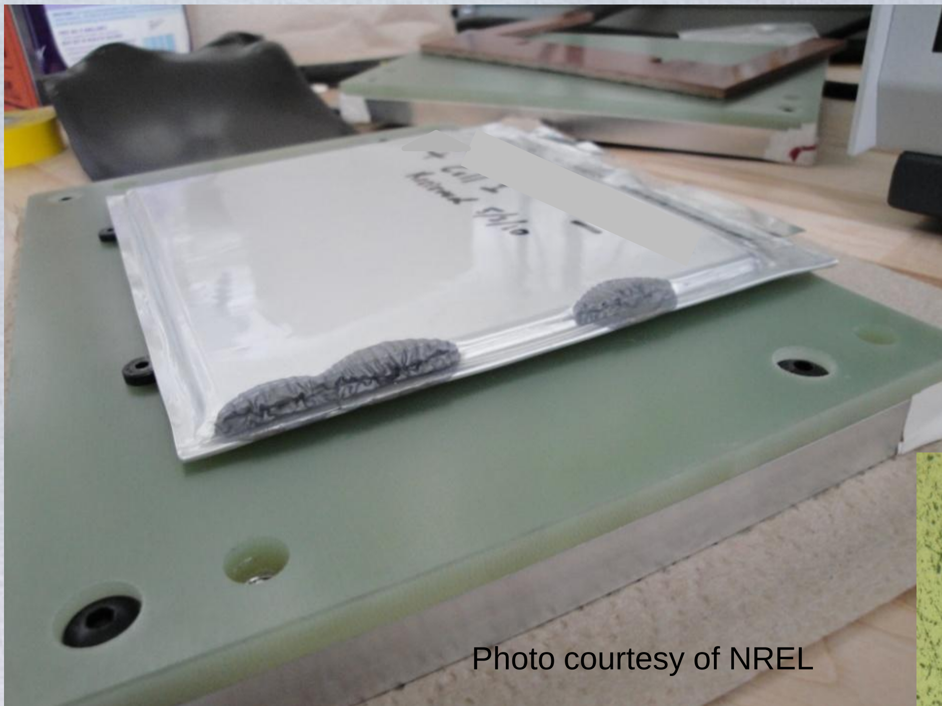
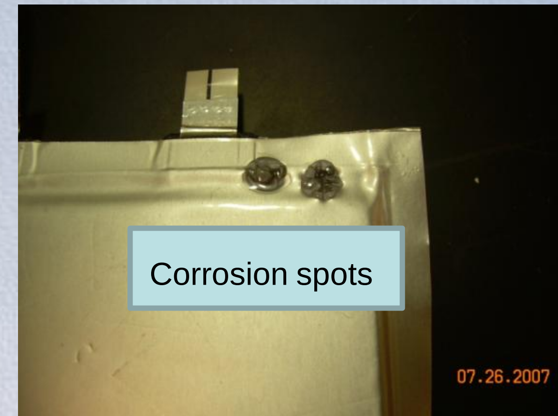
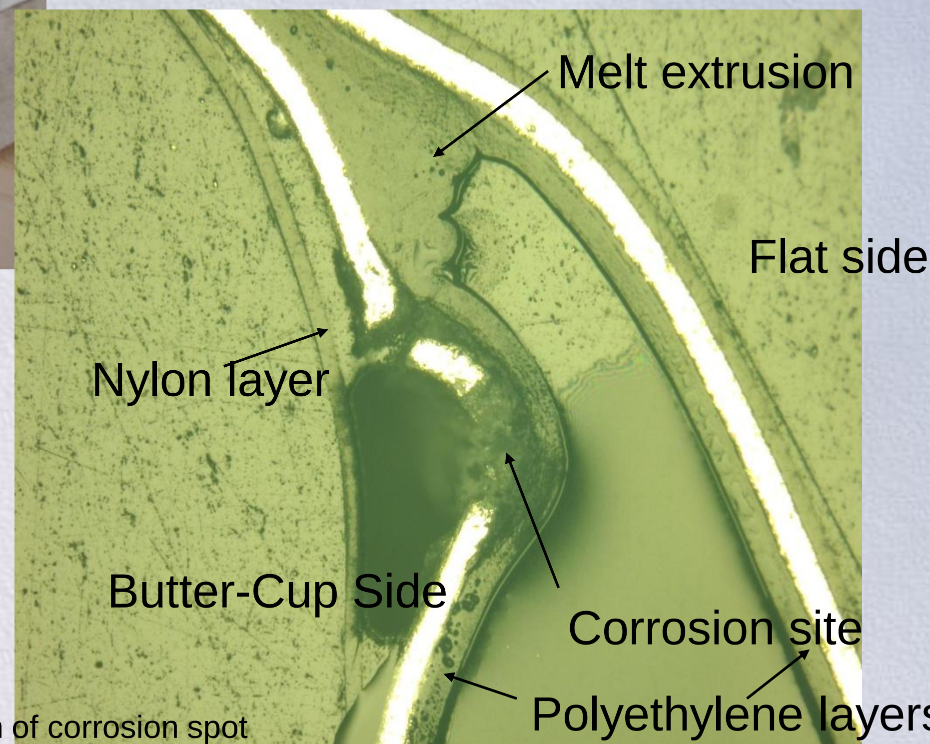


Photo courtesy of NREL



- Defective inner isolation layer of the laminate pouch results in corrosion of the Al layer
- Polarizing the Al layer to the (-) terminal is a quick test method



Cross section of corrosion spot

Conclusions To Date

- Current Li-ion pouch cells designs for electric vehicle market are offering
  - Over 150 Wh/kg and 300 Wh/L at 15 minute (4C) discharge rates
    - Verified by test with 2 cell designs
- Soft short test (or OCV bounce back test) is an excellent discriminator of manufacturing quality
  - Preventing battery assembly with cells with charge retention issues
  - Help precluding battery assembly with cells with latent defects
- DPA’s are also an excellent way to assess manufacturing quality
- Two cell designs were resistance to our pouch corrosion test
- Planned testing will determine their readiness for the demands of crewed spacecraft
  - Manufacturing quality
  - Effectiveness of the seals
  - Durability of performance