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

Gary A. Cameron

Delphi Automotive Systems, LLC

10 May 2011

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

ARRAVT022

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.)

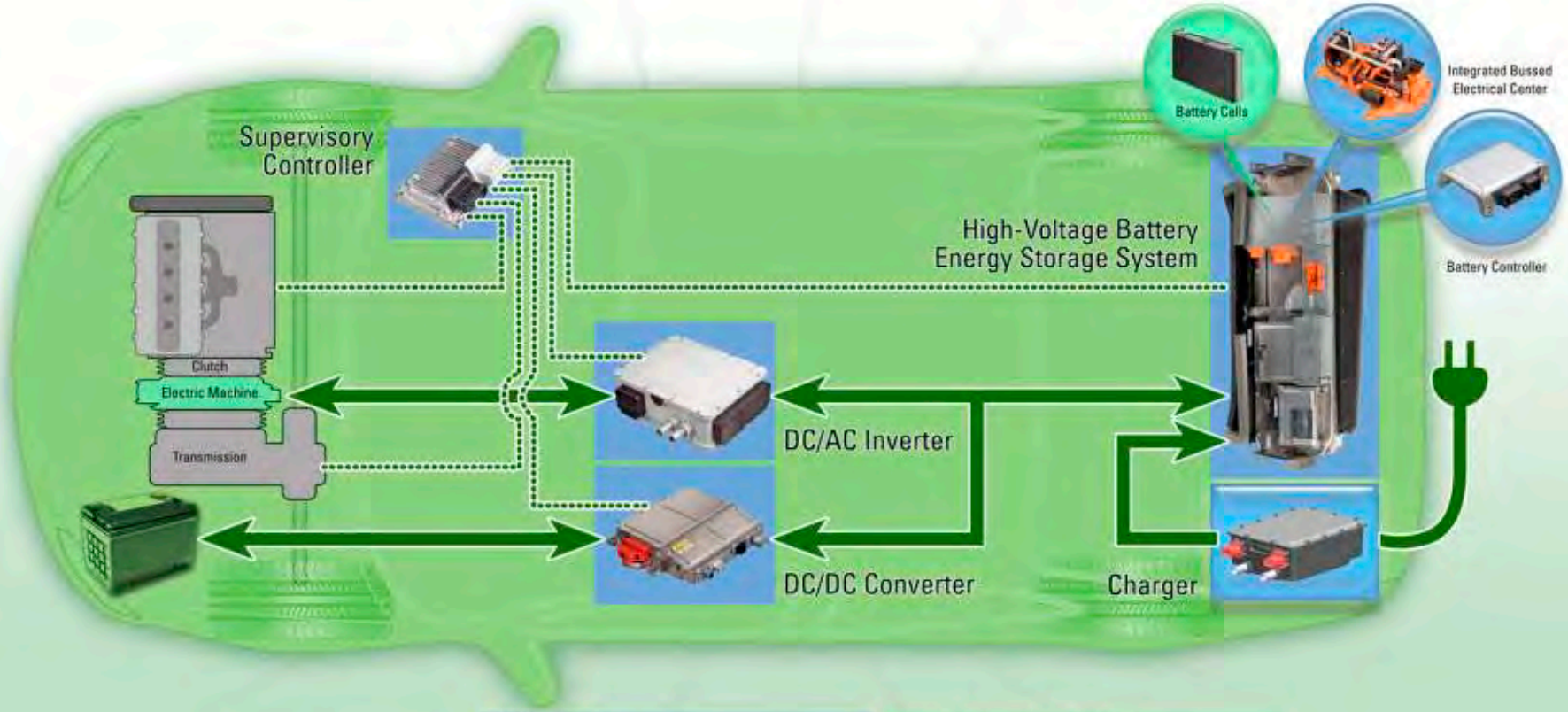
DELPHI

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

DELPHI

Relevance: Lower-cost power electronic products enable expansion of U.S. demand for EDVs



Market Drivers: Performance - Emissions - Fuel Economy

DELPHI

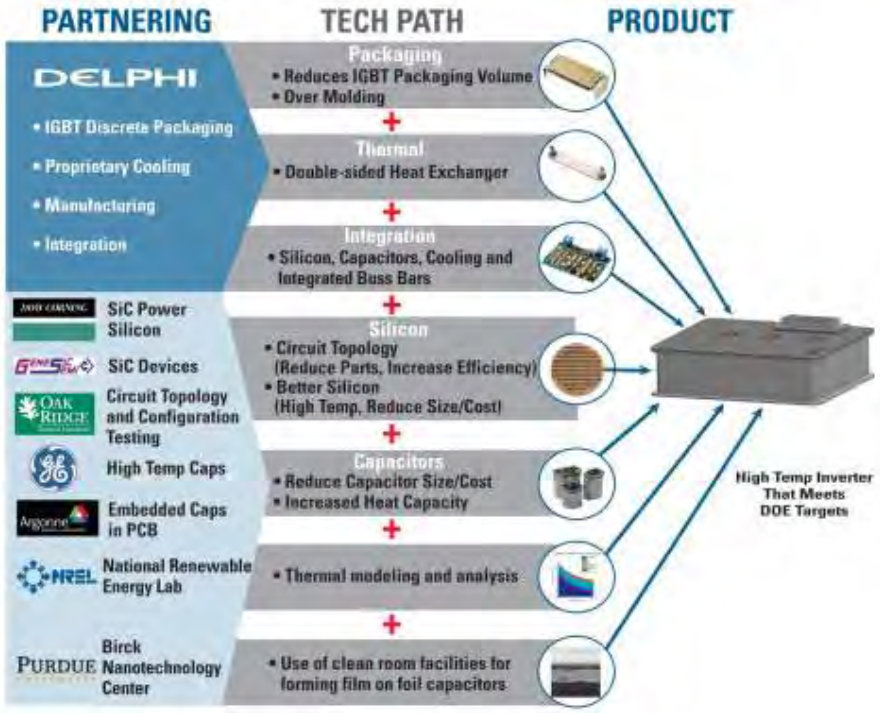
Relevance: Establishes U.S. power electronics production capacity

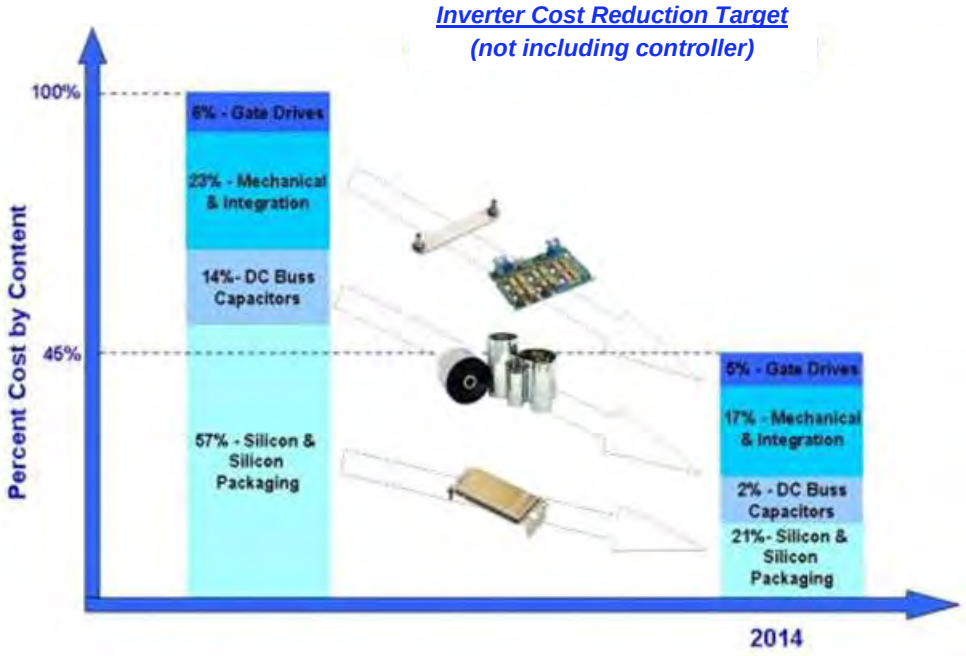
- Build upon Delphi's core capabilities
  - Rapid, concurrent product/process design optimization for production
  - Testing for validation
  - Power electronics product line
    - » Inverters, converters, chargers, controllers, energy storage systems
- Establish a globally competitive, U.S.-based production source for power electronics
  - Automobiles
  - Commercial vehicles
  - Off-road / industrial equipment

Delphi's Power Electronics Manufacturing Site Kokomo, Indiana

DELPHI

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

DELPHI

Approach: Apply more than 20 years of Delphi experience with EV and HEV technology

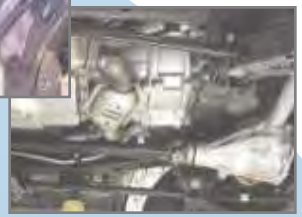
- Largest North American supplier for HEV power electronics components and energy management systems
- HEV propulsion architects for multiple vehicles
- More than 100 relevant patents issued since 2000
- Focusing on aggressively lowering the cost of powertrain electrification
  - System design and architecture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

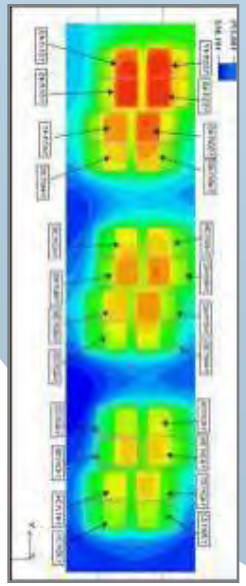
DELPHI

Approach: Use wide array of Delphi EV/HEV component and system development tools

Heat Exchanger
Fluid Dynamics Modeling

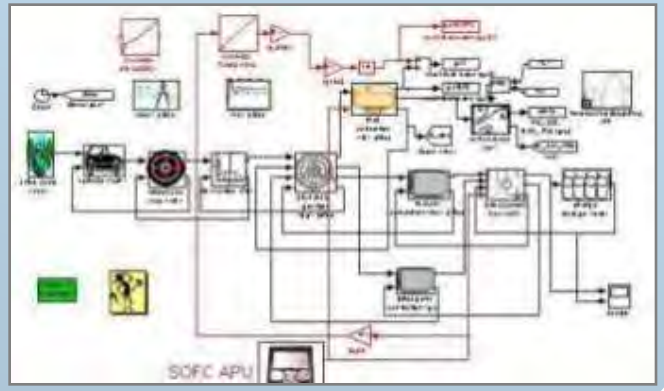


Vehicle
Integration

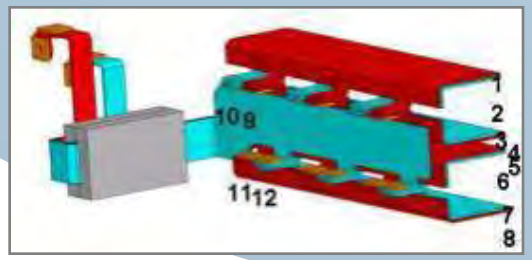


Power Module
Thermal FEA

System Dynamometers



Vehicle Modeling and
Simulation



DC Bus Structure
Q3D Inductance Modeling

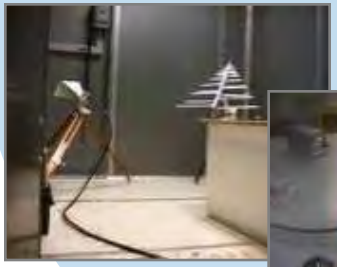
DELPHI

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 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

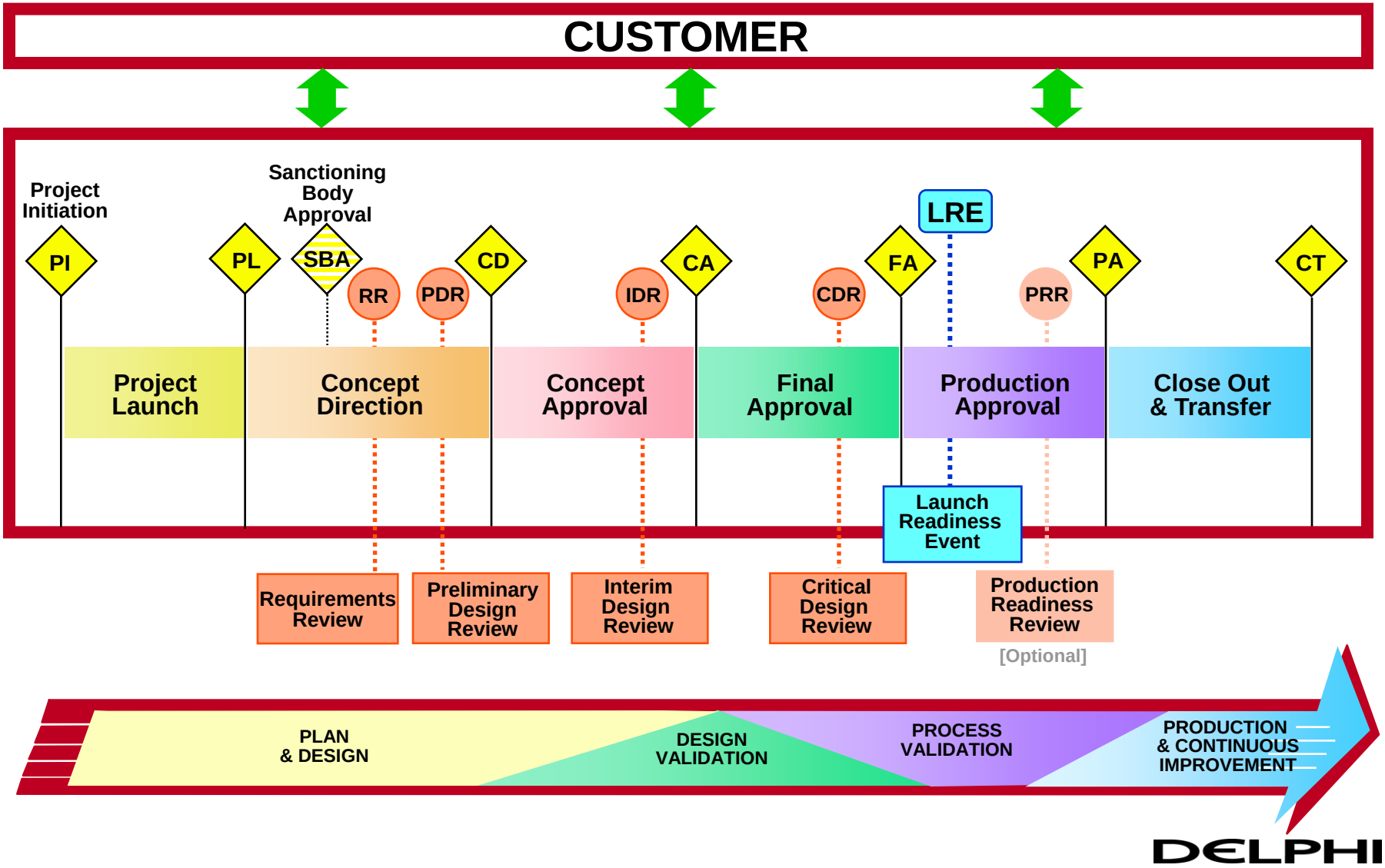
DELPHI

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

DELPHI

Approach:
Use Delphi's Product Development Process



DELPHI

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)

DELPHI

Accomplishments: Chargers 100/220 AC to DC

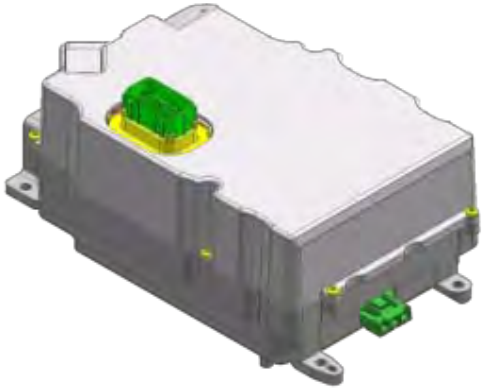
- Progress (April 2010 – March 2011)
  - Customer development activity continues in North America, Europe and Asia (focus on PHEV chargers)
  - Evolving market requirements dictated product design changes

- Additional achievements expected through 2011
  - Anticipate initial customer commitment
  - First low-volume samples produced in controlled process environment

DELPHI

Accomplishments: Passenger Car Inverters

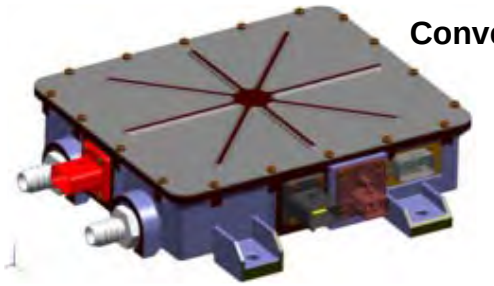
- Progress (April 2010 – March 2011)
  - Customer units delivered for motor calibration (Nov 2010)
  - First reliability evaluation successfully completed (Jan 2011)
  - Validation equipment delivered and installed (March 2011)
  - Second design turn build complete (March 2011)
- Additional achievements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



DELPHI

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



Converter

Inverter

DELPHI

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

DELPHI

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

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

* 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.

DELPHI

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

DELPHI

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

DELPHI