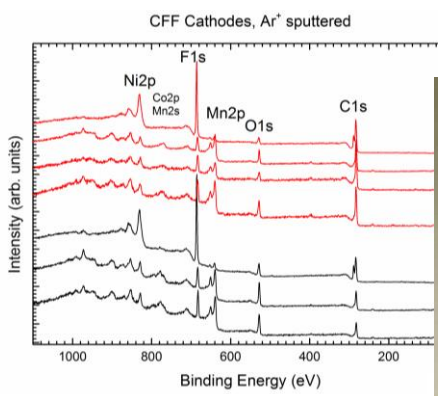
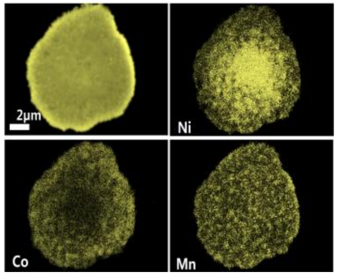
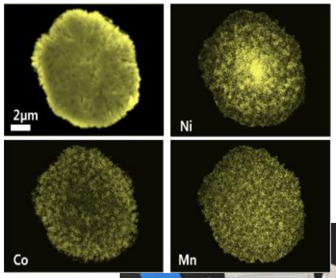
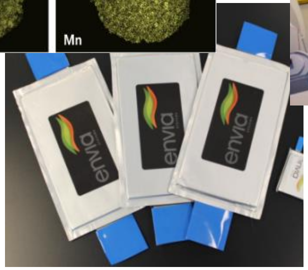
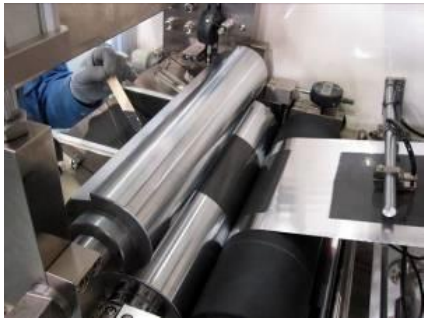
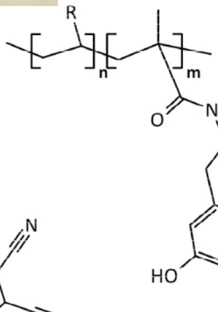


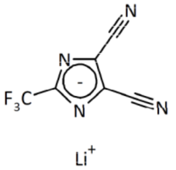


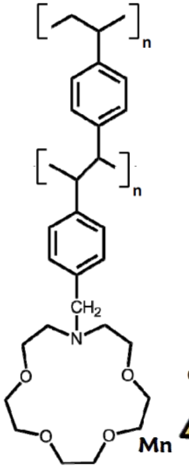


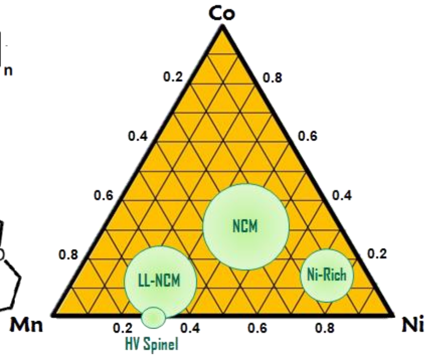


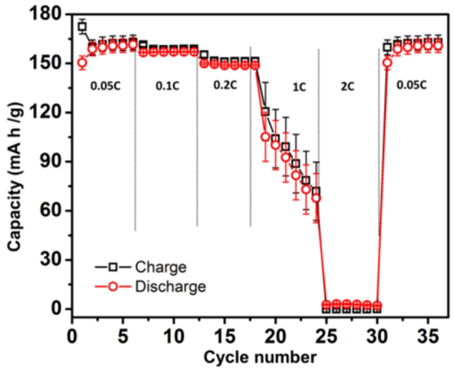












Overview and Progress of Applied Battery Research (ABR) Activities

Peter Faguy

Energy Storage

Hybrid and Electric Systems Team

Overview

The Applied Battery Research portfolio exists to address near-term (< 5 years) opportunities/barriers identified as materials move from R&D to cell construction and validation.

Objectives

- Understand/develop solutions for issues with existing active electrode materials.
- Develop cell chemistries that allow access to higher cell capacity.
- Significantly improve cycle & calendar life.
- Improve battery safety via cell chemistry modification.

Budget

- FY 2013 -- $12.4M
- FY 2014 -- $9.4M + FOA 793 ($16M)*
- FY 2015 -- TBD

* FY2013 funds distributed Q4-2013 for FY2014 – 15

Components

Core (AOP) projects: These leverage significant

- expertise
- infrastructure
- facilities at the national labs

Financial Assistance (FA) projects

- competitively awarded in FY2013
- 2 year projects, FY2014 -- 2015

Barriers

- Existing active electrode materials cannot achieve 200 Wh/kg at the cell level for 40-mile PHEVs.
- Cell chemistries do not yet show high inherent stability towards life and abuse tolerance goals.
- Cell components have yet to enable higher voltage, > 4.2 V, operation.

FA Projects -- Competitively Awarded 2013

Improvements in Cell Composition, Chemistry and Processing

3M	Advanced High Energy Li-ion Cell for PHEV and EV Applications
ANL	New High Energy Electrochemical Couple for Automotive Applications
Envia	High Energy Lithium Batteries for PHEVs
Farasis	High Energy Density Li-ion Cells based On Novel, High Voltage Cathode Material Systems
Penn State	High Energy, Long Cycle Life Lithium-ion Batteries for PHEV Applications
TIAX	High Energy High Power Battery Exceeding PHEV40 Requirements

Program Characteristics:

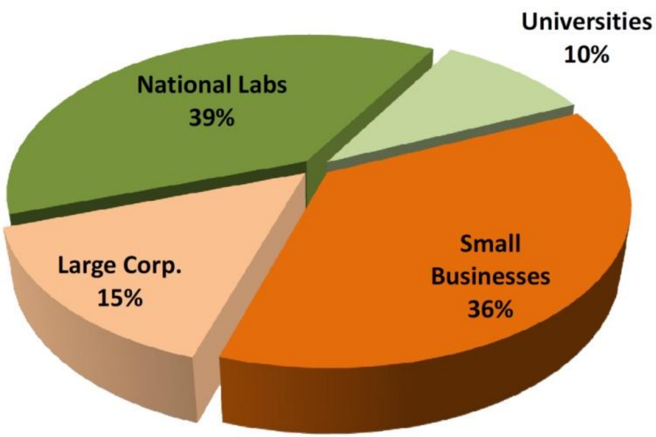
- *Cell chemistry focus*
- *Full cell deliverables—baseline and advanced (~1 Ahr pouch & 18650)*
- *Team-based expertise / workload*
- *24 month duration*
- *10/01/2013 effective start date*

Wednesday Morning
June 18th, 2014

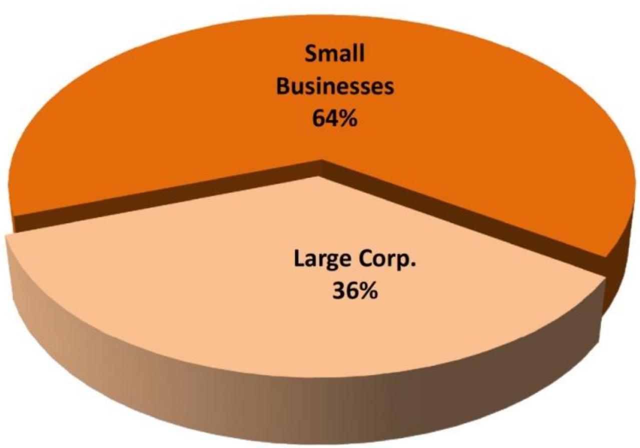
FA Projects -- Competitively Awarded 2013

Improvements in Cell Composition, Chemistry and Processing

DOE Funding ($16.5M)



Cost Share ($2.7M)



Core Programs -- National Lab AOP Projects

Argonne NATIONAL LABORATORY

Core Project: Facility	ANL	Process Development and Scale up of Advanced Cathode Materials	Wednesday Afternoon June 18th, 2014
Core Project: Facility	ANL	Process Development and Scale-up of Advanced Electrolyte Materials	
Core Project: Facility	ANL	Post-Test Diagnostic Activities	
Core Project: Facility	ANL	Cell and Cell Component Activities	
Core Project: Processing	ORNL	Overcoming Processing Cost Barriers of High-Performance Lithium-Ion Battery Electrodes	
Core Project: Processing	ORNL	Roll-to-Roll Electrode Processing and Materials NDE for Advanced Lithium Secondary Batteries	
Core Project: Processing	ORNL	Manufacturability Study and Scale-Up	
Core Project: Abuse Study	SNL	Impact of Materials on Abuse Response	
Core Project: Abuse Study	SNL	Development of Abuse-resistant Electrolyte Components	
Extended Probe & Analysis	ANL	Mitigation of Voltage Fade in Lithium-Manganese-rich Oxide Cathode Materials	Thursday Morning June 19th, 2014
Extended Probe & Analysis	ANL	Characterization of Voltage Fade in Lithium-Manganese-rich Oxide Cathode Materials	

OAK RIDGE National Laboratory

Sandia National Laboratories

Core Project: ANL's CAMP Facility

Argonne NATIONAL LABORATORY

Cell Analysis, Modeling, and Prototyping (CAMP) Facility

- Researchers submit materials with promising energy density
- Small hand-coated electrodes are made
- Coin cells are made and tested

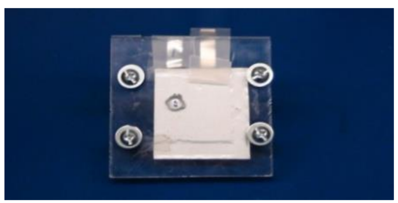
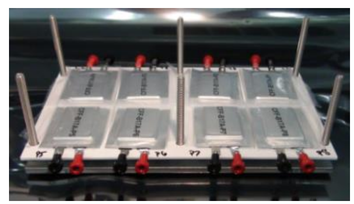
Glove box
Benchtop

ES-030 Jansen

- Larger material samples are obtained (MERF, partnerships, etc.)
- Longer lengths of electrode are made from scaled materials
- Pouch cell or 18650s are made and tested

Dry Room
Pilot scale

- Extensive diagnostics and electrochemical modeling on promising technologies

Battery R&D stakeholders & collaborators utilizing CAMP in 2013 – 2014

TODA AMERICA, SUPERIOR GRAPHITE, SOLVAY, Silatronix, XG sciences, BASF, MILTEC, ARKEMA, SolRayo

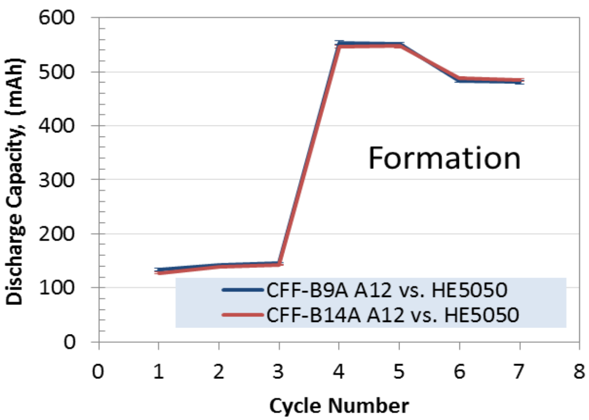
Boulder Ionics, IMRA, JSR Micro, nOHms Technologies, DUPONT, Honeywell, Wildcat Discovery Technologies, EM, ZEON, INVENTEK

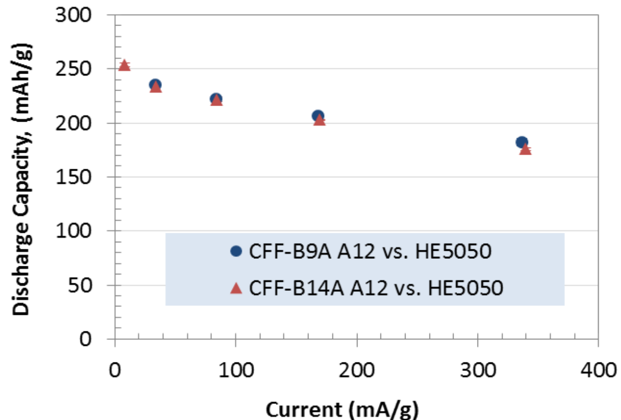
WAYNE STATE, BYU, Cornell University, ILLINOIS, OHIO STATE University, UK Kentucky, IOWA STATE UNIVERSITY, NORTHWESTERN UNIVERSITY, THE UNIVERSITY of WISCONSIN MADISON

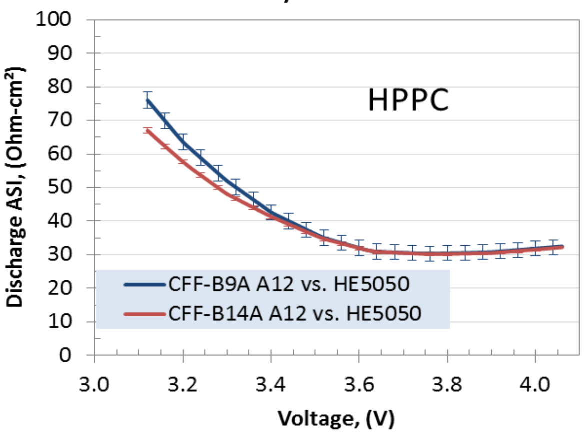
NREL, ARL, JPL Jet Propulsion Laboratory, BERKELEY LAB, Pacific Northwest NATIONAL LABORATORY, OAK RIDGE National Laboratory, INL Idaho National Laboratory, Sandia National Laboratories, BROOKHAVEN NATIONAL LABORATORY

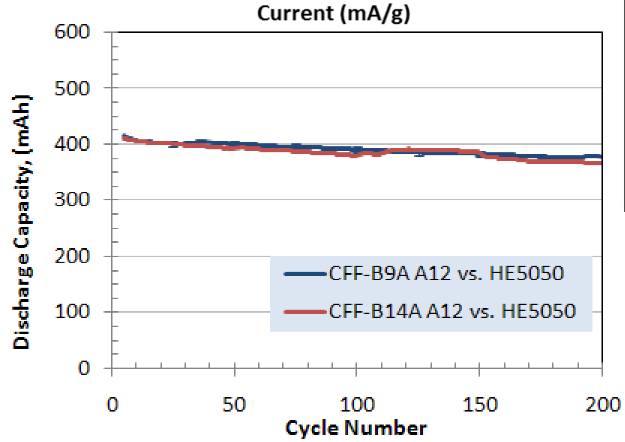
Cell Build Reproducibility Study

A12 Graphite | 1.2M $LiPF_6$ in EC:EMC (3:7 wt.%) | Toda He5050 (LMR-NMC) in xx3450 Pouch Cells









- ***Build 9 duration < 8 weeks***
- ***Build 14 duration ~ 30 weeks***
- ***Same electrode material batches***
- ***Different electrolyte batches***
- ***8 cells in B9A, 4 cells in B14A***
- ***Averaged data trends indicated***
- ***Error bars on all data, all plots***

Materials Engineering Research Facility (MERF)

Two projects funded through VTO Energy Storage

Synthesis and scale-up of organic and polymeric candidates

ES-168 Krumdick

- Electrolyte components – salts, solvents {Li-ion and beyond}
- Polymers – advanced binders, functional electrode and separator components
- Additives – salts, redox shuttles, abuse tolerance, SEI modifiers

Process development and scale-up of advanced cathode materials

ES-167 Pupek

- Target material #2 ($Li_{1.2}Ni_{0.13}Mn_{0.54}Co_{0.13}O_2$) – JPL/UT-Austin
- Target material #3 (layered layered spinel)

Battery R&D stakeholders & collaborators utilizing MERF in 2013 – 2014

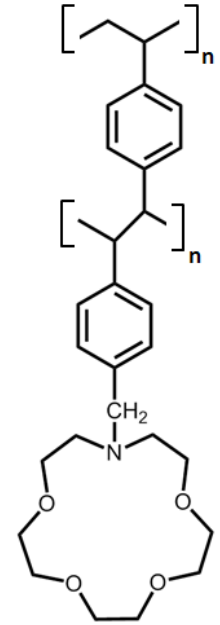
Materials Engineering Research Facility (MERF)

Argonne NATIONAL LABORATORY

Synthesis and scale-up of organic and polymeric candidates

Mn ion getter

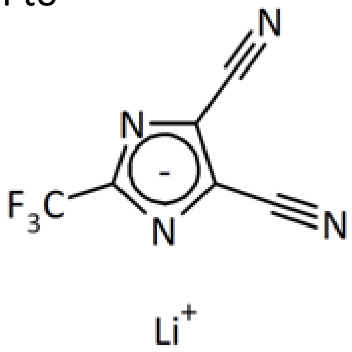
- Rationale: to use tethered chelating agents (crown ethers, cryptands, etc.) to trap—*chelate*—transition metal cations that leach from the positive electrode.
- Polymeric, non-soluble material is to be attached to or incorporated into the separator.



Synthesis and Characterization of LiTDI

(lithium 2-Trifluoromethyl-4,5-dicyanoimidazolide)

- Rationale: many researchers need access to high purity LiTDI to evaluate benefits.
- Role that amount and nature of final impurities play can be scientifically and openly evaluated.

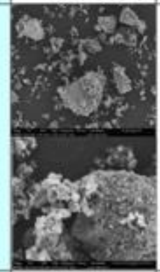
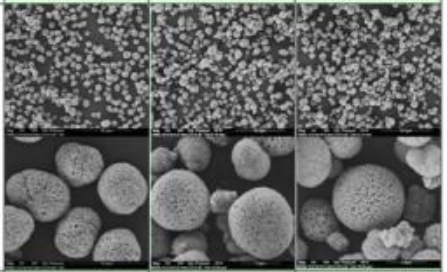


Materials Engineering Research Facility (MERF)

Process development and scale-up of advanced cathode materials

$Li_{1.2}Ni_{0.13}Mn_{0.54}Co_{0.13}O_2$

- High energy Li-, Mn-rich layered, layered transition metal oxide.
- NASA had no source of this material, VTO-ANL provided materials and developed continuous processes to increase tap density.
- Also serves VTO as a baseline cathode material and as a tool to optimize MERF synthesis capabilities.

	JPL/UTA Target Specification	UTA(18 mo.) uncoated	Commercial Scale-up	ES20130924 Scale-up carbonate	ES20131111-1 Scale-up carbonate	ES20131111-2 Scale-up carbonate
		Bench scale	Pre-pilot	Pre-pilot Preliminary 100g delivered	Pre-pilot Production 1 kg delivered	Pre-pilot Production 2 kg delivered
Composition (by ICP)	$Li_{1.5}Ni_{0.1625}Mn_{0.675}Co_{0.1625}O_{2.5}$	$Li_{1.6}Ni_{0.14}Mn_{0.68}Co_{0.18}O_y$	x	$Li_{1.48}Ni_{0.15}Mn_{0.68}Co_{0.17}O_y$	$Li_{1.45}Ni_{0.16}Mn_{0.67}Co_{0.16}O_y$	$Li_{1.47}Ni_{0.16}Mn_{0.67}Co_{0.16}O_y$
SEM x1,000 / SEM x8,000	Uniform spherical morphology		x			
$D_{10}/D_{50}/D_{90}$ [µm]	x	1.2/11.1/29.3	x	4.0/6.7/11.4	3.8/6.4/10.8	3.8/6.3/10.7
Tap density [g/cc]	> 1.50	1.70	1.45 +	1.84	1.68	1.81
Initial disch. gravi. capacity [mAh/g]	> 240	228	223 +	289	299	288
Initial disch. vol. capacity [mAh/cc] **	> 360	388	323	532	503	521

** *Calculated value based on tap density*
+ *Data from SPS Battery KDP meeting (June 25, 2012)*

ANL's Post-Test Analysis Facility

Capabilities

The PTF is capable of systematically studying degradation mechanisms at a multi-scale level. Argonne's unique Post-test Facility has two large connected argon-filled glove boxes with water and oxygen concentrations held below 1 ppm. One glove box is used for the dismantling of cells, both large and small, and the subsequent sample preparation for analysis. Samples are transferred to the second customized glove box (via an air-lock) for XPS, Raman, FTIR and TGA-MS analysis.

Instrumentation

- XPS
- TEM
- Ultramicrotomy
- SEM/EDS/EBSC
- Cross Section Polisher
- Optical Microscopy

- FTIR
- TGA-GC/MS
- Raman
- HPLC-MS
- Metallographic equipment
- Coin cell fabrication and test equipment

Battery R&D stakeholders & collaborators utilizing PTF in 2014

Johnson Controls, ARL, Maxwell Technologies, Oak Ridge National Laboratory, CIC energiGUNE energy cooperative research centre, MILTEC, Argonne National Laboratory, Dalhousie University, JPL, University of Hawai'i, U.S. Department of Energy Energy Efficiency & Renewable Energy

Summary

- Translational (benchtop-to-prototype) R&D in next-generation EDV battery cell composition and construction strongly supports the growth of vehicle electrification in the United States.
- Comprehensive suite of applied R&D activities with substantial resources available to the U.S. battery R&D community through ABR-funded support facilities:
  - full cell calendar, cycling, and abuse performance testing
  - electrode and cell modeling and design
  - materials scale up
  - cell building
  - cell & component diagnostics
- ABR deep-dive focus at ANL
  - Voltage fade results from multiple investigator, multiple research thrust collaborative effort lead to the following
  - Go/No-Go for post treatment/system level fixes
  - 'Working tools' established (test protocols, database, performance metrics)
  - Decisions on tactics toward voltage fade issue
- Process R&D core competency established at Oak Ridge National Laboratory
- Six competitively awarded projects underway:
  - Improvements in Cell Chemistry, Composition, and Processing
  - Team-based
  - Full cell deliverables
  - Ambitious performance goals

For more information …

Contact me

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