



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

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10 June 2010

# Project Overview

## Timeline

- ◆ Start: January 2010
- ◆ Finish: December 2012
- ◆ Approx. 7% complete  
(through March 2010)

## Budget

- ◆ Total project funding
  - DOE: \$89.3M
  - Contractor: \$89.3M
- ◆ DOE funding to date
  - FY2010: \$ 6.2M

(through March 2010)

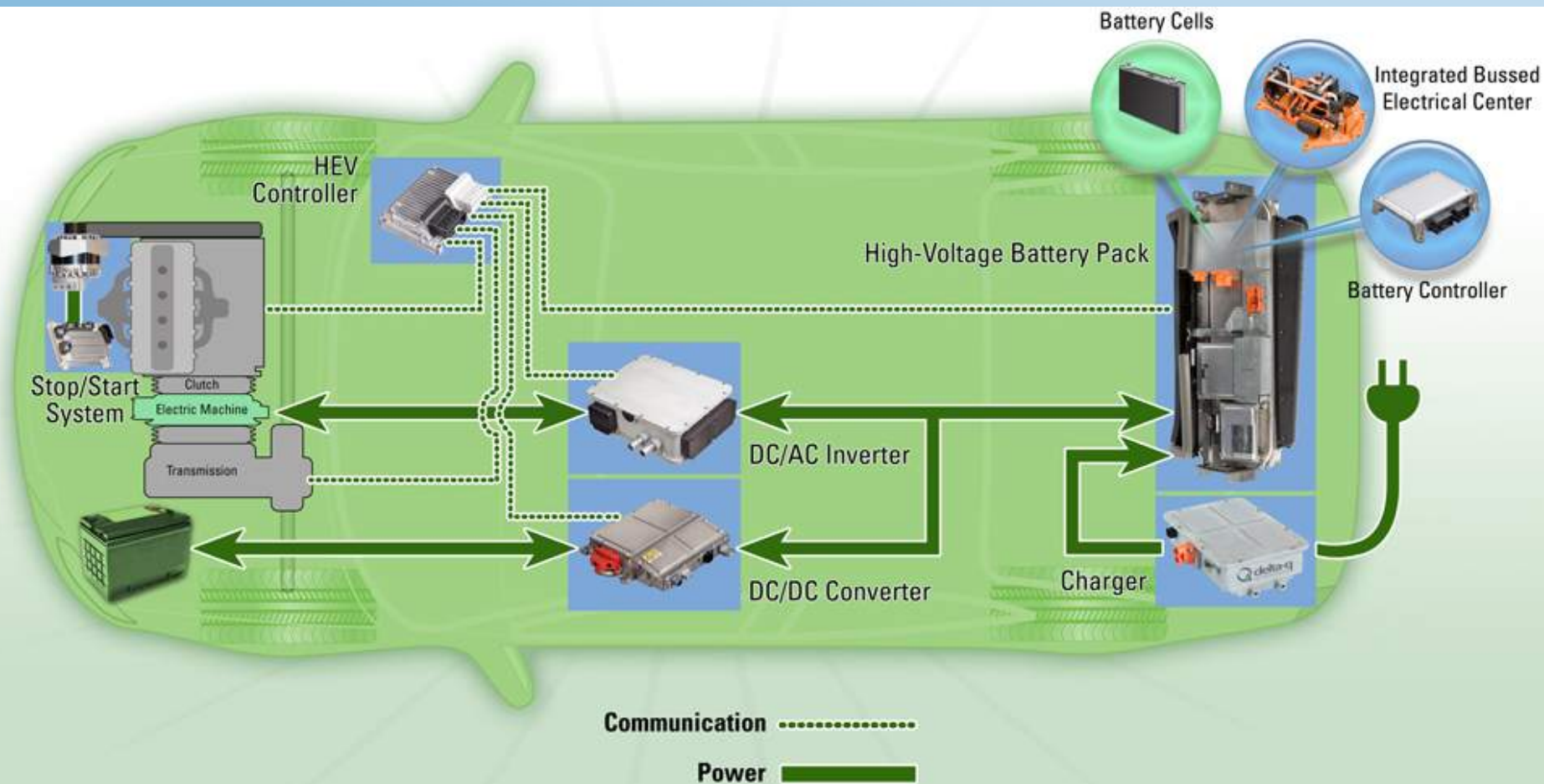
## Barriers

- ◆ 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

## Collaborators

- ◆ Project Lead: Delphi
- ◆ Vehicle OEMs: GM, Coda Automotive
- ◆ Powertrain OEM Customers: Allison
- ◆ Suppliers: Power Silicon, Capacitors, etc.
  - 145 qualified for power electronics (68 U.S.)

# Relevance: Lower-cost Power Electronic Products to Enable Expansion of U.S. Demand for EDVs



**Market Drivers:** Performance - Emissions - Fuel Economy

**DELPHI**

# Relevance: Establishes U.S. Power Electronics Production Capacity

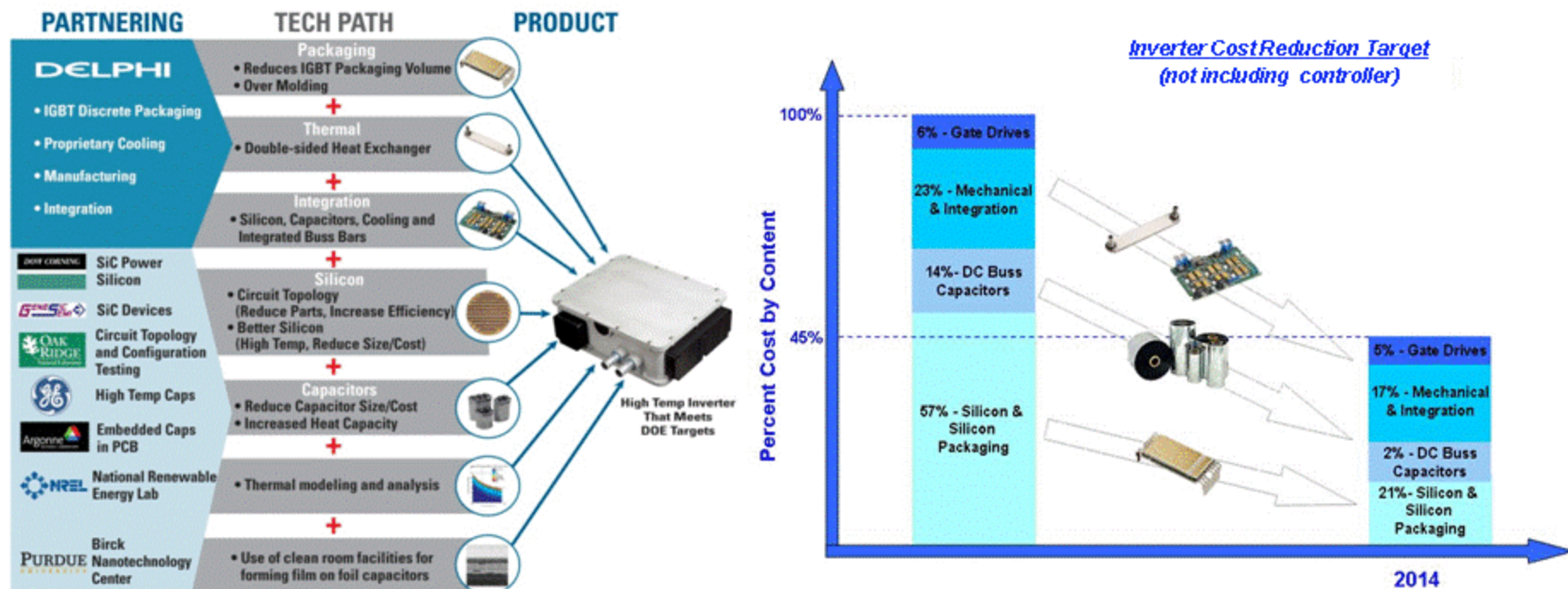
- ◆ Build upon Delphi's core capabilities
  - Rapid, concurrent product/process design optimization for production
  - Testing for validation
  - Power electronics product line
    - » Inverters, converters, chargers, and controllers
- ◆ Establish a globally competitive, U.S.-based production source for power electronics
  - Automobiles
  - Commercial Vehicles
  - Off-Road / Industrial Equipment



**Delphi 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 –

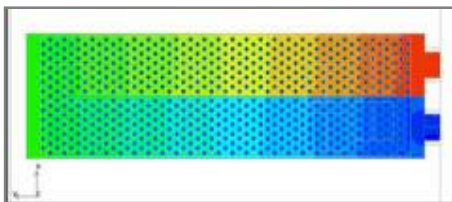
Delphi Awarded \$8.4M DOE program to develop GaN devices for HEV/PHEV/EV/FCV

# 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**

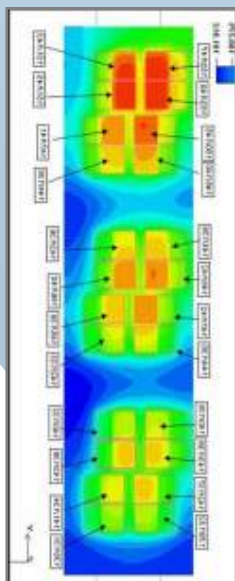
# Approach: Use Wide Array of Delphi EV/HEV Component and System Development Tools



**Heat Exchanger  
Fluid Dynamics Modeling**



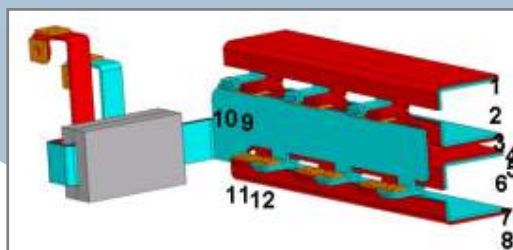
**Vehicle  
Integration**



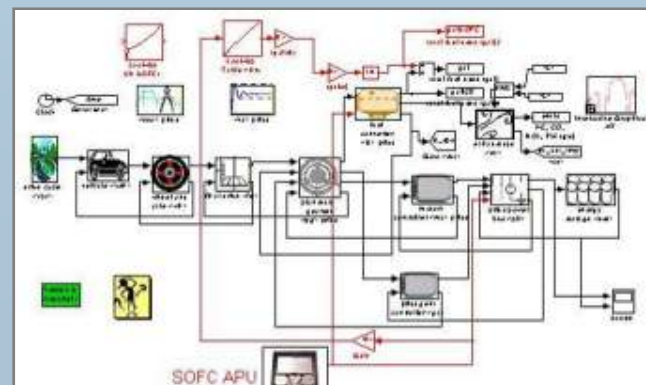
**Power Module  
Thermal FEA**



**System Dynamometers**



**DC Bus Structure  
Q3D Inductance Modeling**



**Vehicle Modeling and  
Simulation**

**DELPHI**



# Approach: Build Upon Delphi's Extensive Validation Test Capability



**Performance/Temperature  
Tri-Temperature  
Thermal Shock**



**Mechanical  
Test**



**Vibration +  
Thermal Shock**



**EMI EMC**  
• Emissions  
• Susceptibility  
• Immunity



**Environmental**  
• Humidity  
• Dust  
• Corrosion  
• Humidity



**Powered Temperature Cycling**



**Highly Accelerated Life Test**



**DELPHI**



# 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 economies of scale from volume production

## ◆ Innovation

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

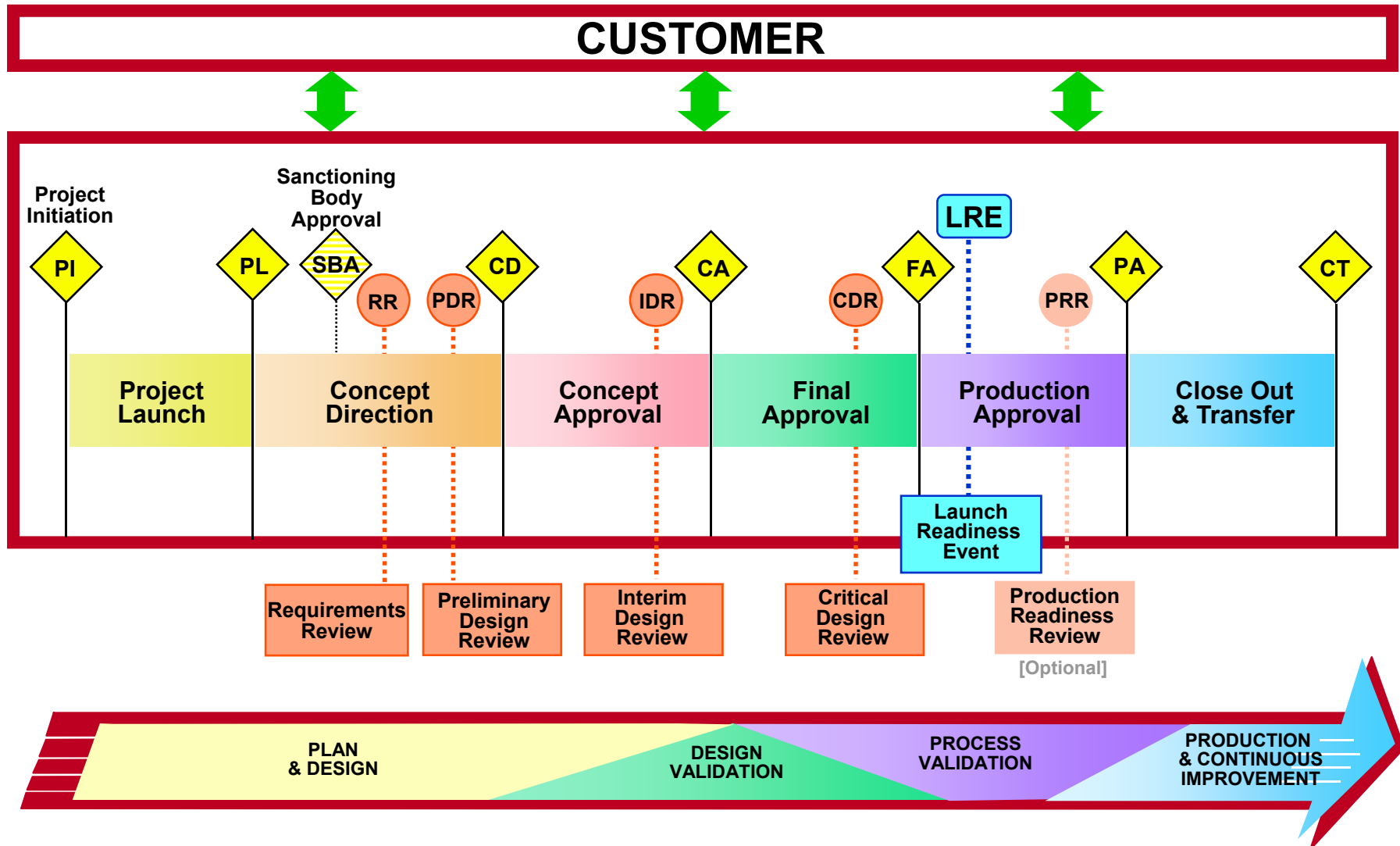
## ◆ Proven Reliability

- 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
  - Commercial vehicle
  - Off-road/industrial OEM 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



**DELPHI**



# Accomplishments: New Power Electronics Production Facility

## ◆ Progress to date (January-March 2010)

- Received full environmental (NEPA) clearance
- First surface mount test boards completed (Feb. 17, 2010)
- First pre-design, two-sided surface mount boards for inverter phase board completed (March 9 and April 19, 2010)

## ◆ Achievements expected through end of FY2010

For Automotive Power Electronics:

- First production intent practice build – May 2010
- First product validation build – May 2010
- Production start – September 2010

# Accomplishments:

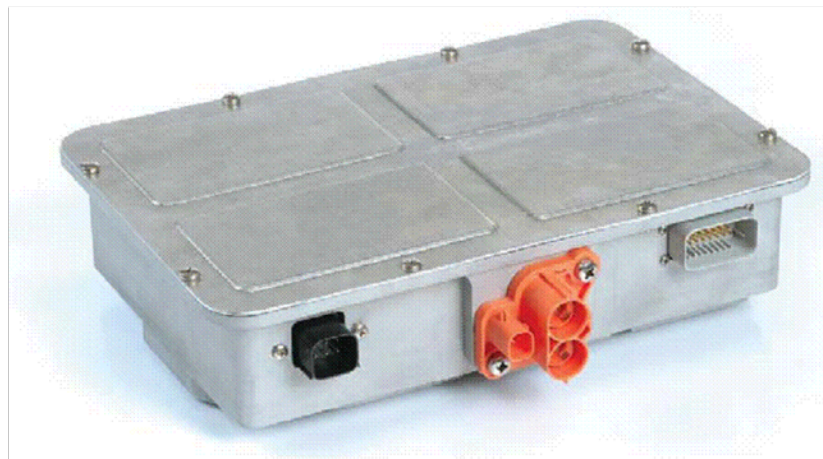
## Chargers 100/220 AC to DC

### ◆ Progress to date (January-March 2010)

- Customer development activity continues in North America, Europe and Asia (focus on PHEV chargers)

### ◆ Achievements expected through end of FY2010

- Anticipate initial customer commitment – Q2 2010
- First low-volume samples produced in controlled process environment – July 2010



# Accomplishments: Passenger Car Inverters

- ◆ Progress to date (January-March 2010)
  - First design confirmation units built
  - Inverter successfully rotated dynamometer motor
  - Customer engineering inverters delivered
- ◆ Achievements expected through end of FY2010
  - First reliability evaluation complete – May 2010
  - Next design turn build complete – September 2010



# Accomplishments: Commercial Vehicle Systems

- ◆ Progress to date (January-March 2010)
  - Populated inverter circuit boards at new manufacturing site
  - Populated battery controller boards in engineering build facility
- ◆ Achievements expected through end of FY2010
  - First inverter will have driven a motor – May 2010
  - First complete customer system delivered – June 2010
  - First reliability evaluation completed – August 2010

# Accomplishments: Passenger Car DC-DC Converters

- ◆ Progress to date (January-March 2010)
  - Project approved in January by Delphi for funding, initiating PDP process
  - Manufacturing capital and tooling orders placed
- ◆ Achievements expected through end of FY2010
  - First process confirmation build – May 2010
  - Validation build – May 2010
  - First production shipment – August 2010
    - » First shipments to China



# Accomplishments:

## Estimated Number of Jobs Created / Retained

**Project has resulted in 196 jobs being created or retained during the first quarter of 2010**

<b><u>U.S. Jobs Created or Retained</u></b>	<b>DOE's 50% Cost-Share</b>	<b>Delphi's 50% Cost-Share</b>	<b>Total</b>
<b>Delphi Direct FTEs (ARRA Reported FTEs)</b>	<b>21.8</b>	<b>21.8</b>	<b>43.6</b>
<b><u>Delphi Indirect/Support FTEs</u></b>	<b><u>10.0</u></b>	<b><u>10.0</u></b>	<b><u>20.1</u></b>
Subtotal Delphi	31.8	31.8	63.7
Est. Suppliers' FTEs (1.036 x Delphi) *	33.0	33.0	65.9
<b><u>Est. Indiana Community FTEs (1.049 x Delphi) *</u></b>	<b><u>33.4</u></b>	<b><u>33.4</u></b>	<b><u>66.8</u></b>
<b>Est. Total Jobs Created / Retained</b>	<b>98.2</b>	<b>98.2</b>	<b>196.4</b>

\* Multipliers based on State of Indiana Study: "What Indiana Makes, Makes Indiana: Analysis of the Indiana Manufacturing Sector," by Thomas P. Miller & Associates for the Central Indiana Corporate Partnership, January 17, 2005.



# Collaborators

- ◆ Vehicle OEM Customers
  - E.g. GM, Coda Automotive
- ◆ Powertrain OEM Customers
  - E.g. Allison Transmission
- ◆ Suppliers
  - Silicon, Capacitors, Circuit Boards, Castings, Magnetics, etc.
  - 2012 total qualified suppliers to Delphi Corporation
  - 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

# Future Work

- ◆ Establish rapid product / process design optimization capability for volume production with validation test capacity to meet OEM specifications
- ◆ Implement scalable, lean and cost-effective manufacturing processes that can be rapidly expanded to meet increases in demand
- ◆ Create a fully ISO/TS16949 quality certified production facility
- ◆ Create a world-class skilled workforce at both Delphi and our suppliers to meet the needs of the emerging U.S. and global demand for power electronics components for EDVs (e.g. working with Purdue University)
- ◆ Establish a test and remanufacturing operation for power electronics components associated with EDVs
  - Provide necessary infrastructure to reduce warranty and lifecycle ownership costs (including repair) for end consumers, as well as minimizing waste to landfills via recycle/reuse
- ◆ Establish U.S. production capacity for power electronics components that will support at least 200,000 EDVs by end of 2012

# 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 energy reduction benefits of EDVs
- ◆ Project will help ensure that vehicle OEMs and power system integrators have a globally competitive U.S. source for power electronics



**Kokomo, Indiana  
Power Electronics  
Manufacturing Site**

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