Development of High Energy Lithium Batteries for Electric Vehicles

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Envia Systems

2012 DOE Vehicle Technologies Program Review

Project ID: ES137

Date: May 16th, 2012

Overview

TIMELINE

- Project start date: Dec 2010
- Project end date: Jun 2013
- Percent complete: 57%

BUDGET

- **Total project funding:**
  - ✓ DOE: $1,832K
  - ✓ Contractor: $1,832K
- **Funding received in FY2011**
  - ✓ $761K
- **Funding for FY2012**
  - ✓ $1,030K

GOALS

Develop high capacity cathodes, screen commercial anodes and electrolyte formulations and integrate them to build high capacity (20-40Ah) pouch cells that meet the USABC minimum target goals for Electric Vehicles

TASKS

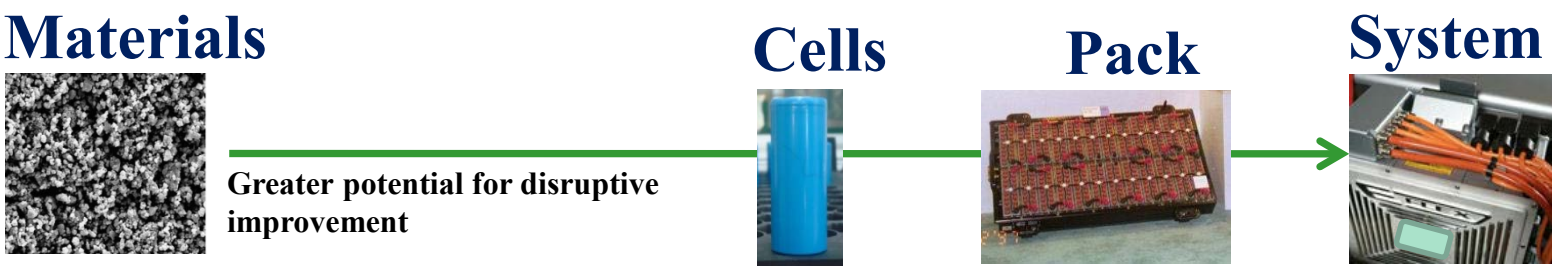
- Material screening & development
- Material scale-up
- Large cell development
- Large cell testing

DELIVERABLES

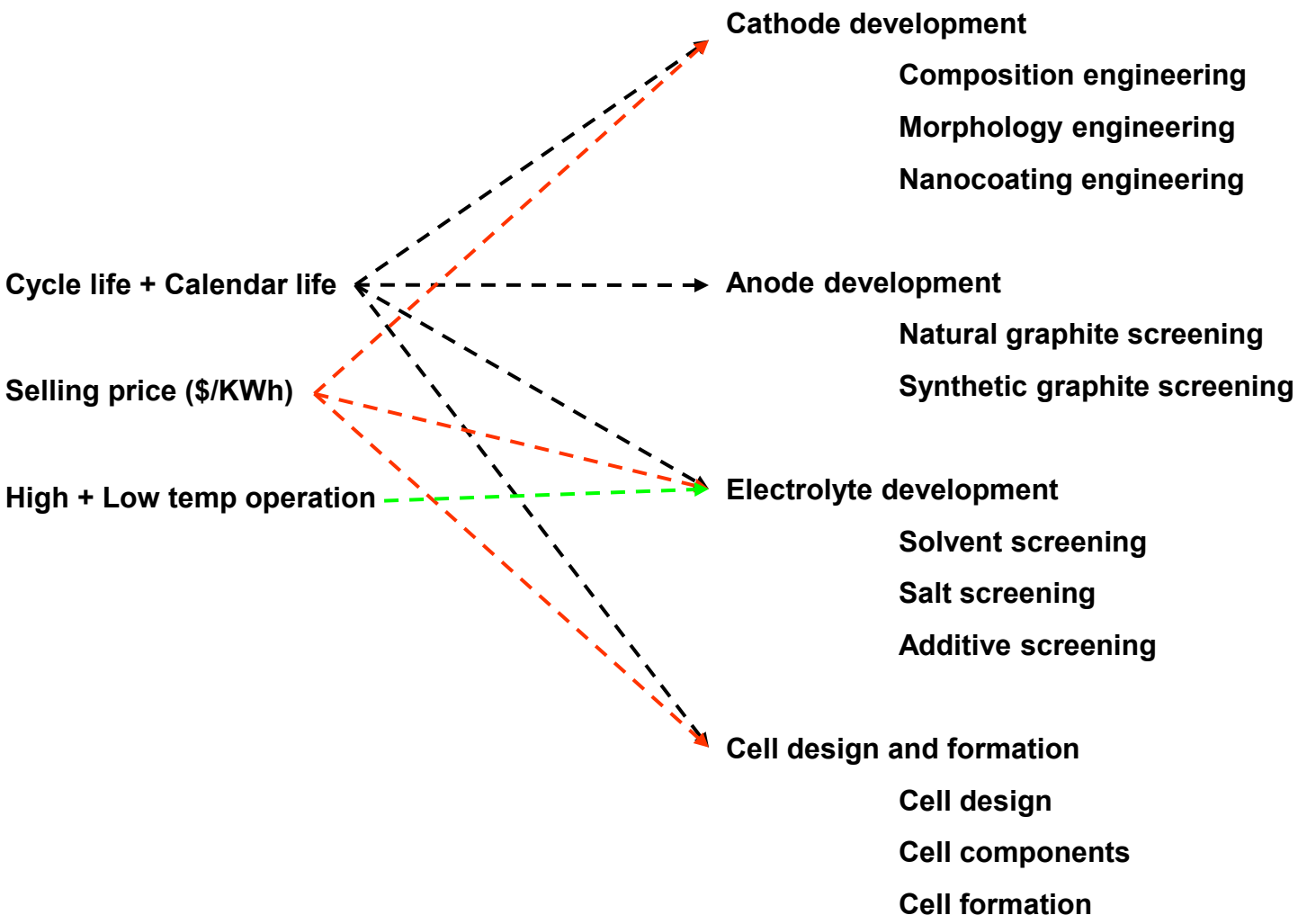
- Demonstrate cells that meet the minimum USABC EV targets and deliver them to a third party (INL, SNL & NREL) for independent validation

Company Introduction

- Incorporated in July, 2007. Located in Silicon Valley, California
- Investments from venture capital, GM, Asahi Glass & Asahi Kasei
- Focused on High Capacity Manganese Rich (HCMR™) cathodes & Silicon-Carbon composite anodes for Lithium ion batteries
- Envia's high energy Li-ion battery materials reduce battery costs at the material and pack level and also improve miles per charge and reduce weight
- Recipient of USABC, ARPA-E, R&D 100 awards



Improvement Plan

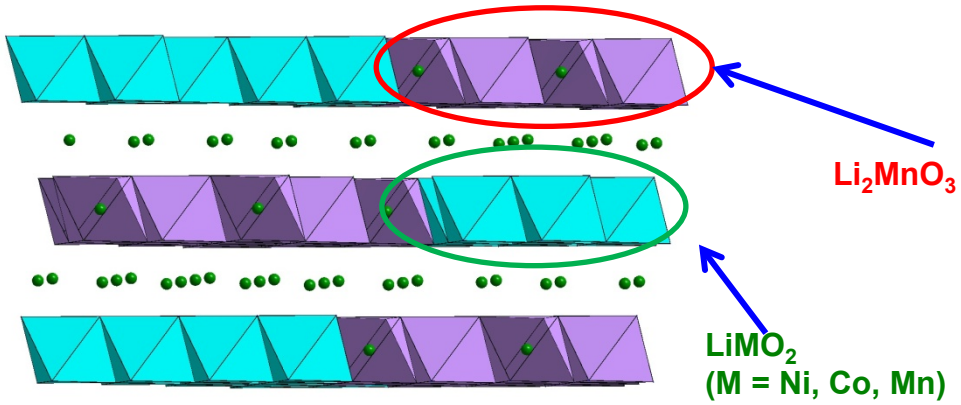


Cell Specification

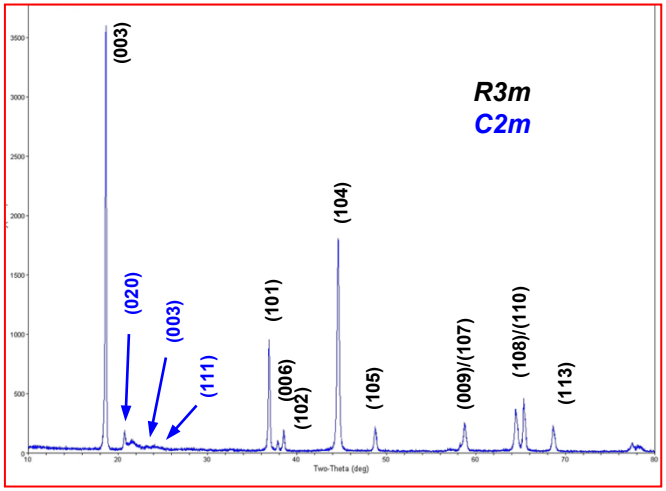
Number	Systems Performance Metrics	SYSTEM VALUES: LONG TERM GOALS	SYSTEM VALUES: MINIMUM GOALS FOR LONG TEARM COMMERCIALIZATION	CELL VALUES: EXPECTED CELLS USABC LONG Term Goals for Commercialization	CELL VALUES: EXPECTED CELLS (USABC MINIMUM Goals for Long Term Commercialization)
1	Power Density 80% DOD/30 sec (W/L)	600	460	1034	793
2	Specific Power - Discharge, 80% DOD/30 sec (W/kg)	400	300	571	429
3	Specific Power - Regen, 20% DOD/10 sec (W/kg)	200	150	286	214
4	Energy Density - C/3 Discharge (Wh/L)	300	230	517	397
5	Specific Energy - C/3 Discharge Rate (Wh/kg)	200	150	286	214
6	Specific Power/Specific Energy Ratio	2:1	2:1	2:1	2:1
7	Total Pack/Cell Size (kWh)	40	40	0.144	0.144
8	Life (Years)	10	10	10	10
9	Cycle Life - 80% DOD (Cycles)	1000	1000	1000	1000
10	Power & Capacity Degradation (% of rated spec)	20	20	20	20
11	Selling Price - 25,000 units @ 40 kWh ($/kWh)	100	<150	100	<150
12	Operating Environment (°C)	-40 to +85	-40 to +50	-40 to +85	-40 to +50
13	Normal Recharge Time (hr)	3 to 6	6	3 to 6	6
14	High Rate Charge @ 150 W/kg	40-80% SOC in 15 min	20-70% SOC in <30 min	40-80% SOC in 15 min	20-70% SOC in <30 min
15	Continuous discharge in 1 hr - No Failure (% of rated energy capacity)	75	75	75	75
16	Battery scaling factor (BSF)			279 (93s, 3p)	279 (93s, 3p)
17	Battery Capacity (Ah)			40	40

Cell Specifications were derived from USABC SYSTEM goals

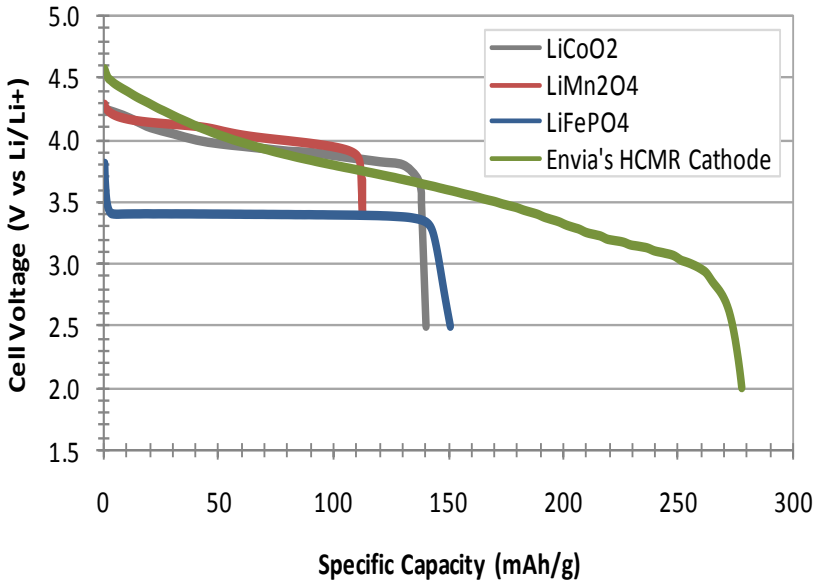
High Capacity Manganese Rich (HCMR™) Cathode



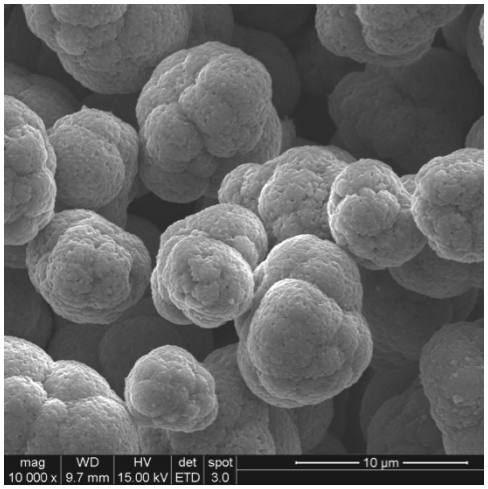
Lithium-rich Layered-Layered Li_2MnO_3.$LiMO_2$ Composites



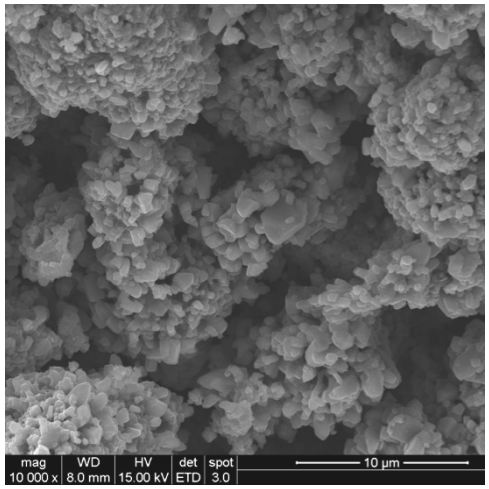
- Composite HCMR™ cathode materials with 2x higher specific capacity and lower cost when compared to commercially available materials



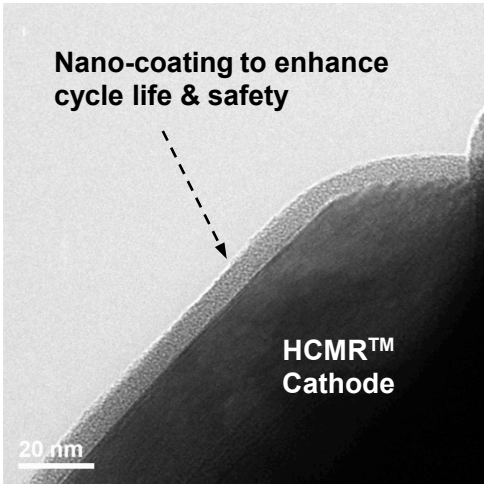
Envia's HCMR™ Cathode Development



SEM image of HCMR™ Cathode
(dense cathode for high energy applications)



SEM image of HCMR™ Cathode
cathode for high power applications)



TEM image of nanocoated
HCMR™ Cathode

By engineering the cathode composition, structure, dopants, morphology and nano-coating, Envia is able to precisely control and tune the specific capacity, cycle life, calendar life, rate capability and physical properties of the material to match any application

Electrolyte Development

Electrolyte Target Specifications:

Performance Metrics	Electrolyte Target
Low and high temperature working range (°C)	-40 to 50
Conductivity (mS/cm)	> 1
Large operating voltage window (V)	2.0 to 5.0
Support long cycle life	1000

- Investigate various electrolytes compositions (solvents, salt concentrations & additives) to improve:
  - ✓ *High voltage operation*
  - ✓ *Anode-electrolyte SEI*
  - ✓ *Cathode-electrolyte SEI*
  - ✓ *Low temperature and high temperature operation*
- Electrolyte screening/testing plans:
  - ✓ *Oxidation potential*
  - ✓ *Conductivity at different temperatures*
  - ✓ *Cycle life in coin cell and pouch cell formats (single layer, 1Ah, 20Ah & 40Ah)*

Electrolyte Development

- Envia's electrolyte is based on commercially available chemicals:
  - ✓ *Salt – $LiPF_6$, salt 2#, salt #3 .*
  - ✓ *Solvents – Proprietary organic solvents (commercially available carbonates)*
  - ✓ *Additives – Commercially available Lithium compounds*
- All components for Envia's high voltage electrolyte are in mass production, readily available and commonly used in consumer electronics
- A new Electrolyte has been developed that exhibits improved low temperature performance when compared to current high voltage Baseline electrolyte
  - ✓ USABC low temperature target specifications are meet down to -30°C (>10% energy retention)

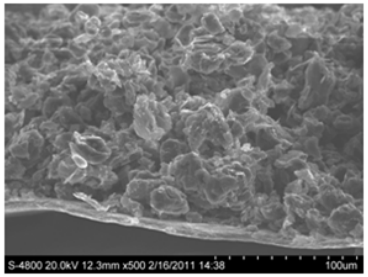
Anode Development

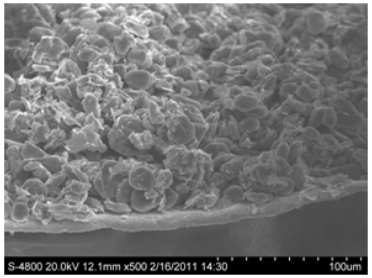
Anode requirements:

- High rate capability (minimum capacity loss up to 2C)
- Low impedance (low charge transfer resistance)
- High thermal stability

Screening of Different Anodes:

- Various commercially available graphite anodes were identified and screened
- Anodes tested had different morphologies (particle size, tap density and surface area):



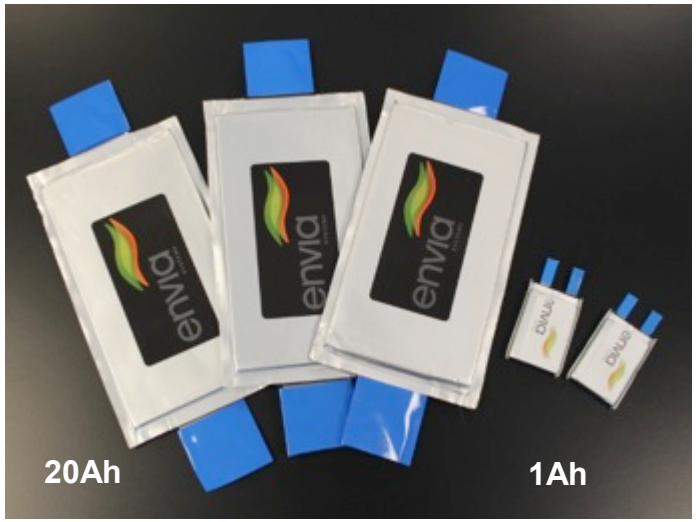


Anode Summary:

- After screening numerous commercially available carbon-based anodes, Envia down selected an anode that works well with HCMR™ cathode

Testing Development Update

- Testing has been carried out by following USABC testing protocols
- Detail HPPC (hybrid pulse power characterization) and DST (dynamic stress test) protocols were obtained from Idaho National Lab
- Testing has been carried out on 1Ah and 20Ah pouch cells



Ongoing cell testing:

- *Baseline, 1Ah cells*
- *Cell build #1, 1Ah cells*
- *Cell build #1, 20Ah cells*
- *Cell build #2, 20Ah cells*
- *Cell build #3, 20Ah cells*

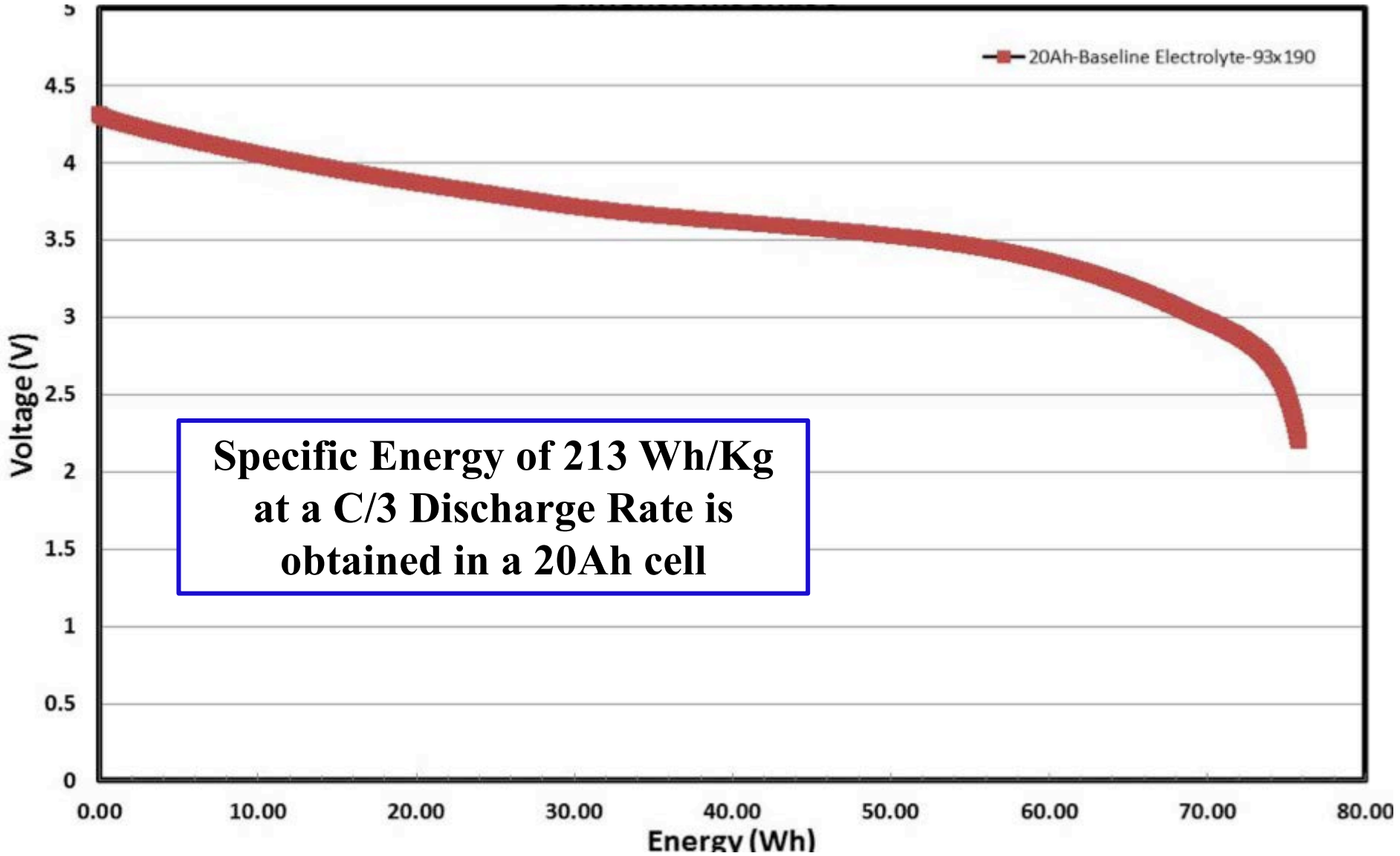
Cell Specifications

Cell Type	**Prismatic Polymer**
Size	**0993190P**
Capacity	**20.5 Ah**
Nominal Voltage	**3.56 V**
Specific Energy	**218 Wh/kg**
Power Density	**1100 W/L**
Discharge Pulse Power@80%DoD	**600 W/kg**
Max. continuous Discharge current	**60 Amps**
Weight	**0.335 kg**

73Wh, 20Ah Cell

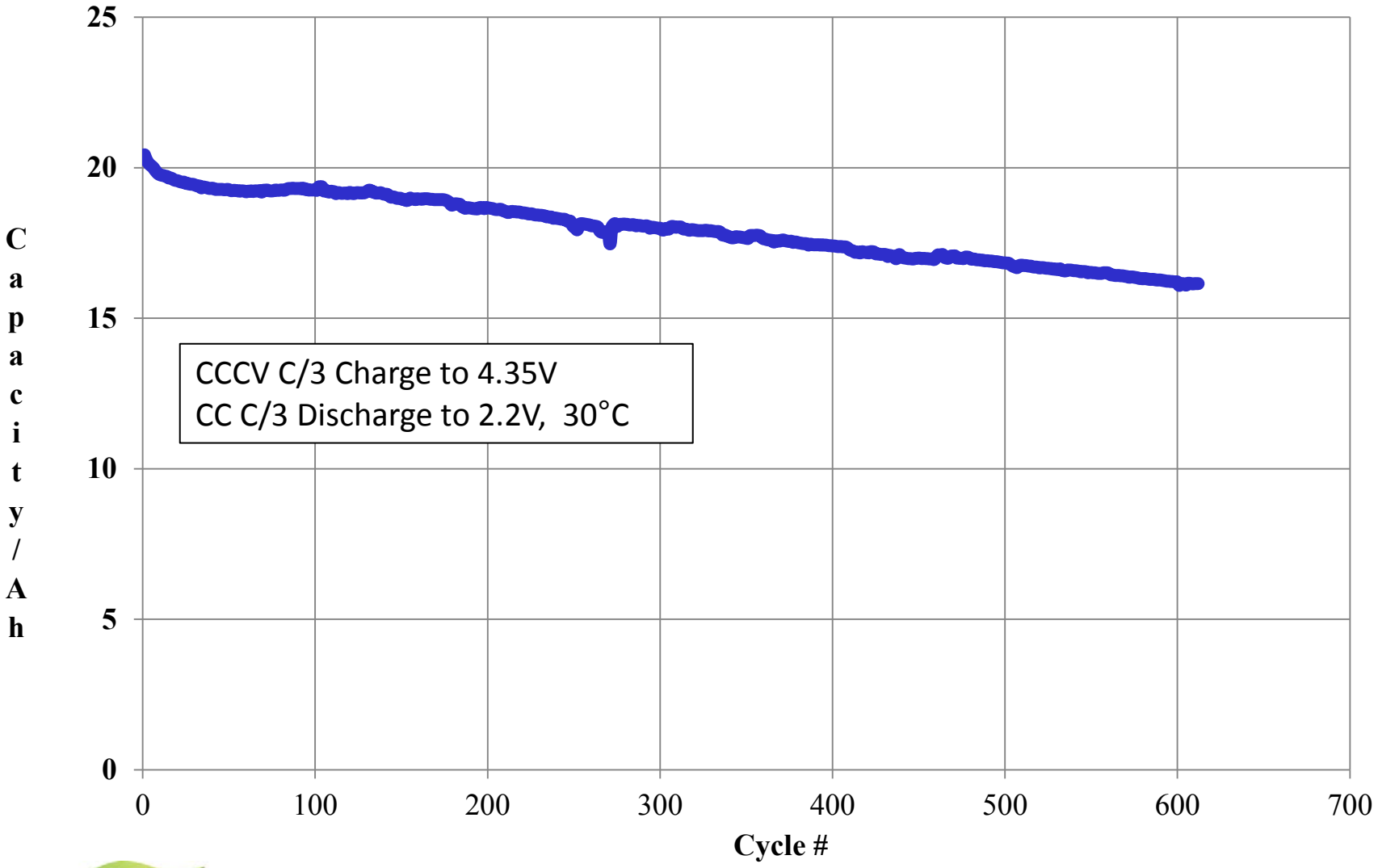
Cells are tested at 30 ℃

Discharge Curve at C/3 Rate

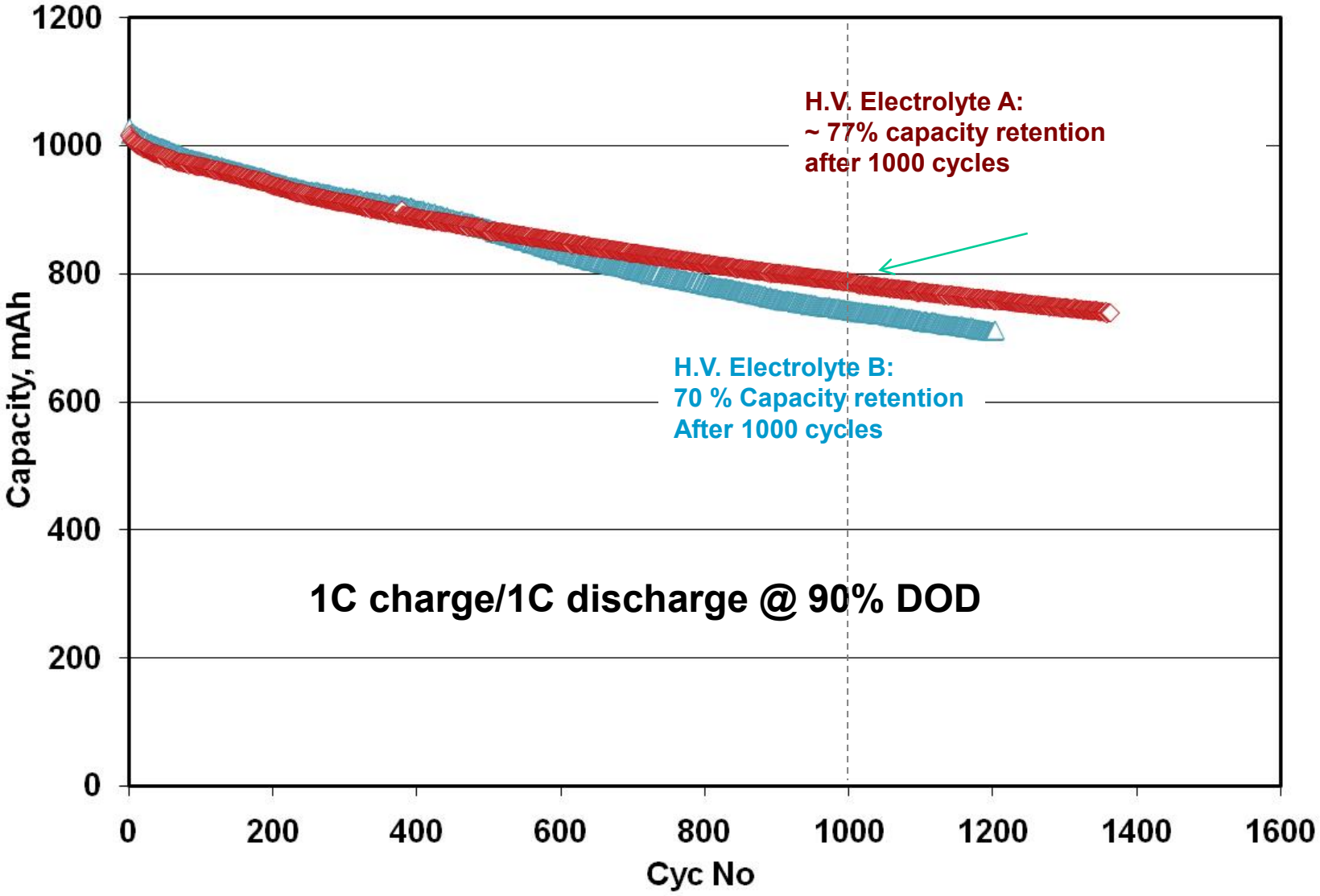


Specific Energy of 213 Wh/Kg at a C/3 Discharge Rate is obtained in a 20Ah cell

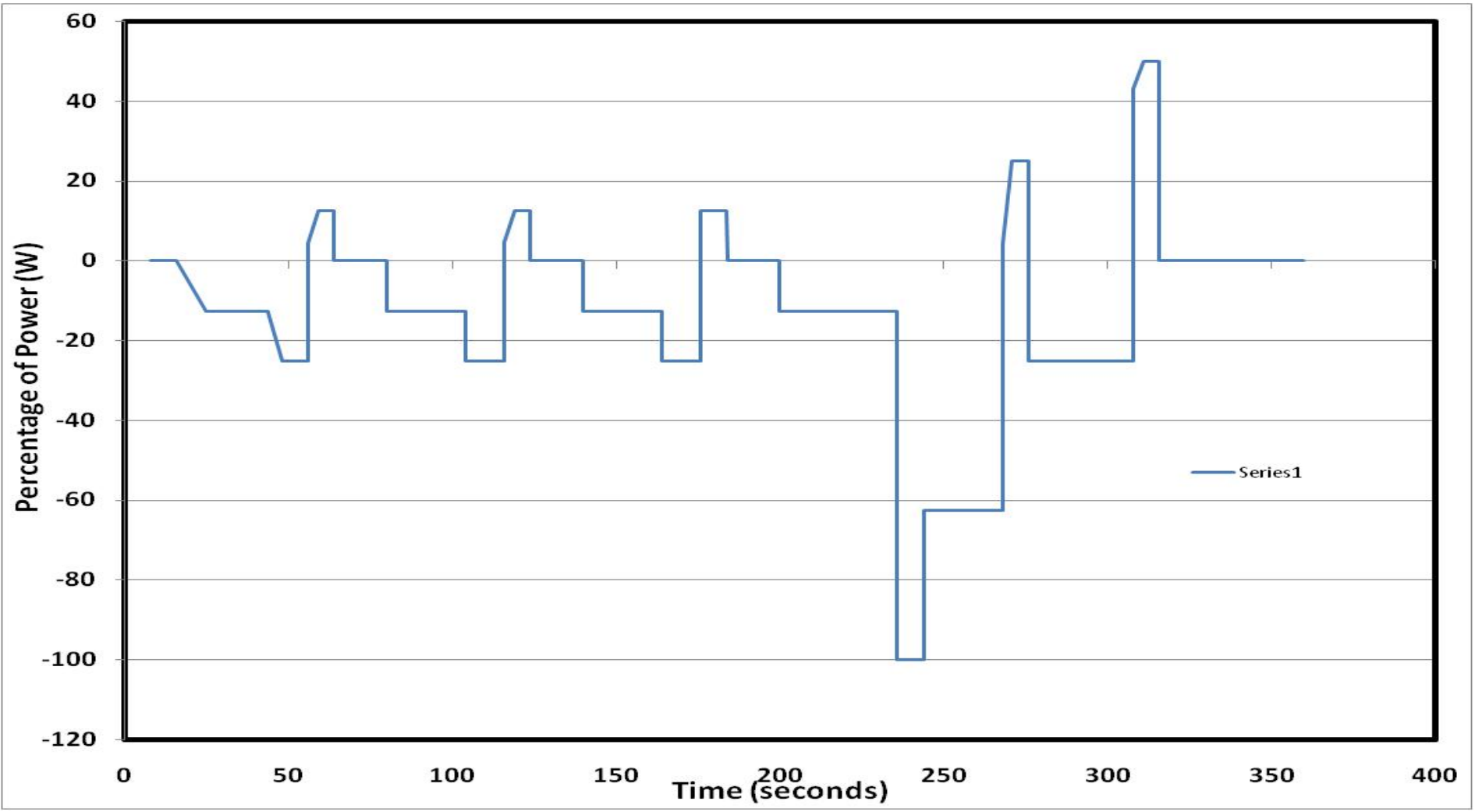
Cycle life of 73Wh, 20Ah Cell



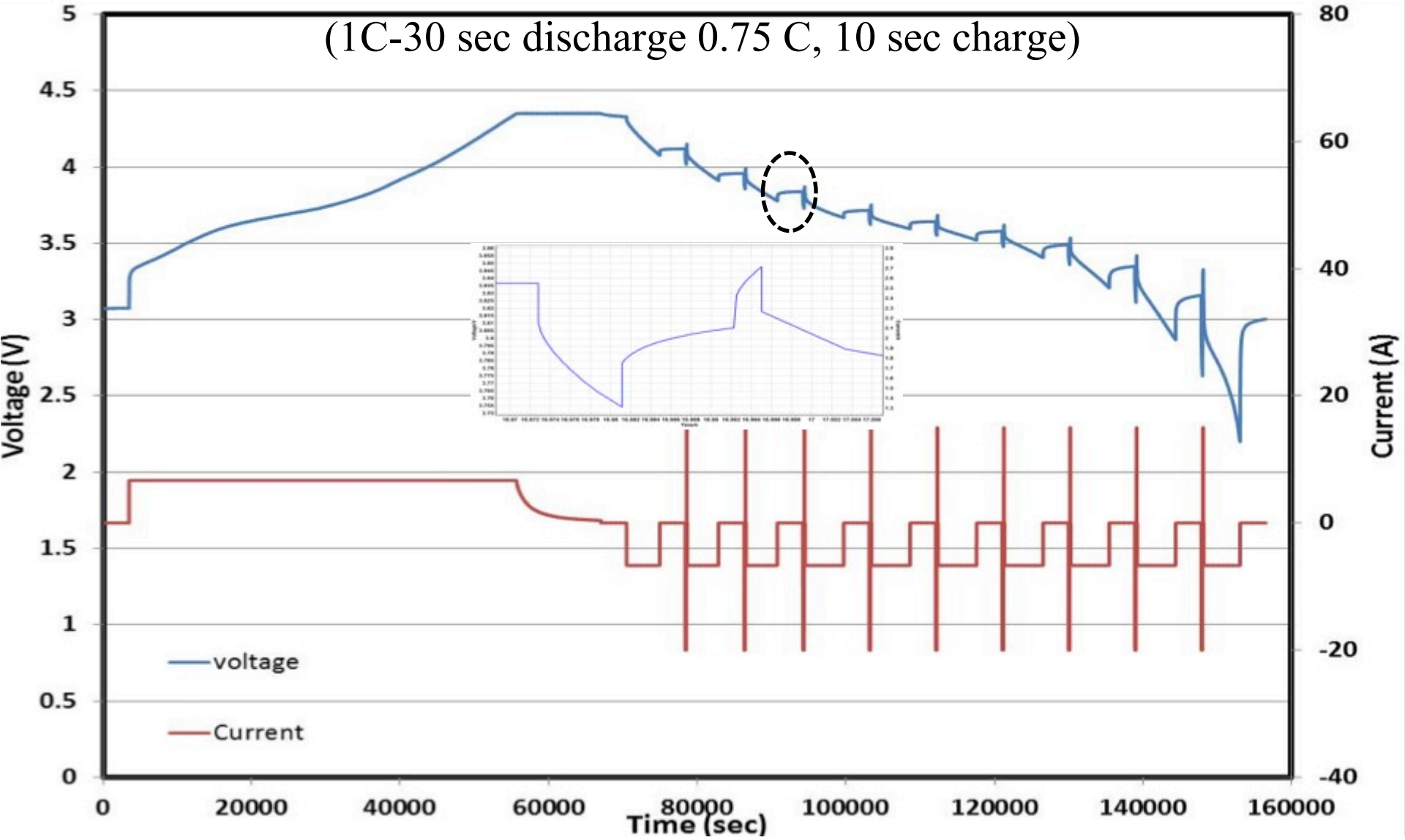
1Ah Cells: 1C Rate Cycling at 45°C



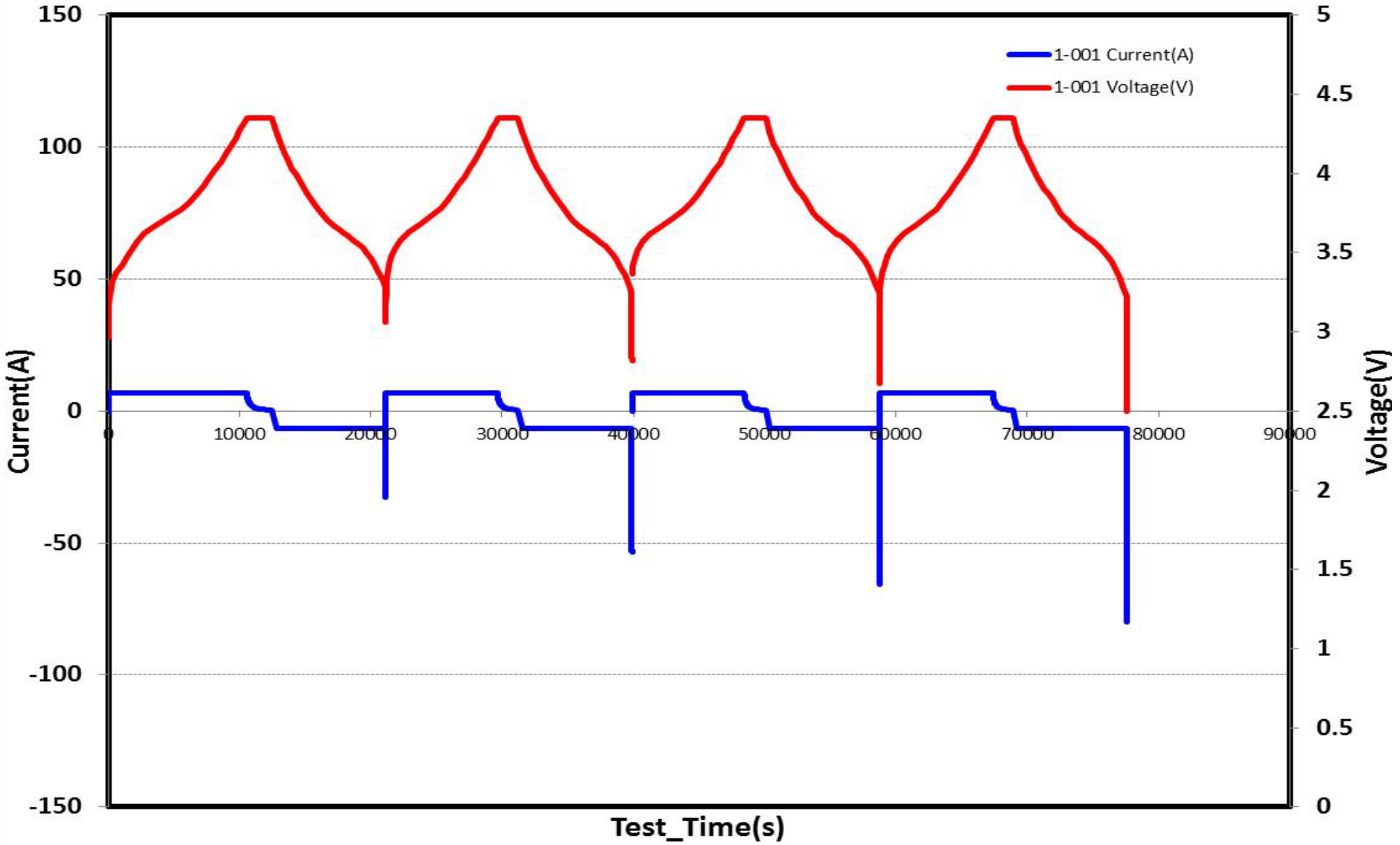
DST Power Cycle



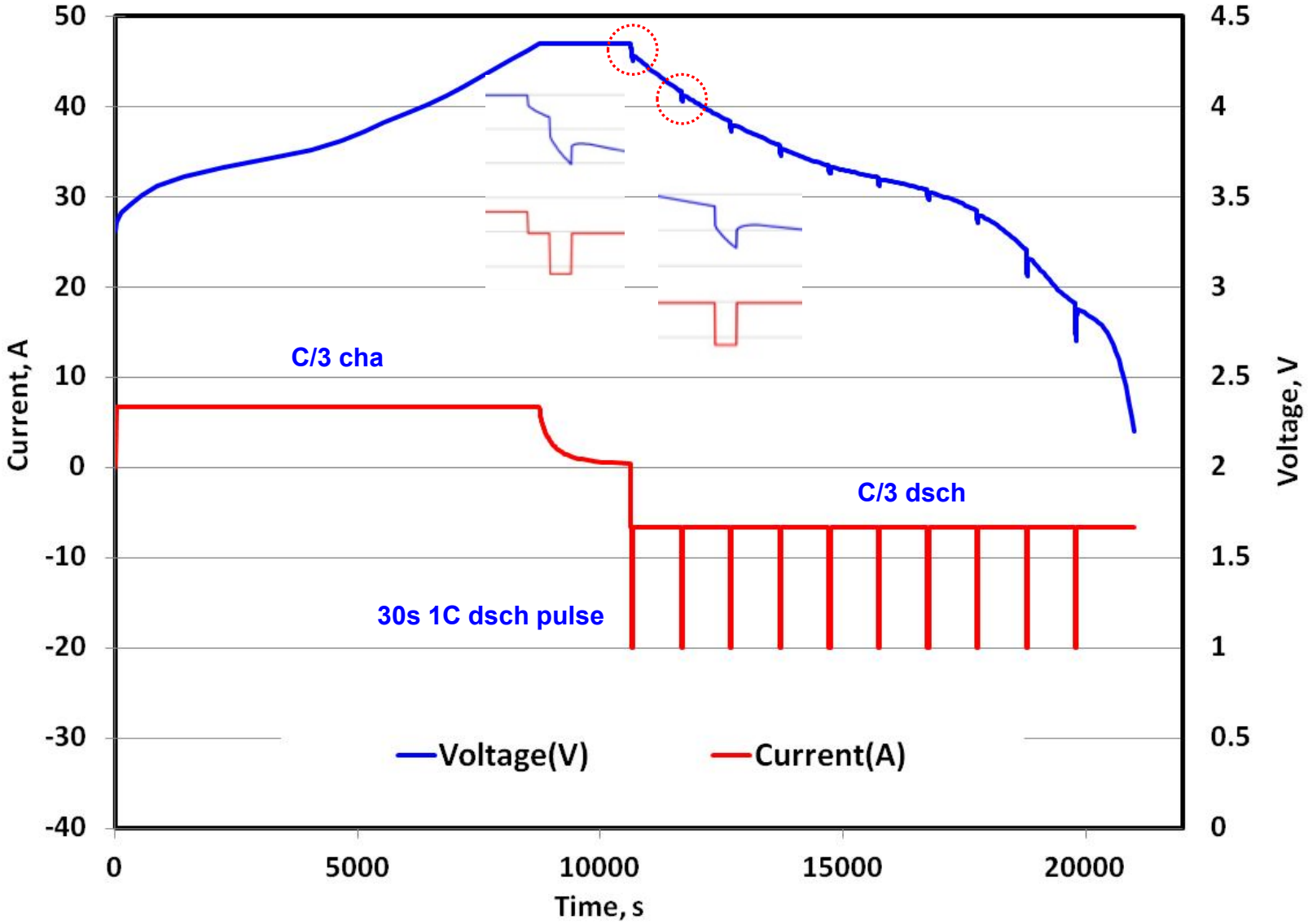
EVPC Study


(1C-30 sec discharge 0.75 C, 10 sec charge)
Voltage (V)
Current (A)
Time (sec)
voltage
Current
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
-40
-20
0
20
40
60
80
0
20000
40000
60000
80000
100000
120000
140000
160000

Peak Power Evaluation



Low Peak Power Test (LPPT) Protocol



Summary

- Continuing to develop materials and cell designs that meet the minimum USABC EV target specifications
- Value Proposition:
  - Highest Energy Density with low cost metals implies:
    - Lowest battery Weight
    - Lowest cost $/KWh
    - Long driving range
  - Excellent safety
  - Mass manufacturable process
- Strong IP portfolio: Over 25 pending patents
- Market: Fast growing and emerging EV & PHEV market