Grant Progress Review

Materials and Manufacturing Technologies for High Energy Lithium-ion Batteries

Development of High Energy/Power Electric Drive Vehicles

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ARRA Battery Manufacturing for Electric Drive Vehicles

Presenter

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2012 Merit Review - Electrochemical Storage

Energy Storage R&D

2008 - Materials and Manufacturing Technologies for High Energy Lithium-ion Batteries

Expedite the development of improved Li Ion batteries, and cost effective manufacturing processes conducive to high volume production of Li-ion batteries. Supports national effort to develop PHEV capable of 40 mile electric range

- New High-Energy Anode Materials for Li-ion Batteries
- Li-ion Internal Short Circuit Testing, Modeling, and Mitigation
- More Stable, Less Expensive Electrolyte Salts and Overcharge Shuttles for Li-ion
- Scalable Manufacturing Processes for Li-ion Battery Materials and Components

2011 - Develop Advanced Cells And Design Technology For Electric Drive Vehicle Batteries

Develop high energy or high power Electric Drive Vehicles (EDVs) cells that significantly exceed existing state-of the-art technologies in terms of performance and/or cost. The subtopic areas include extremely high energy cells for use in Electric Vehicles (EVs) and Plug-In Hybrid Electric vehicles (PHEVs) with extended all electric range and high power systems that offer significant performance enhancements & cost reductions over existing technologies for Hybrid Electric Vehicle (HEV) applications.

- Develop Advanced Cells for Electric Drive Vehicle Batteries
- Develop Cells and/or Battery Packs With Significant Cost Improvement
- Improve Cell and/or Battery Pack Inactive Component Designs for Significant Cost Improvement
- Improve Cell and/or Battery Pack Thermal Management Approaches

2009 - Electric Drive Vehicle Battery and Component Manufacturing Initiative

The Recovery Act's purposes are to stimulate the economy & to create and retain jobs. The battery manufacturing area is focused on battery manufacturing plants, material and component supplier manufacturing plants, and recycling plants, including facilities and manufacturing equipment, for Li ion and other advanced batteries for advanced vehicles such as electric drive vehicles

- Cell and Battery Manufacturing Facilities
- Advanced Battery Supplier Manufacturing Facilities
- Combined Applications for Areas of Interest 1 and 2
- Advanced Lithium ion Battery Recycling Facilities

2008 Topics & Awards

DOE share $17,544,081
Total project value $32,620,713

Areas of Interest	Awards
New High-Energy Anode Materials for Li-ion Batteries	**Angstron** - Hybrid Nano Carbon Fiber/Graphene Platelet-Based High Capacity Anodes for Lithium Ion Batteries **Highlight** - Fabricated nano silicon doped carbon nano fibers (CNFs) as substrate and then further coated with silicon by magnetron sputtering technique or Chemical Vapor Deposition (CVD) process. Achieved approximately twice the capacity of the PAN nano fiber base material after 60 cycles (C/5).
New High-Energy Anode Materials for Li-ion Batteries	**NC State** - New High-Energy Nanofiber Materials **Highlight** - Obtained Si/C-C core-shell nanofiber structures by co-electrospinning Si/PAN and PAN precursor solutions *simultaneously, with Si/PAN as the core* and PAN as the shell, followed by carbonization. Half cell data shows greater than 400mAh/gram after 50 cycles(current density 50mA/g)
New High-Energy Anode Materials for Li-ion Batteries	**3M** - Advanced Negative Electrode Materials for PHEVs **Highlight** - 18650 cells built using NMC cathode and V3A/Graphite (silicon alloy) anode in a power-cell design were cycled with a PHEV protocol with 750 charge depleting cycles and ~80% of static capacity was retained.

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Areas of Interest	Awards
Li-ion Internal Short Circuit Testing, Modeling, and Mitigation	**TIAX** - Internal Short Circuits in Lithium-Ion Cells for PHEVs: Modeling of Thermal Runaway Threshold Parameters, Verification in Lithium-Ion Cells **Highlight** - Thermal FEA models for 33Ah cylindrical and prismatic PHEV cells were constructed. Model predictions qualitatively match observed cell response from particle-induced internal short circuit tests. Prototyping facility to fabricate small numbers of high-quality Li-ion cells for internal short testing.
More Stable, Less Expensive Electrolyte Salts and Overcharge Shuttles for Li-ion	**EnerDel** - Chemical Shuttle Additives in Lithium Ion Batteries **Highlight** -ANL-RS2, ANL-RS4, and $Li_2B_{12}F_{12}$ were evaluated. Cells employing ANL-RS2 had long overcharge cycle life, achieving nearly 100 overcharge cycles in cells employing graphite anodes and nearly 400 overcharge cycles in cells employing LTO anodes. Molecular imprinting may play a role in the reduction of the oxidized form of the redox shuttle at carbon anodes.
More Stable, Less Expensive Electrolyte Salts and Overcharge Shuttles for Li-ion	**Sion Power** - Protection of Lithium Anodes Using a Dual Phase Electrolyte **Highlight** - Large format 2.5 Ah cells were manufactured and tested: Cells delivered 2.7-2.9 Ah capacity and Temperature ramp safety tests showed increased thermal stability of Dual Phase Electrolyte cells.

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Areas of Interest	Awards
Scalable Manufacturing Processes for Li-ion Battery Materials and Components	**FMC** - Semi Commercial Production of Stabilized Lithium Powder **Highlight** - – Alternative method production technique development produced material similar with respect to the particle as product produced using traditional dispersion method. Worked continued evaluating Si-based anodes applications with two developers of anode material.
Scalable Manufacturing Processes for Li-ion Battery Materials and Components	**A123** - High throughput manufacturing (fast coating & electrode cutting) **Highlight** - Coating trials were accomplished during the past quarter using treated substrate and coating at 40 and 45 mpm speeds. Performed a trial to determine the potential viability and benefit of an alternative dryer method.
Scalable Manufacturing Processes for Li-ion Battery Materials and Components	**BASF** - Process for Low Cost Domestic Production of LIB Cathode Materials **Highlight** - 2.4Ahr pouch cells were produced by cell partner from pilot plant produced NCM 111 and NCM 424 and tested against a competitive sample in order to determine product quality and performance. Successful scale up of high energy NCM to 100 Kg Lot size.

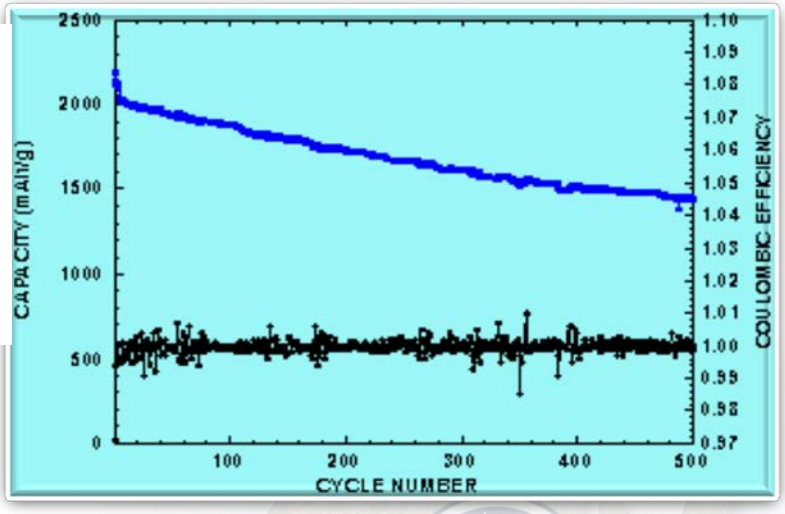
3M

Advanced Negative Electrode Materials for PHEV Lithium Ion Batteries

Discharge capacity for 18650 cells built using NMC cathode and V3A/Graphite anode

	BC618 / V3A & CPG8	
	Discharge Capacity (mAh)	% vs. BOL
BOL	1198	100
RPT1 (250 cycle)	1103	92.1
RPT2 (500 cycle)	1022	85.3
RPT3 (750 cycle)	953	79.5

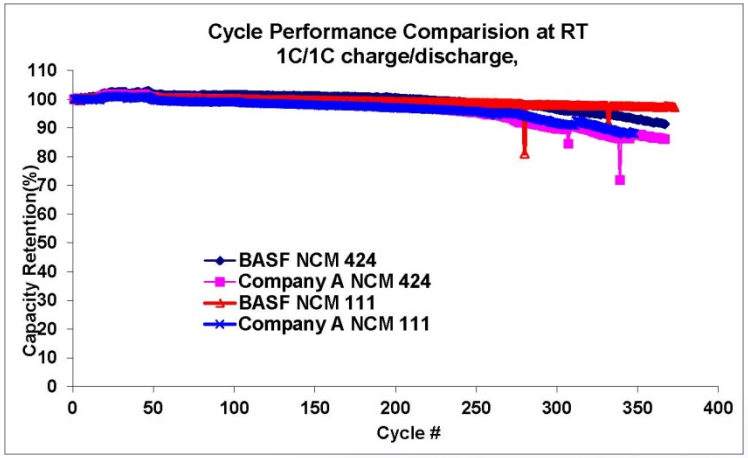
Table 1. Percent Static Capacity decrease after 250, 500 and 750 Charge Depleting Cycles.

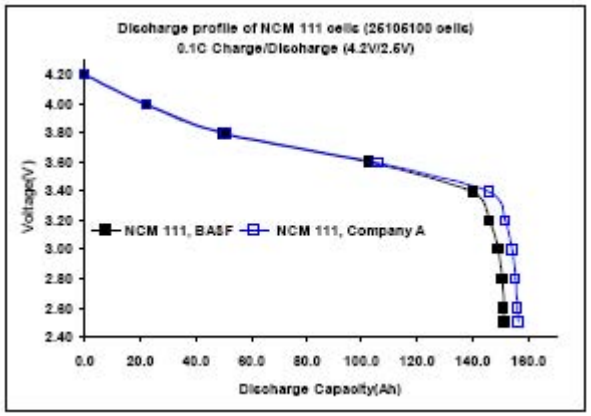


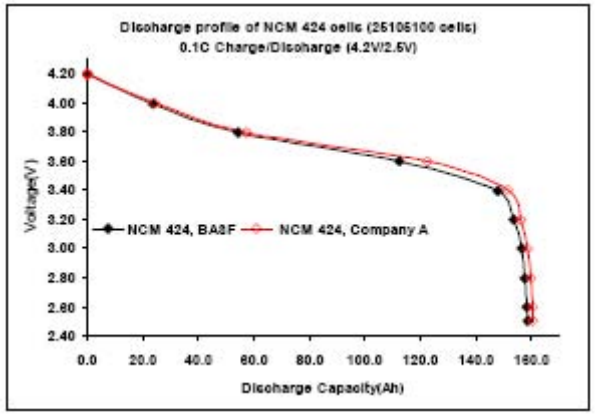
BASF

PROCESS FOR LOW COST DOMESTIC PRODUCTION OF LIB CATHODE MATERIALS

- **Lower cost precursor chemistry in pilot plant at 100Kg size**

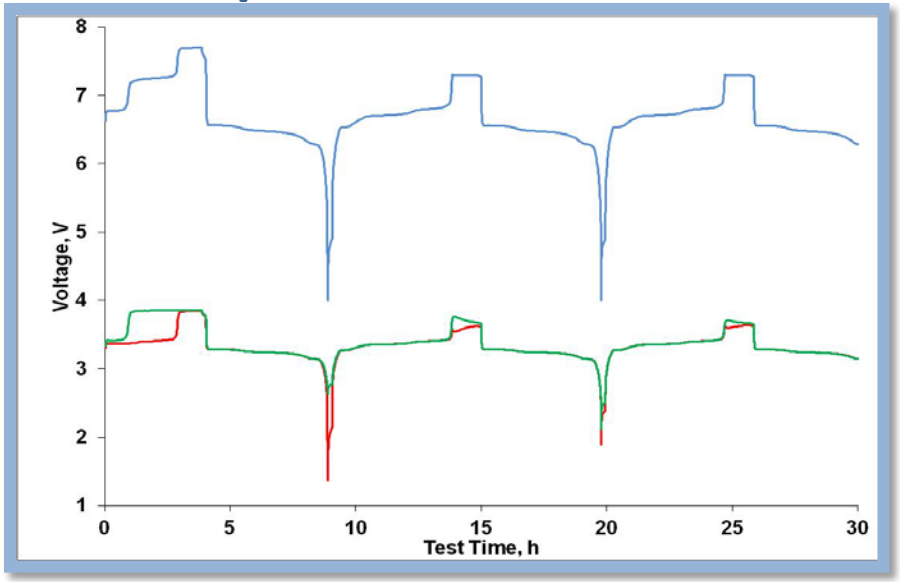




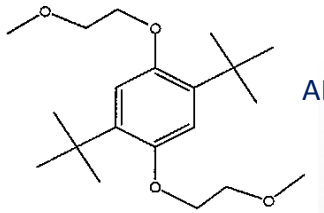


EnerDel

LFP - Graphite Series Cell Rebalancing with ANL-RS2 Redox Shuttle



- Cycle 1: the redox shuttle is activated first in the cell that was initially at 80% SOC, then in the cell that was initially at 40% SOC
- Cycles 2 and 3: the cells are rebalanced
- Without the redox shuttle, the cells do not rebalance (data not shown)



ANL-RS2 from Argonne National Laboratory

- This data is from two cells in series containing electrolyte & ANL-RS2 redox shuttle
- Top blue trace is the series battery voltage
- Bottom traces are individual cell voltages
  - Green trace is the cell initially at 80% state of charge
  - Red trace is the cell initially at 40% state of charge
- ANL-RS2 prevents the overcharge of cells and also rebalances cells
- electrochemically WITHOUT battery management system electronics

2011 Topics & Awards

DOE share $50,112,756 (64%)
Total project value $78,338,585

Areas of Interest	Awards
Develop Advanced Cells for Electric Drive Vehicle Batteries	**Amprius** - Silicon-nanowire based lithium ion batteries for electric vehicles with double the energy density **Highlight –** Working to define performance specifications for various battery components including anode materials, electrolyte and baseline and high energy cathodes. Identifying anode issues, adding anode production capacity, and continuing electrolyte formulation work, including SEI additives. Working with partners on baseline and HE cathodes (BASF) and cell development (Yardney). Partners: Yardney, Nissan, BASF
Develop Advanced Cells for Electric Drive Vehicle Batteries	**Nanosys Inc**. - Innovative Cell and Material Designs for 300 mile EV Range **Highlight –** Anode-specific capacity has been increased up to 700~1450 mAh/g as needed. Targeting 300~500 cycles for the baseline SiNANOde of ~650mAh/g in full cells in Budget Period I. Partners: LG Chem
Develop Advanced Cells for Electric Drive Vehicle Batteries	**Pennsylvania State University** - Development of High-Energy Density Lithium-Sulfur Cells **Highlight –** Demonstrated 1100 mAh/g with sulfur loading of 80% in a carbon-sulfur composite cathode. Coulombic efficiency was around 90% for these electrodes, and capacity retention was 85% after 100 cycles at C/2 rate. Partners: EC Power LLC, Johnson Controls, ANL

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Develop Advanced Cells for Electric Drive Vehicle Batteries	**Applied Materials** - Modular Process Equipment for Low Cost Manufacturing of High Capacity Prismatic Li-Ion Cell Alloy Anodes **Highlight** – Demonstrated 3D anode coating and water soluble process for Graphite coating on 3D anode substrates. Demonstrated rate capability improvement in these anodes. Constructed and performed initial tests on full cells containing 3D alloy anode and standard cathode material. Partners: A123, FMC, Nissan, ORNL, LBNL
Develop Advanced Cells for Electric Drive Vehicle Batteries	**Dow Kokam LLC** - Development of Large Format Lithium Ion Cells with Higher Energy Density Exceeding 500 Wh/L **Highlight** – Reported progress on baseline Model (for cell design) and setting of cell testing protocols with results provided. Vendor supplied silicon based anodes (first of several vendor/partners for silicon based anodes) were obtained and initial testing completed. Completed anode and cathode slurry rheology testing for slot die design requirements. Partner: Wildcat Discovery Technologies, Inc., ORNL
Develop Advanced Cells for Electric Drive Vehicle Batteries	**Seeo Inc.** - High-Voltage Solid Polymer Batteries for Electric Drive Vehicles **Highlight** – Currently working on developing high-voltage stable polymer electrolytes (synthesis work on new chemistries for high-voltage stable polymers) and initial sourcing of high-voltage cathode materials. Partners: Hydro Quebec, LRCS-consultant

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Areas of Interest	Awards
Develop Advanced Cells for Electric Drive Vehicle Batteries	**3M** - High Energy Novel Cathode / Alloy Automotive Cell **Highlight** – Scale up of surface coated cathode material, down select to two primary candidate cathodes, identified new carbon coating technique, demonstrated improve alloy anode performance with carbon type and synthesized a beneficial new Electrolyte additive. Partners: None
Develop Cells and/or Battery Packs with Significant Cost Improvement	**Johnson Controls Inc** – Significant cost improvement of Li-ion cells through Non-NMP electrode coating, direct separator coating, & fast formation technologies **Highlight** – Working closely with partners to have a well-defined approach and working plan Design baseline cell based on Johnson Controls' production cell design. Will use production level JCI pouch cells as baseline cells for the project. additive. Partners: Entek, Maxwell
Develop Cells and/or Battery Packs with Significant Cost Improvement	**Miltec UV International** –Utilization of UV or EB Curing Technology to Significantly Reduce Costs & VOCs in the Manufacture of Lithium Ion Battery Electrodes **Highlight** – Identified binder matrix components, created cathode coatings with good adhesion and low resistance, and also installing new equipment and working to optimize the cathode loading. Partners: Actega Kelstar, ANL, ORNL, A123

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Areas of Interest	Awards
Develop Cells and/or Battery Packs with Significant Cost Improvement	**A123** – Dry Process Electrode Fabrication **Highlight** – They have developed evaluation criteria and begun screening of anode binder materials. The work also includes microstructural evaluation of dry processed cells. Improvement in the mechanical properties of the anode coatings is needed. Partners: Maxwell
Improve Cell and/or Battery Pack Inactive Component Designs for Significant Cost Improvement	**Optodot** – Innovative Manufacturing and Materials for Low Cost Lithium Ion Batteries **Highlight** – Pilot scale ceramic separator coatings produced with initial performance testing completed, including some abuse testing. NMP recycling work initiated. **Partners**: Dow Kokam, University of Rhode Island, Ashland, Madico, Inc.
Improve Cell and/or Battery Pack Thermal Management Approaches	**Denso** - Stand Alone Battery Thermal Management System **Highlight** – Working to create the battery model that will be used, in collaboration with LMS. Worked with Chrysler to obtain battery packs for testing. Signed NDA with NREL. Partners: Chrysler, LLC, NREL,

ARRA Battery Manufacturing for Electric Drive Vehicles - Objective

Establish the supply chain capacity and market entry required for the introduction of the next generation of plug in hybrid vehicles – at volumes required to meet the Administration's goal of 1M PHEV's by 2015.

$1.5B Battery Manufacturing Initiative

Designed to accelerate transition to the next generation of hybrid vehicle transportation

Award Categories:

- Cell and Battery Manufacturing Facilities
- Advanced Battery Supplier Manufacturing Facilities
- Combined applications for first two award categories
- Advanced Lithium ion Battery Recycling Facilities

Battery Lifecycle

2012 Merit Review - Electrochemical Storage

2012 Merit Review - Electrochemical Storage

Raw Materials → Cell Components → Cell Fabrication → Pack Assembly → Recycling

Chemetall Foote Corp. Silver Peak, NV Kings Mtn, NC	**Lithium Carbonate and Hydroxide**
EnerG2, Inc. Albany, OR	**Nano-Carbon for Ultracapacitors and Batteries**
Honeywell Int. Inc. Buffalo, NY Metropolis, IL	**Electrolyte Salt (LiPF6)**
H&T Waterbury Holland, MI	**Aluminum Cell Containers and Cell Parts**
FutureFuel Chemical Co. Batesville, AZ	**Carbon Anode Precursor**

2012 Merit Review - Electrochemical Storage

Raw Materials → Cell Components → Cell Fabrication → Pack Assembly → Recycling

Pyrotek Inc. Sanborn, NY	**Graphitization of Carbon Anode Material**
BASF Catalysts, LLC Elryria, OH	**Low Cost Cathode Materials**
Novolyte Tech. Inc. Zachary, LA	**Lithium Ion Electrolyte Solutions**
Celgard, LLC Charlotte, NC	**Polymer Separator Material**
Toda America Inc. Goose Creek, SC	**Lithium Ion Cathode Materials**

2012 Merit Review - Electrochemical Storage

Raw Materials → Cell Components → Cell Fabrication → Pack Assembly → Recycling

Johnson Controls Holland, MI Milwaukee, WI Lebanon,OR	Cell Production, Pack Assembly, Separator Production
A123 Systems, Inc. Livonia, MI Romulus, MI Hopkinton, MA	Nanophosphate Cathode, Cell Fabrication, Complete Battery Systems
LG Chem, MI Holland, MI	Lithium Ion Polymer Cells
DOW Kokam, MI LLC Midland, MI	Lithium Ion Polymer Batteries
EnerDel Inc. Indianapolis, IN	Lithium Ion Cells, Modules and Packs

2012 Merit Review - Electrochemical Storage

Raw Materials → Cell Components → Cell Fabrication → Pack Assembly → Recycling

Saft America Inc. Jacksonville, FL	Lithium Ion Cells, Modules and Batteries
General Motors LLC Brownstown, MI	Automotive Battery Pack
East Penn Mfg. Co. Lyon Station, PA	Valve Regulated Lead-Acid Batteries & the UltraBattery
Exide Tech. Bristol, TN Columbus, GA	Absorbed Glass Mat (AGM) Lead Acid Batteries
TOXCO Inc. Lancaster, OH	Recycling of Lithium Ion Batteries

2012 Merit Review - Electrochemical Storage

FutureFuel's
site construction (top right image), and additions to their tank farm (top and bottom left images)

2012 Merit Review - Electrochemical Storage

Pyrotek's 93,000 square foot addition to an existing facility in Sanborn, NY.

2012 Merit Review - Electrochemical Storage

EnerG2's new battery materials plant in Albany, Oregon. Early site construction photo above, and adjacent photo is of their Ribbon Cutting Ceremony on February 13, 2012.

2012 Merit Review - Electrochemical Storage

Construction Progress as of October 2010

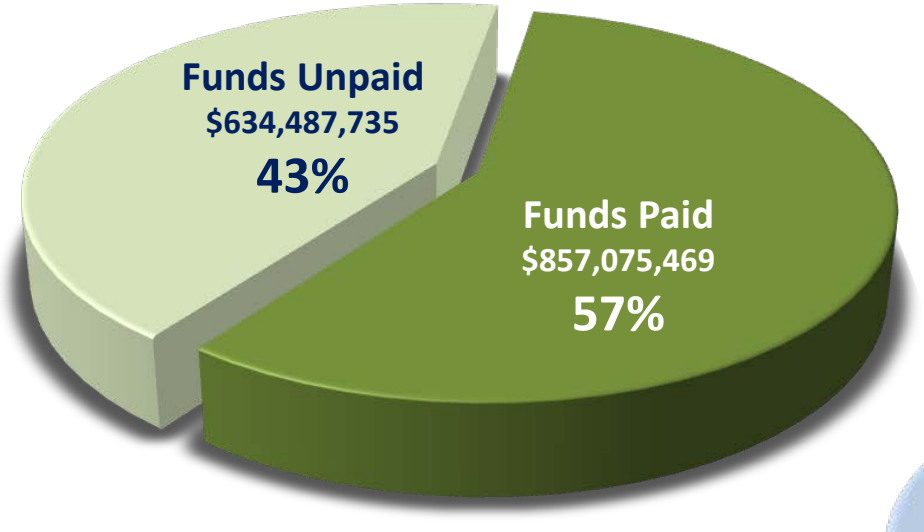
LG Chem Michigan's 850,000 ft2 manufacturing facility located in Holland, MI

Construction Progress as of April 2011

Chemetall Foote's

Salt Harvester and drill rig in Silver Peak, NV are featured in the above image, and also tank farm construction at their Kings Mountain, NC site in the adjacent image.

Program Summary



Funds Payments

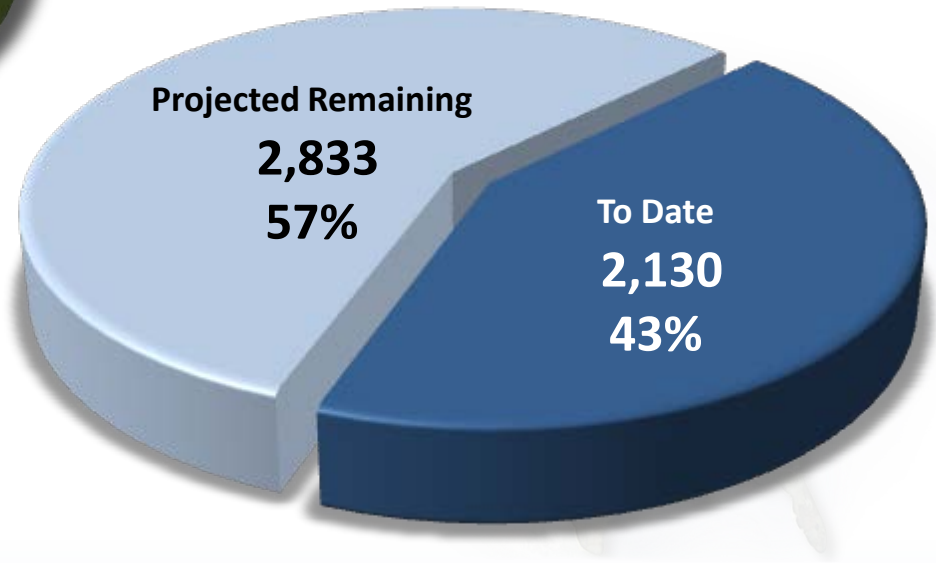
as of 1/31/2012

Total Planned Payments by End of All Projects: $1.491B

Direct Jobs Status

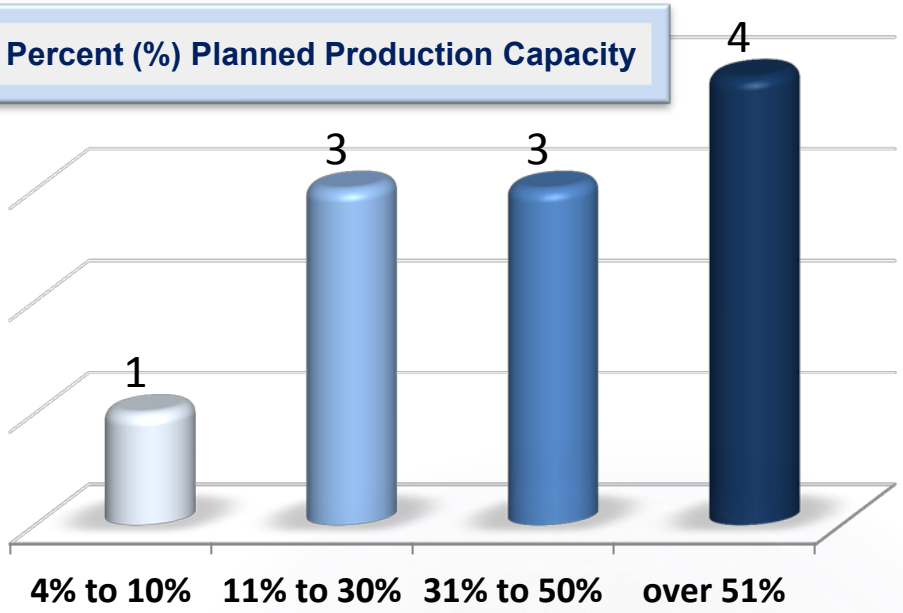
as of 12/31/2011

Total Direct Jobs Planned by End of All Projects: 4,963



Battery Projects with Production Capacity as of 12/31/10

11 Out of 20 Projects Are Already Reporting Production Capacity

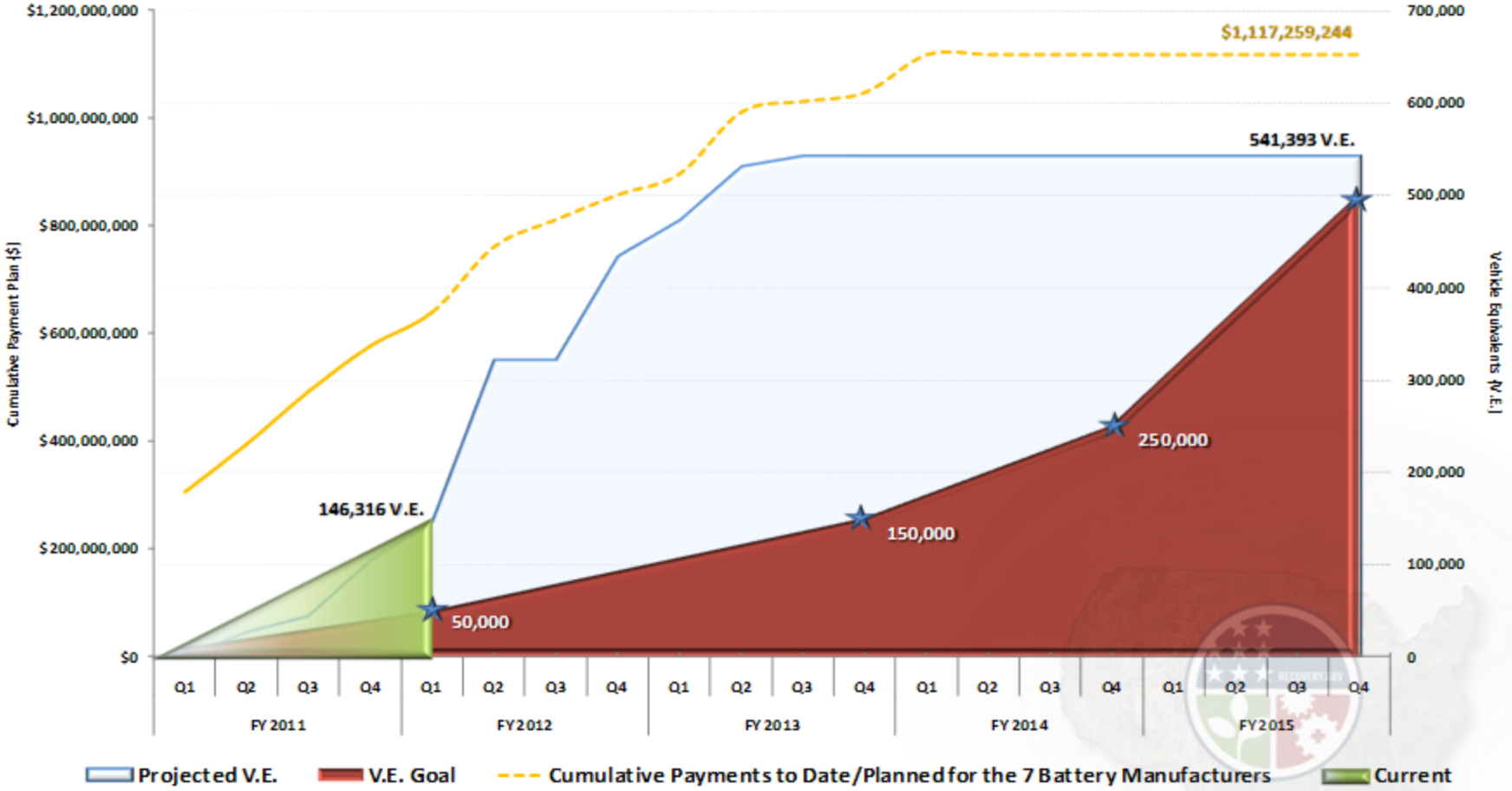


Projects in Pre-Production Phase

Projects with Production Capacity

Production Capacity HPPG

Vehicle Equivalent is based on a 10-kWh battery



The Capacity for Electrical Components and Battery Manufacturing is based on a 10 kWh Battery Equivalent Capacity. This supports DOE's goal of a 500,000-vehicle annual cell and battery pack production capacity by FY 2015.

2012 Merit Review - Electrochemical Storage

•The DOE directly supports President Obama's goal of making the United States the first country in the world to put one million advanced technology vehicles on the road. Just a few years ago, the United States produced less than two percent of the world's advanced batteries. By 2015, the United States will have the capacity to produce enough batteries and components to support 500,000 plug-in hybrid and electric vehicles.

•Through the Recovery Act, the Department of Energy has invested $2.4 billion dollars to help the U.S. compete in the electric drive vehicle and component manufacturing industry. The Battery Projects are progressing on schedule with planned construction, manufacturing goals, and spending plans.


Questions ?
RECOVERY.GOV