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

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15 May 2012

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## Project Overview

### Timeline
- **Start:** January 2010
- **Finish:** December 2012
- **Approx. 78% complete** (through Feb 2012)

### 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/12: $69.6M

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

- **Vehicle and Powertrain OEM Customers**
  - GM®, Allison Transmission®, Coda Automotive™, Fisker, others

- **Suppliers**
  - Silicon, capacitors, circuit boards, castings, magnetics, etc.
  - 2012 total qualified suppliers to Delphi
  - 145 currently in use for Power Electronics (68 U.S. based)

- **State of Indiana – incentives offered**
  - EDGE Tax Credit over ten-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 (w/ Purdue University & State of Indiana)

Delphi has in place the customers, suppliers and community foundation to succeed
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
  - Based on power electronics building blocks
  - 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 – Expanding Use of Energy-saving EV and HEV Technology in Transportation
Approach: Focus on three major areas

- Optimizing Delphi’s power electronics component and system designs for volume production for a broad range of applications
  - Automotive vehicle manufacturers
  - Commercial vehicle manufacturers
  - Off-road vehicle manufacturers
  - Industrial equipment manufacturers

- Retrofitting existing and install required new equipment and tools

- Validating the readiness of Delphi’s component and system designs for production
Approach: Apply 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 power semiconductor packaging 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: Apply a 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 Modeling and Simulation
- Vehicle Integration
Approach:
Build upon Delphi’s extensive validation test capability

- EMI / EMC
  - Emissions
  - Susceptibility
  - Immunity

- Mechanical Test

- Performance / Temperature
  - Tri-Temperature
  - Thermal Shock

- Environmental
  - Humidity
  - Dust
  - Corrosion
  - Humidity

- Vibration + Thermal Shock

- Powered Temperature Cycling

- Highly Accelerated Life Test
Approach: Utilize Delphi’s Product Development Process
Accomplishments:
New Power Electronics Production and Validation Facilities

- Feb 2010: First surface mount test boards completed
- July 2010: First production started (for 1st export customer)
- Sep 2010: Certification received for ISO/TS 16949 Quality Management System
- Nov 2010: ISO 14001 Environmental Certification
- Dec 2010: Completed installation of validation equipment at Kokomo Morgan Street (KMS) facility
- Dec 2010: Groundbreaking for new validation facility at Kokomo Corporate Technology Center
- Feb 2011: Successfully passed a new customer run-at-rate
- Mar 2011: Low volume production initiated (for 2nd export customer)
- Apr 2011: Energy Storage System test lab and proto build area completed
- Apr 2011: Prep completed for validation and manufacturing areas for Energy Storage System
- Sep 2011: Initial assembly and test equipment complement installed for Passenger Car Inverter
- Oct 2011: New engineering/validation laboratory was completed, with DOE ribbon-cutting on Oct 17
- Oct 2011: First pre-design proto builds scheduled for converters and inverters
- Oct 2011: First flexible final assembly & test area installed
- Dec 2011: Recertification of TS 16949 & ISO 14001
- Mar 2012: Run-at-rate scheduled for next production launch product
- Sep 2012: Start of production scheduled for lithium-ion battery controller
Accomplishments:
Chargers 100/220 AC to DC

- Jan - Sep 2010: Engineering samples sent to OEM customers in North America and Europe
- July 2011: First low-volume samples produced in controlled process environment
- Oct 2011: Second generation prototype design development initiated
- Nov 2011: First prototype samples delivered to Asian customer
- Nov 2011: Award of production business for European customer
- Jan 2012: Long lead validation equipment ordered
Accomplishments: Passenger Car Inverters

- Mar 2010: Received customer commitment
- May 2010: First reliability evaluation completed
- July 2010: First design confirmation units built
- Aug 2010: First customer deliverables achieved
- Sep 2010: Next design turn build completed
- Nov 2010: Customer units delivered for motor calibration
- Jan 2011: First phase reliability successfully completed
- Mar 2011: Validation equipment delivered and installed
- Mar 2011: Second design turn build complete
- July 2011: Second phase reliability testing started
- Aug 2011: Vehicle testing started
- Sep 2011: Initial complement of production equipment ordered / installation started
- Dec 2011: Completed second phase customer deliveries
- Jan 2012: Third design turn frozen
Accomplishments: Commercial Vehicle Systems

- May 2010: Populated inverter circuit boards at new manufacturing site
- May 2010: Populated battery controller boards in engineering build facility
- May 2010: First inverter drives a motor
- July 2010: First complete customer system delivered
- Aug 2010: First reliability evaluation completed
- Feb 2011: First vehicle test complete with inverter, converter and battery system
- Aug 2011: Delivered second design turn hardware to customer
- Aug 2011: Design validation testing initiated
- Dec 2011: ESS Design validation testing completed
- Feb 2012: Converter design validation testing completed
- Feb 2012: First customer reliability testing started for the battery controller, converter, inverter and energy storage system
Accomplishments:
Passenger Car DC/DC Converters

- Jan 2010: Project approved by Delphi for funding, initiating PDP process
- Feb 2010: Manufacturing capital and tooling orders placed
- Jun 2010: First process confirmation build
- Sep 2010: Validation build and testing completed
- Oct 2010: First production shipment to a China customer
- Feb 2011: First production shipments to two European customers
- Jan 2012: Validation build and testing begins for cost optimized production design
FY12 Summary of Achievements
(actual for Oct 2011 – Feb 2012 and planned)

- Nov 2011: Charger low-volume samples sent to customers
- Nov 2011: Assembly and test equipment installation
  - Passenger Car power electronics: started Dec 2011, completes July 2012
- Dec 2011: Re-certification to TS 16949 and ISO 14001 standards
- Jun 2012: Design validation testing completed for...
  - Commercial Vehicle Systems: testing started Aug/11, completes Jun/12
  - Passenger Car Inverter: testing started July/11, completes Jun/12
- Aug 2012: Production starts for Energy Storage System Control Module
- Dec 2012: Production process validation builds and testing
  - Passenger Car Inverter: build Aug/12 - Oct/12, testing Oct/12 - Dec/12
Accomplishments: Project goal of 190 direct jobs has already been exceeded

**Estimated U.S. Jobs (as of 31Dec2011)**

<table>
<thead>
<tr>
<th></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>99.0</td>
<td>99.0</td>
<td>198.0</td>
</tr>
<tr>
<td>Delphi Indirect/Support FTEs</td>
<td>49.5</td>
<td>49.5</td>
<td>99.0</td>
</tr>
<tr>
<td>Subtotal Delphi</td>
<td>148.5</td>
<td>148.5</td>
<td>297.0</td>
</tr>
<tr>
<td>Est. Suppliers' FTEs (1.036 x Delphi) *</td>
<td>153.8</td>
<td>153.8</td>
<td>307.6</td>
</tr>
<tr>
<td>Est. Indiana Community FTs (1.049 x Delphi) *</td>
<td>155.7</td>
<td>155.7</td>
<td>311.4</td>
</tr>
<tr>
<td><strong>Estimated Total U.S. Jobs Created / Retained by this project</strong></td>
<td>458.0</td>
<td>458.0</td>
<td>916.0</td>
</tr>
</tbody>
</table>


This project has directly resulted in 198 jobs at Delphi and many more U.S. jobs indirectly
Future Work

Beyond FY12 (by 31 Dec 2012)

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

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

- 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’s Power Electronics Manufacturing Site
Kokomo, Indiana

- Delphi has in place the customer base, strategic partnerships and supplier foundation necessary to achieve the goals of this project