Expanding U.S.-based Lithium-ion Battery Manufacturing

P.I.: Robert Kamischke
EnerDel, Inc.
May 2013
Project ID: ARRAVT003

This presentation does not contain any proprietary, confidential or otherwise restricted information.
Overview

**Timeline**

- Start January 2010
- End April 2014
- > 91% Complete (Phase I)

**Budget**

- Total Project Funding $236 M
  - DOE - $118 M
  - EnerDel - $118 M
- Funding Received FY 2012: $62 M

**Barriers**

- Lagging Customer Demand
- Financing
- Long Development Cycle(s)

**Partners**

- Equipment Suppliers
- EV Partners (Volvo, HHI, ATC)
- Purdue University
- USABC
Objectives - Relevance

• Develop competitive mass production capability for Lithium-ion battery cells & battery pack systems
  – Vertically integrated cell fabrication through pack assembly
  – Create domestic manufacturing capacity & skilled workforce

• Enhance supply chain & competitiveness of base materials
  – Develop and qualify domestic & international material suppliers
  – Improve performance, cost, & availability
Objectives - Relevance

• Position EnerDel as a tier-one transportation supplier of advanced Lithium-ion battery pack systems
  – Implement APQP product development framework
  – Meet standards and acquire industry certification
  – Qualify manufacturing systems
Approach

• Scalable facility footprint
  – Adapt & upgrade existing cell fabrication site
  – Acquire a new mixed-use manufacturing facility

• Achieve maximum leverage of process infrastructure
  – Achieve break-through process cycle times to minimize equipment & people footprint
Approach
Approach

• “Seed” initial capacity installation; scale upon customer acquisition
  – Design-in batch & serial production build capability
  – Flex capacity with manpower/line-shifts
  – Address system bottlenecks as needed
  – Develop capability to process alternative source rolled or cut electrode materials
    • Develop material packaging & storage methods
Approach

• Layout and automation guidelines
  – Follow lean manufacturing principles
  – Focus automation on Key Product (KPC) and Special Process Characteristics (SPC)
  – Flex through-put with manpower +/-
Approach

• Tool to one standard form factor for cell
  – Adjust chemistry or electrode content to specialize cell characteristics
  – High capacity, mid-power, and high power models

• Tool to one standard form factor for battery module
  – Standardized stack-up from cell to element to module

• Customize for applications at pack level
## Technical Accomplishments/Progress

### Manufacturing Start-up

<table>
<thead>
<tr>
<th>Facility II</th>
<th>Acquire</th>
<th>Install</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode</td>
<td>3 mos.</td>
<td>1 mos.</td>
<td>2 mos.</td>
</tr>
<tr>
<td>Cell Assy</td>
<td>14 mos.</td>
<td>2 mos.</td>
<td>2 mos.</td>
</tr>
<tr>
<td>Formation</td>
<td>7 mos.</td>
<td>2 mos.</td>
<td>7 mos.</td>
</tr>
<tr>
<td>Module/Pack</td>
<td>9 mos.</td>
<td>3 mos.</td>
<td>3 mos.</td>
</tr>
</tbody>
</table>
Technical Accomplishments/Progress

• Cell manufacturing
  – Production approval for EnerDel’s first Lithium-ion cell mass production system
  – Cell Validation phase Overall Equipment Effectiveness (OEE) improvement

High Capacity Cell

Mid-Power Cell
## Technical Accomplishments/Progress

- Production Validation: Model Types & 2\textsuperscript{nd} Material Sources

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Model</th>
<th>DS Anode</th>
<th>SS Cathode</th>
<th>DS Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Korea</td>
<td>US</td>
<td>Korea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Notched</td>
<td>Die-Cut</td>
<td>Notched</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laser Cut</td>
<td></td>
<td>Laser Cut</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material Validation - 2nd Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/Oxide</td>
</tr>
</tbody>
</table>

---

**EV-Capacity**

- A
- D
- E
- E1
- F
- F1
- G
- G1
- H
- H1
- J
- J1
- K
- K1
- K2

**PHEV-Mid Power**

- K
- K1
- K2
Technical Accomplishments/Progress

• Production validation cell cycling test results

High Capacity Cell – Standard Cycling

• Passed cycling test acceptance criteria
Technical Accomplishments/Progress

- Production validation cell cycling test results

Mid-Power Cell – Standard Cycling

- Acceptance pending test completion – on track
Technical Accomplishments/Progress

• Module & pack manufacturing
  – Capacity ramped in 6 months to 17k equivalent EV Packs
  – Packs in customer use
Collaborations/Partnerships

- Strategic alliances result in the most advanced solutions as technology and infrastructure evolve
Future Work

VT Grant (EE-002724) Project Plan: Phase I Extension Request of January 2013

<table>
<thead>
<tr>
<th>Event</th>
<th>2012 Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>2013 Calendar Year</th>
<th>2014 Calendar Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>EnerDel Power Cell: Prototype Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel Power Cell: PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel Power Cell (PV) Cycling Test/PPAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel 18 Ah PHEV II Cell: Prototype Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel 18 Ah PHEV II Cell: PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel 18 Ah PHEV II Cell: (PV) Cycling Test/PPAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel 22 Ah PHEV III Cell: Prototype Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel 22 Ah PHEV III Cell: PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnerDel 22 Ah PHEV III Cell: (PV) Cycling Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Electrolyte - PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Electrolyte - Cycling Test/PPAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Separator - PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Separator - Cycling Test/PPAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Mixed Oxide - PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Mixed Oxide - Cycling Test/PPAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Graphite - PV Build</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material Supplier Graphite - Cycling Test/PPAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validate Cell Assy Line #3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validate Cell Assy Line #4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validate Anode Laser System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validate Cathode Laser System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specify/Source/Qualify Alternate Cutting System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remedy Faults in Manufacturing Enterprise System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Provisional based on laser system validation
## Summary Performance

<table>
<thead>
<tr>
<th>Objective</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Facilities for LIB Production</td>
<td>in-place</td>
</tr>
<tr>
<td>Qualified LIB Mfg’ing System</td>
<td>on-track</td>
</tr>
<tr>
<td>Qualified/Trained Mfg’ing Staff</td>
<td>on-track</td>
</tr>
<tr>
<td>Domestic Raw Material Suppliers</td>
<td>on-track</td>
</tr>
</tbody>
</table>