DOW KOKAM

2013 DOE Hydrogen and Fuel Cells Program Review

ES-127

Development of Large Format Lithium Ion Cells with Higher Energy Density

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Dow Kokam

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Overview

Timeline

- Project start date: Oct. 1, 2011
- Project end date: Mar. 31, 2015
- Percent complete: ~30%

Barriers

- Barriers addressed
  - Increase energy density of lithium ion battery
  - Reduce cost
  - Maintain good cycle life

Budget

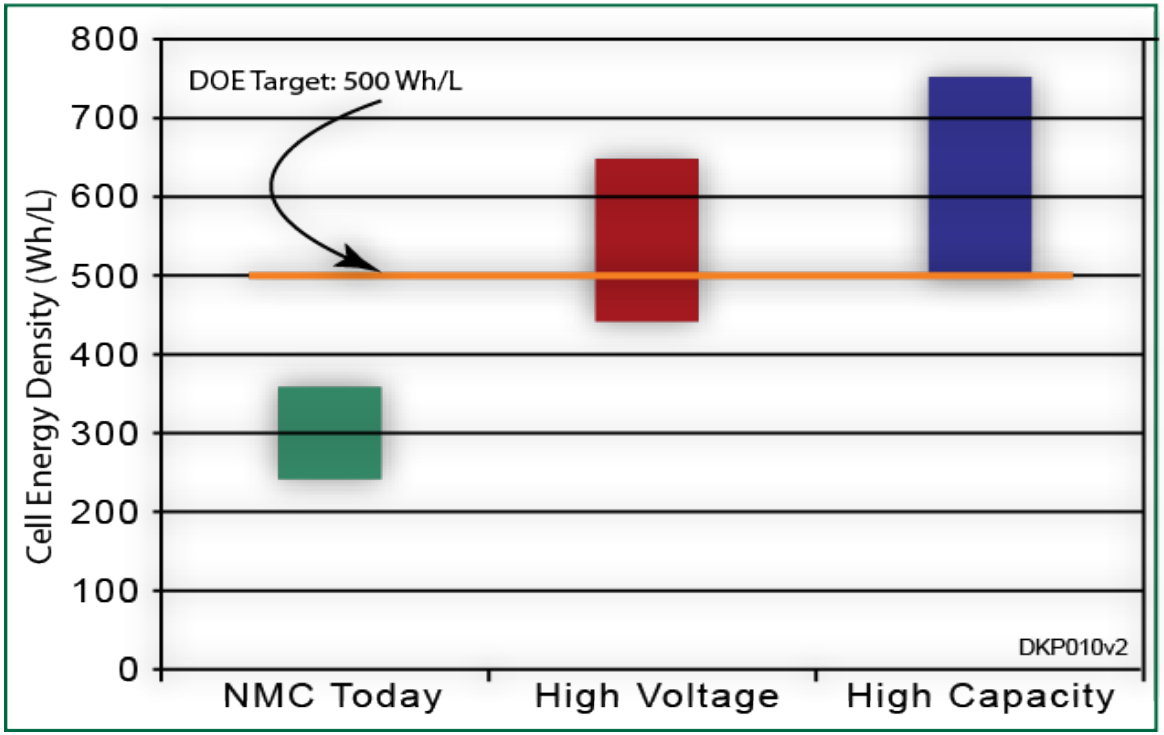
- Total estimated project cost:
  - DOE share: $4,986,984
  - Dow Kokam share: $2,431,606
- Funding received in FY11: $1,957,460
- Funding for FY12: $997,560
- Total funding received: $2,955,020

Partners

- Dow Kokam – Project Lead
- Wildcat Discovery Technology (WDT) – Cathode Materials and High Voltage Electrolytes
- Oak Ridge National Lab (ORNL) – Material Characterization
- University of Missouri, Kansas City (UMKC) – Analytical Support

Project Objectives

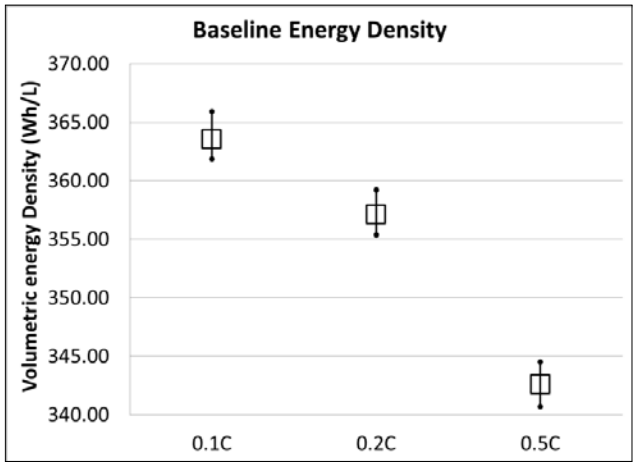
- To research, develop, and demonstrate Li-ion battery cells that are capable of achieving an energy density of >500 Wh/L and a power density of >500 W/L while maintaining comparable performance standards in terms of cycle life (300-1000 cycles at 80% initial capacity), calendar life (5-10 years), and durable cell construction and design capable of being affordably mass produced.

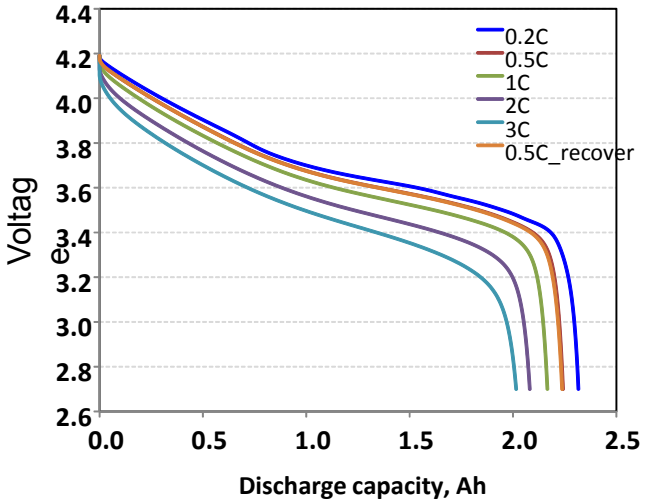


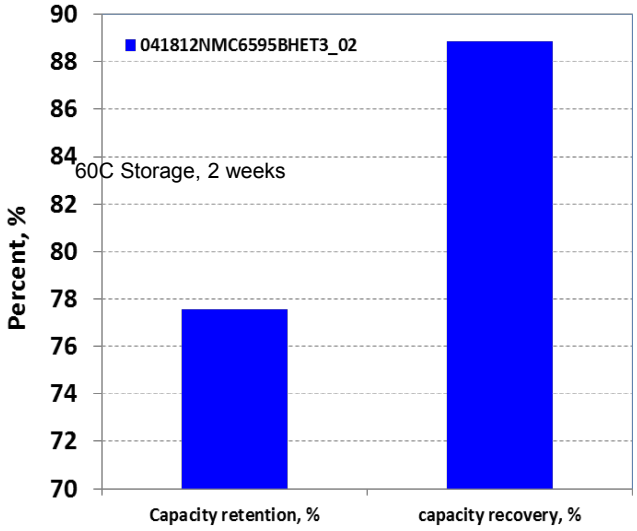
Project Approach

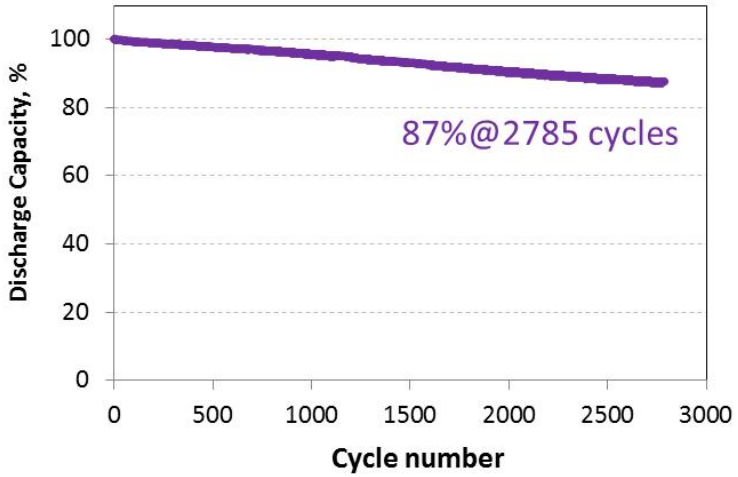
- **Phase 1:** Mobilize Resources, Implement Project Management Plan, Institute Project Controls (On-going)
- **Phase 2:** Establish Model & Performance Baseline NMC/Graphite Cell, Establish Baseline Capacity For Cells, Install Equipment (90% Completed)
- **Phase 3:** Optimize High Voltage Cell Design and Finalize Materials Development, Scale Up High Voltage Cathode Material, Produce High Energy Interim Cells, Estimate Costs (40% Completed)
- **Phase 4:** Develop and Optimize High Capacity Materials and Cell Designs, Produce High Energy Interim Cells, Estimate Costs (20% Completed)
- **Phase 5:** Produce And Deliver Large Format Baseline and High Energy Cells (Not Scheduled to Start Until 2014)
- **Phase 6:** Verify Achievement of Cost Goals and Develop Commercialization Plan (20% Completed)

Performance of 2-Ah Hand-Assembled Baseline Cells



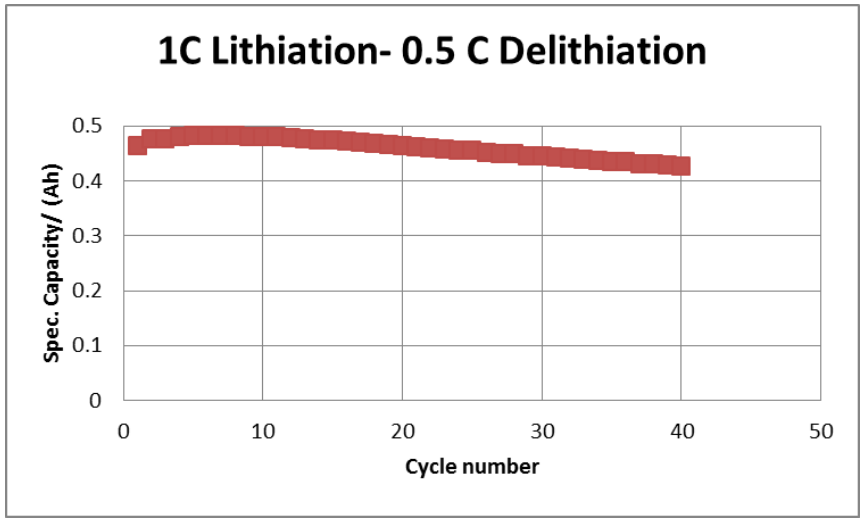


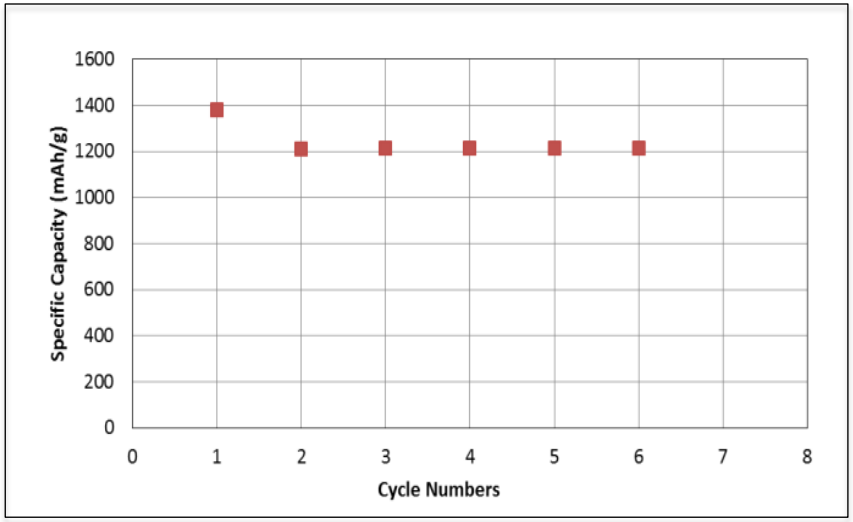




Baseline cells passed all tests; they will be delivered to ANL for testing in April 2013

High Capacity Anode Development



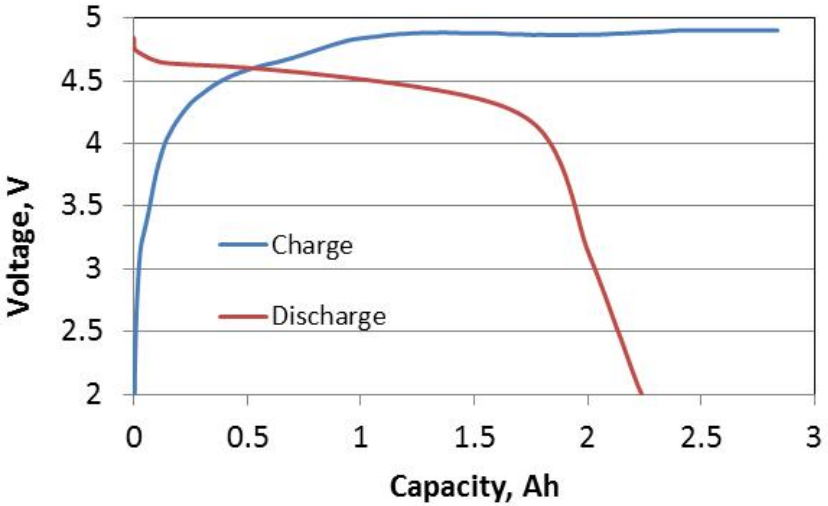


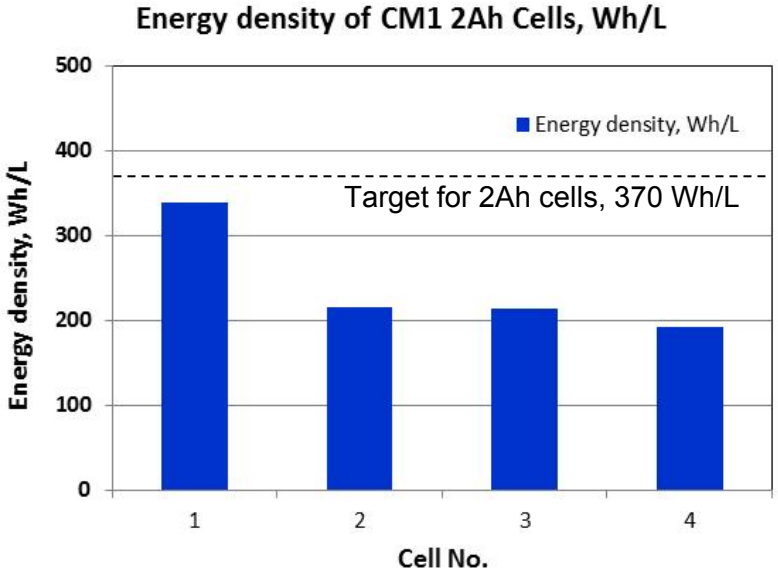
Anode Material 1

Anode Material 2

- Si-based anodes provide high capacity as claimed
- Matching between anode and cathode is important
- Charging conditions must be optimized
- DK is now testing full cells

High Voltage Cathode Development





- The high voltage material system, CM1/EM1/Graphite, achieved an energy density of ~340 Wh/L in 65X95-mm hand-made cells
- Gas generation continued throughout the cycle life test
- Three-electrode cells showed that the cathode reached >5V during cycling
- Presently:
  - Developing improved HVC with higher specific energy
  - Evaluating effects of cell resistance by changing electrode design

Wildcat Discovery Technologies

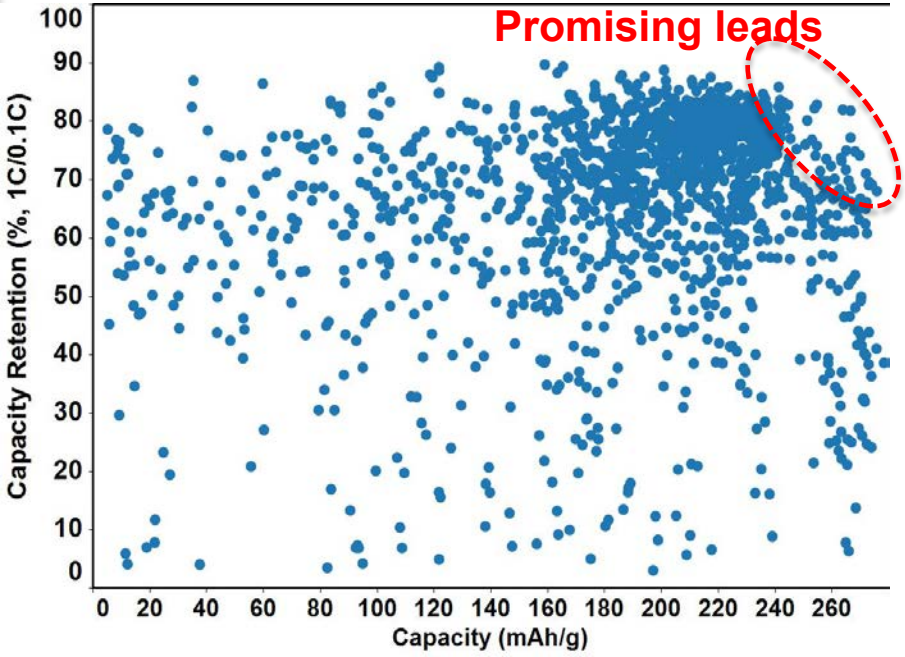
High Capacity Cathode Development

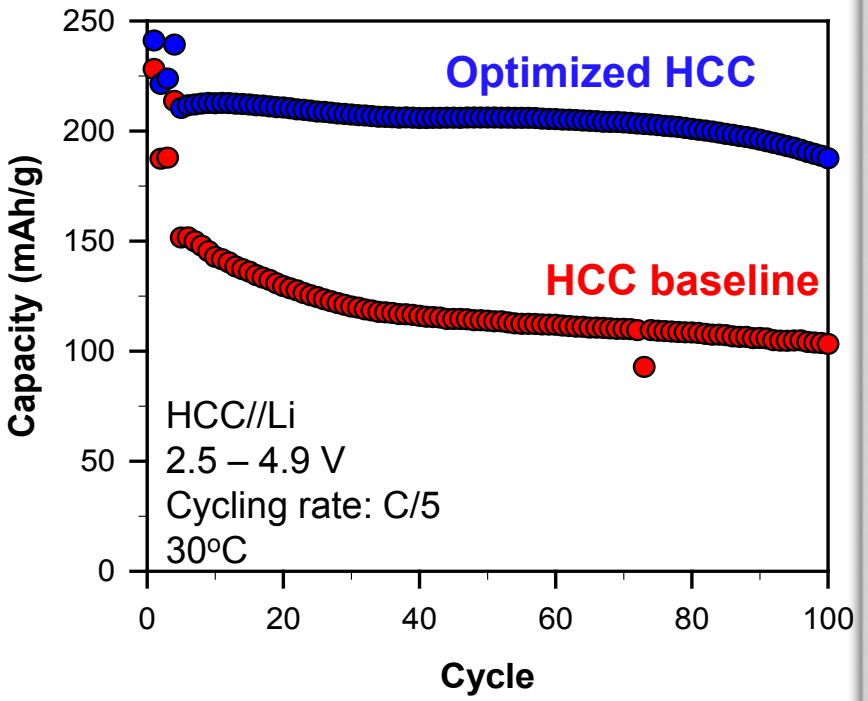
Metric	Comparison with State of the Art			
	NMC $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$	LMNO $LiMn_{1.5}Ni_{0.5}O_4$	OLO $Li_{1+a}Ni_xMn_yCo_zO_2$	HCC
Capacity (mAh/g)	155	147	274	288#
Gr. Energy (Wh/kg)	590	690	1000	1090#
Vol. Energy (Wh/L)	2760	3060	4470	4790#
Rate Performance (% at 1C)	87	95	80	-
Cycle Life (80% of Initial)	>1000	~700	300	-
Cost ($/kg)	24-30	~20	~22	~21*

Theoretical Values * Estimation based on similar process cost of OLO

- Low irreversible capacity and no voltage fade are expected for HCC
- HCC has potential to directly compete with OLO

High Capacity Cathode Development Status





- Screen more than ~2000 materials
- Improve stability to air, capacity, and energy density
- Develop low cost solid state synthesis for HCC

Wildcat Discovery Technologies

High Capacity Cathode Development Status

Metrics	Theoretical	HCC Baseline	HCC from Primary Screen
Capacity (mAh/g)	288	240	267
Energy (Wh/kg)	1090	864	977
Rate Performance (% at 1C)	-	68	77
Reversible Capacity (%)	-	75	90
Full Cell Cycle Life (80% of Initial)	-	50	N/A
Stability	-	Air sensitive	Air stable

- Promising HCC materials are identified by WDT
- WDT is screening for precursors and dopants

Collaboration

- Wildcat Discovery Technologies – Dr. Bin Li
  - Screening of new HVC and HCC materials
  - Screening of dopants to improve material performance
  - Development of synthesis techniques
- Oak Ridge National Laboratory – Dr. David Wood
  - Materials characterization
  - Failure mode analysis
- University of Missouri, Kansas City – Prof. Xiaobo Chen
  - Analytical support

Proposed Work in 2013

- High Capacity Anode (HCA)
  - Fabricate and test 2-Ah full cells with HCA as the anode
- High Voltage Cathode (HVC)
  - Test improved CM1 in half cells and full cells
  - Search and down-select alternative high voltage electrolytes
  - Combine HVC and HCA in 2-Ah format full cells, deliver to ANL for testing if performance is promising
- High Capacity Cathode (HCC)
  - Complete material development and finalize candidate materials
  - Material characterization for physical and electrochemical properties
  - Test the compatibility of HCC and HCA

Program Summary

- Goal: To develop a large format lithium ion cell with energy density > 500 Wh/L
- Approach: Develop 2-Ah format baseline cells using high voltage and high capacity cathodes, in parallel, with high capacity anodes
- Technical accomplishments in 2012:
  - Baseline cells completed, will be delivered to ANL (est April 2013)
  - Si-Based anodes screened and selected, specific capacity >500 mAh/g
  - High voltage cathode demonstrated 340 Wh/L in 64X95-format full cells with graphite anode
  - Development of high capacity cathode material initiated, currently achieved ~250 mAh/g before optimization