Process for Low Cost Domestic Production of LIB Cathode Materials

Project ID # ES013

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BASF Catalysts, LLC
June 8, 2010

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Overview

Timeline
• Project Start – February 2009
• Project End – June 2012
• 30% Complete

Budget
• $5.0 Million Award
  • 50% DOE ($2.5M)
  • 50% BASF ($2.5M)
• FY09 Funding Received = $ 472K
• FY10 Funding Expected = $ 890K

Barriers
• Reduce the production cost of Cathode Material
• Meet PHEV battery requirements for a 40 mile all-electric range
• Enable cost competitive market entry into electric vehicles by 2014.

Partners
• Farasis Energy Inc, Hayward CA
  • Production of 18650 Cells
  • Cell design/modification guidance
Objective

Successfully produce two cathode materials, suitable for electric vehicle application, (HEV,PHEV, EV), using BASF’s existing assets and low cost production process. Validate that cost and quality targets are met via coin cells, pouch cells and 18650 cells, with final incorporation into a battery pack for complete testing and extensive material characterization. Work closely with a Tier I auto supplier and/or auto OEM to insure that the products meet required specifications and expectations.
BASF has a low cost production process for Li ion battery cathode materials. In this project, the cathode materials developed in the laboratory will be scaled-up in a pilot plant and finally produced in a production plant at a few ton levels. BASF will work with a sub-contractor, Farasis Energy, Inc. (Hayward, California) to make and test 18650 cells and commercial partners such as automotive OEMs and Tier I suppliers to validate BASF’s cathode materials and finally test a Li ion battery pack containing BASF’s cathode materials. BASF will use its production and R&D facilities in the US for this project. When successful, this project will strengthen BASF’s position as a US based LIB cathode material supplier for the global market and provide an assurance of quality and supply to US consumers.
Approach

- Selection of preferred starting materials
- Combined with intimate and uniform blending
- Reduction of calcination time by utilization of advanced processing
- Finish processing as needed
Current Process changes have resulted in reduced processing time and increased potential production capacity while maintaining product performance.

BASF-1 is a standard laboratory synthesis, BASF-2 represents process improvements in the lab and BASF-3 is a Pilot Sample incorporating some of the lab process improvements.

<table>
<thead>
<tr>
<th></th>
<th>1st Charge mAh/g</th>
<th>Variation (+/-)</th>
<th>1st Discharge mAh/g</th>
<th>Variation (+/-)</th>
<th>Coulombic Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASF-1</td>
<td>167.11</td>
<td>0.56/0.65</td>
<td>148.49</td>
<td>0.77/0.64</td>
<td>88.9%</td>
</tr>
<tr>
<td>BASF-2</td>
<td>169.70</td>
<td>1.40/0.60</td>
<td>150.16</td>
<td>1.40/0.60</td>
<td>88.5%</td>
</tr>
<tr>
<td>BASF-3</td>
<td>196.94</td>
<td>1.10/0.60</td>
<td>151.32</td>
<td>0.60/0.90</td>
<td>89.0%</td>
</tr>
</tbody>
</table>
Technical Accomplishments & Progress
NCM-111 Rate Capability vs. Process

Cell type: Coin cell
Cathode: BASF NCM
Anode: Li
Charge: 4.3V, CC, 0.2C
Discharge: 3.0V, CC, various
Temperature: room temperature

Discharge Capacity (mAh/g)

- BASF-1
- BASF-2
- BASF-3

Rate (C)

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Technical Accomplishments & Progress

NCM-111 Capacity vs. Process

Cell type: Coin cell
Cathode: BASF NCM
Anode: Li
Charge: 4.3V, CC, 0.2C
Discharge: 3.0V, CC, various
Temperature: room temperature

Specific Capacity (mAh/g)

Cycle No.

BASF-1
BASF-2
BASF-3
Technical Accomplishments & Progress
NCM-111 Pouch Cell Data

Cell type: Pouch cell
Cathode: NCM 111 (high loading weight)
Anode: Graphite
Charge: 4.2V, CCCV, 0.5C
Discharge: 2.7V, CC, 0.5C, 100% DOD
Temperature: room temperature

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Technical Accomplishments & Progress

Next Materials for Evaluation - NCM-A and NCM-B

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Charge mAh/g</th>
<th>Discharge mAh/g</th>
<th>Columbic Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCM-A</td>
<td>186.85</td>
<td>164.53</td>
<td>88.1%</td>
</tr>
<tr>
<td>NCM-B</td>
<td>180.30</td>
<td>155.15</td>
<td>86.1%</td>
</tr>
<tr>
<td>NCM-B2</td>
<td>176.09</td>
<td>156.07</td>
<td>88.6%</td>
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</table>

NCM-A has better initial discharge capacity and slightly better columbic efficiency but presents some processing difficulties in scale-up from the lab to pilot plant.

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Technical Accomplishments & Progress
NCM-A and NCM-B – Rate Comparison

Discharge Capacity (mAh/g)

Rate (C)

Cell type: Coin cell
Cathode: BASF NCM
Anode: Li
Charge: 4.3V, CC, 0.2C
Discharge: 3.0V, CC, various
Temperature: room temperature

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Technical Accomplishments & Progress
NCM-A - Effect of Li/Metal ratio

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>1st Charge mA/h/g</th>
<th>1st Discharge mA/h/g</th>
<th>Columbic Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCM-A-113A</td>
<td>190.52</td>
<td>161.36</td>
<td>84.7%</td>
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<tr>
<td>NCM-A-113B</td>
<td>191.13</td>
<td>163.41</td>
<td>85.5%</td>
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<tr>
<td>NCM-A-113C</td>
<td>191.01</td>
<td>166.36</td>
<td>87.1%</td>
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<tr>
<td>NCM-A-113D</td>
<td>187.50</td>
<td>167.31</td>
<td>89.2%</td>
</tr>
<tr>
<td>NCM-A-008A</td>
<td>188.12</td>
<td>161.47</td>
<td>85.8%</td>
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Optimization of Lithium Stoichiometry helps reduce raw material costs and improves post processing efficiency.
Increased Li/metal ratio yields better rate capability…To a break point at 113D

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### Milestone Timeline

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Milestone or Go/No-Go Decision</th>
</tr>
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<tbody>
<tr>
<td>Sept - 09</td>
<td>Milestone: Establish lab synthesis process of NCM up to 5 kg level to determine baseline performance</td>
</tr>
<tr>
<td>June - 10</td>
<td>Milestone: Complete pilot plant synthesis of NCM up to 100 kg level, Go/No-Go: Confirm product quality meets or exceeds lab produced sample.</td>
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<tr>
<td>Oct - 10</td>
<td>Milestone: Establish lab synthesis procedure for advanced cathode material – Prepare 5kg sample and determine baseline performance Go/No-Go: Confirm acceptable product quality and cost are achieved prior to Pilot Phase</td>
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<td>Dec - 10</td>
<td>Milestone: Begin Pilot Phase for advanced cathode material</td>
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### Task Table

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Synthesis NMC at lab scale process - 5kg</td>
<td></td>
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<td>2</td>
<td>Produce NMC at Pilot Plant - 100 kg</td>
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<td>3</td>
<td>Produce NMC at Plant Level - 1MT</td>
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<td>4</td>
<td>NMC Production Go/No Go</td>
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<tr>
<td>5</td>
<td>Synthesis of LFP at lab scale process - 5kg</td>
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<tr>
<td>6</td>
<td>Produce ACM at Pilot Plant - 100 kg</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>ACM Production Advancement Go/No Go</td>
<td></td>
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<tr>
<td>8</td>
<td>Design, Fabricate and test 18550 cells</td>
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<td>9</td>
<td>LIB Prototype Pack Production</td>
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<td>10</td>
<td>Commercial Production of Low Cost CatMat</td>
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<tr>
<td>11</td>
<td>LIB Prototype delivered to DoE Auto OEM</td>
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Collaboration

Farasis Energy Inc
23575 Cabot Blvd.
Suite 205-206
Hayward, CA 94545

Assembly and testing of 18650 cells and packs from BASF produced NCM cathode materials

Provide guidance for design modifications in order to meet customer requirements

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2010 Project Objectives

- Complete Pilot Production Trials for NCM 111, NCM-A and NCM-B
  - Validation of BASF Process
  - Cost analysis for Production
  - Customer evaluation and validation
- NCM production at Plant level
  - Starting Q1 2011
- Initiate advanced cathode material lab phase in Q3-Q4 2010
  - Pilot Trials for advanced cathode material to begin in Q1 2011
Today the competitive landscape for Cathode Materials is dominated by Asian companies where the primary applications are consumer electronics and power tools.

The development of a low cost Cathode Material process for lithium ion batteries for application in all electric vehicles (HEV, PHEV, EV) is BASF’s objective. To do this, BASF will leverage it’s license from Argonne National Labs, existing US assets, technological expertise and years of production experience to make this a reality.
Acknowledgment: "This material is based upon work supported by the Department of Energy [National Energy Technology Lab under Award Number DE-EE0000563]."

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