Low-Cost U.S. Manufacturing of Power Electronics for Electric Drive Vehicles

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## Project Overview

### Timeline
- **Start:** January 2010
- **Finish:** December 2012
- **Approx. 35% complete** (through Feb 2011)

### Barriers
- **Limited supply of technical resources**
  - Technical training and experience with high-voltage, high-current (power) electronics
- **Market demand for EDVs sensitive to:**
  - Unstable/unpredictable fuel prices
  - U.S. policy incentives for EDVs and U.S. sourcing

### Budget
- **Total project funding**
  - DOE: $89.3M
  - Contractor: $89.3M
- **DOE funding to date**
  - As of Feb/11: $31.6M

### Collaborators
- **Project Lead:** Delphi
- **Vehicle OEMs:** GM, Coda Automotive, others
- **Powertrain OEM Customers:** Allison
- **Suppliers:** power silicon, capacitors, etc.
  - 145 qualified for power electronics (68 U.S.)
Collaborators

- Vehicle OEM Customers
  - E.g. GM, Coda Automotive

- Powertrain OEM Customers
  - E.g. Allison Transmission

- Suppliers
  - Silicon, capacitors, circuit boards, castings, magnetics, etc.
  - 561 total qualified suppliers to Delphi
  - 145 in use for Power Electronics (68 U.S. based)

- State of Indiana – incentives offered
  - EDGE Tax Credit over ten-year period
  - Skills Enhancement Fund support over two-year period

- City of Kokomo, Indiana – incentives offered
  - Personal Property Tax Abatement – five years on manufacturing equipment and special tooling – approved by City Council on 26Apr2010
  - Revolving Loan Fund
  - Workforce development support
Relevance: Lower-cost power electronic products enable expansion of U.S. demand for EDVs
Relevance: Establishes U.S. power electronics production capacity

◆ Build upon Delphi’s core capabilities
  – Rapid, concurrent product/process design optimization for production
  – Testing for validation
  – Power electronics product line
    » Inverters, converters, chargers, controllers, energy storage systems

◆ Establish a globally competitive, U.S.-based production source for power electronics
  – Automobiles
  – Commercial vehicles
  – Off-road / industrial equipment

Delphi’s Power Electronics Manufacturing Site
Kokomo, Indiana
Relevance: Provides a commercial path for future power electronics technology

– October 2007 –
Delphi Awarded $8.2M DOE program for Development, Test and Demonstration of a Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Propulsion Inverter

– November 2009 –
Delphi Awarded $8.4M DOE program to develop GaN devices for HEV/PHEV/EV/FCV
Approach: Apply more than 20 years of Delphi experience with EV and HEV technology

- Largest North American supplier for HEV power electronics components and energy management systems
- HEV propulsion architects for multiple vehicles
- More than 100 relevant patents issued since 2000
- Focusing on aggressively lowering the cost of powertrain electrification
  - System design and architecture
  - Component design and development
  - Controls and algorithm development
  - Design for manufacturability

The Result – Higher Market Use of Energy-reducing EV and HEV Technology in Transportation
Approach: Use wide array of Delphi EV/HEV component and system development tools

- Heat Exchanger
- Fluid Dynamics Modeling
- System Dynamometers
- Power Module
- Thermal FEA
- DC Bus Structure
- Q3D Inductance Modeling
- Vehicle Integration
- Vehicle Modeling and Simulation
Approach: Build Upon Delphi’s Extensive Validation Test Capability

Performance / Temperature
Tri-Temperature
Thermal Shock

EMI / EMC
• Emissions
• Susceptibility
• Immunity

Mechanical Test

Vibration +
Thermal Shock

Environmental
• Humidity
• Dust
• Corrosion
• Humidity

Highly Accelerated Life Test

Powered Temperature Cycling
Approach: Employ Delphi’s Value-Add

◆ Cost Efficiency
  – Delphi understands automotive cost challenges and price competition
  – Delphi leverages a large supplier base and technology building blocks to create affordable products, through volume production with economies of scale

◆ Innovation
  – Invention applied to high-volume production
  – Proprietary IGBT technology
  – Solving the problems of thermal management and packaging for transportation

◆ Proven Reliability
  – Delphi track record of single-digit PPM production of automotive power electronics and energy storage systems
Approach: 
Target Work in Three Major Areas

- Optimize Delphi’s power electronics component and system designs for volume production
  - Automotive vehicle manufacturers
  - Commercial vehicle manufacturers
  - Off-road/industrial equipment and vehicle manufacturer/customers

- Retrofit existing and install required new equipment and tools

- Validate the readiness of Delphi’s component and system designs for production
Approach: Use Delphi’s Product Development Process
Accomplishments:
New Power Electronics Production Facility

◆ Progress (April 2010 – March 2011)
  – First product validation build (May 2010)
  – First production started (July 2010)
  – ISO/TS 16949 Quality Management System Certification (Number: TS 567383) achieved for new facility and remote support services (Sept 27, 2010)
  – Installed additional test capacity for DC/DC converter (Jan 19, 2011)
  – Completed validation lab construction, and began testing inverters (Feb 5, 2011)
  – Installed a Nitrogen on-demand generator system (March, 2011)
  – Successfully passed a new customer run-at-rate (Feb 17, 2011)

◆ Additional achievements expected through 2011
  – Establish new engineering office area (April, 2011)
  – First pre-design proto builds scheduled for converters and inverters (Q3)
  – First flexible final assembly & test area installed (Q3)
  – Recertification of TS 16949 & ISO 14001 (Q4)
Accomplishments: Chargers 100/220 AC to DC

- **Progress (April 2010 – March 2011)**
  - Customer development activity continues in North America, Europe and Asia (focus on PHEV chargers)
  - Evolving market requirements dictated product design changes

- **Additional achievements expected through 2011**
  - Anticipate initial customer commitment
  - First low-volume samples produced in controlled process environment
Accomplishments: Passenger Car Inverters

**Progress (April 2010 – March 2011)**
- Customer units delivered for motor calibration (Nov 2010)
- First reliability evaluation successfully completed (Jan 2011)
- Validation equipment delivered and installed (March 2011)
- Second design turn build complete (March 2011)

**Additional achievements expected through 2011**
- Second design turn reliability testing will be started
- Customer vehicle testing will be started
- Initial compliment of production equipment ordered / installation started
Accomplishments: Commercial Vehicle Systems

◆ Progress (April 2010 – March 2011)
  – First inverter drove a motor (April 2010)
  – First complete customer system delivered (July 2010)
  – First reliability evaluation completed (October 2010)
  – First vehicle test complete with inverter, converter and battery system (Feb 2011)

◆ Additional achievements expected through 2011
  – First reliability testing will start for the battery controller, commercial converter, commercial inverter and commercial battery system
  – Multiple customer deliveries will occur
Accomplishments: Passenger Car DC-DC Converters

◆ Progress (April 2010 – March 2011)
  – First process confirmation build completed (June 2010)
  – Validation build and testing completed (Sept 2010)
  – First production shipment to a China customer (Oct 2010)
  – First production shipments to two European customers (Feb 2011)

◆ Additional achievements expected through 2011
  – Continue sales activity to expand production volume
Accomplishments:
Estimated Number of Jobs Created / Retained

This project has resulted in 127 jobs *directly* created or retained at Delphi (as of 31Dec2010) and many more U.S. jobs indirectly.

<table>
<thead>
<tr>
<th>U.S. Jobs Created or Retained</th>
<th>DOE's 50% Cost-Share</th>
<th>Delphi's 50% Cost-Share</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delphi Direct FTEs (ARRA Reported FTEs)</td>
<td>63.6</td>
<td>63.6</td>
<td>127.3</td>
</tr>
<tr>
<td>Delphi Indirect/Support FTEs</td>
<td>31.8</td>
<td>31.8</td>
<td>63.6</td>
</tr>
<tr>
<td>Subtotal Delphi</td>
<td>95.4</td>
<td>95.4</td>
<td>190.9</td>
</tr>
<tr>
<td>Est. Suppliers' FTEs (1.036 x Delphi) *</td>
<td>98.9</td>
<td>98.9</td>
<td>197.8</td>
</tr>
<tr>
<td>Est. Indiana Community FTEs (1.049 x Delphi) *</td>
<td>100.1</td>
<td>100.1</td>
<td>200.2</td>
</tr>
<tr>
<td><strong>Est. Total Jobs Created / Retained</strong></td>
<td><strong>294.4</strong></td>
<td><strong>294.4</strong></td>
<td><strong>588.9</strong></td>
</tr>
</tbody>
</table>

Future Work: FY12 & FY13

Determination of Project Success

☑ An ISO/TS16949 quality certified U.S. power electronics production facility

☑ A world-class U.S. skilled workforce at Delphi and our suppliers, capable of meeting the needs of the emerging U.S. and global demand for power electronics components and systems for EDVs

- Complete implementation of scalable, lean and cost-effective manufacturing processes that can be rapidly expanded to meet increases in demand

- An established U.S. test and remanufacturing operation for power electronics components and systems associated with EDVs

- U.S. production capacity established for power electronics components and systems capable of supporting annual production of at least 200,000 EDVs
Summary

- Delphi is the largest North American supplier of power electronics components for EDVs
- Delphi is committed to the future of power electronics and the petroleum reduction benefits of EDVs
- This project will help ensure that vehicle OEMs and power system integrators have a globally competitive U.S. source for power electronics
- Delphi has in place the customer base, strategic partnerships and supplier foundation necessary to achieve the goals of this project