DELPHI

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

Gregory L. Grant
Delphi Automotive Systems, LLC
14 May 2013

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

ARRAVT022

Project Overview

Timeline

- Start: January 2010
- Finish: December 2012
- 100% complete

Barriers

- Market demand for EDVs sensitive to:
  - Unstable/unpredictable fuel prices
  - U.S. policy incentives for EDVs and U.S. sourcing/investment

Budget

- Total project funding
  - DOE: $89.3M
  - Delphi: $89.3M

Collaborators

- Project Lead: Delphi
- Vehicle OEMs: GM, Ford, others
- Powertrain OEMs: Allison Transmission
- Suppliers: power silicon, capacitors, etc.
  - 145 qualified for power electronics (68 U.S.)

DELPHI

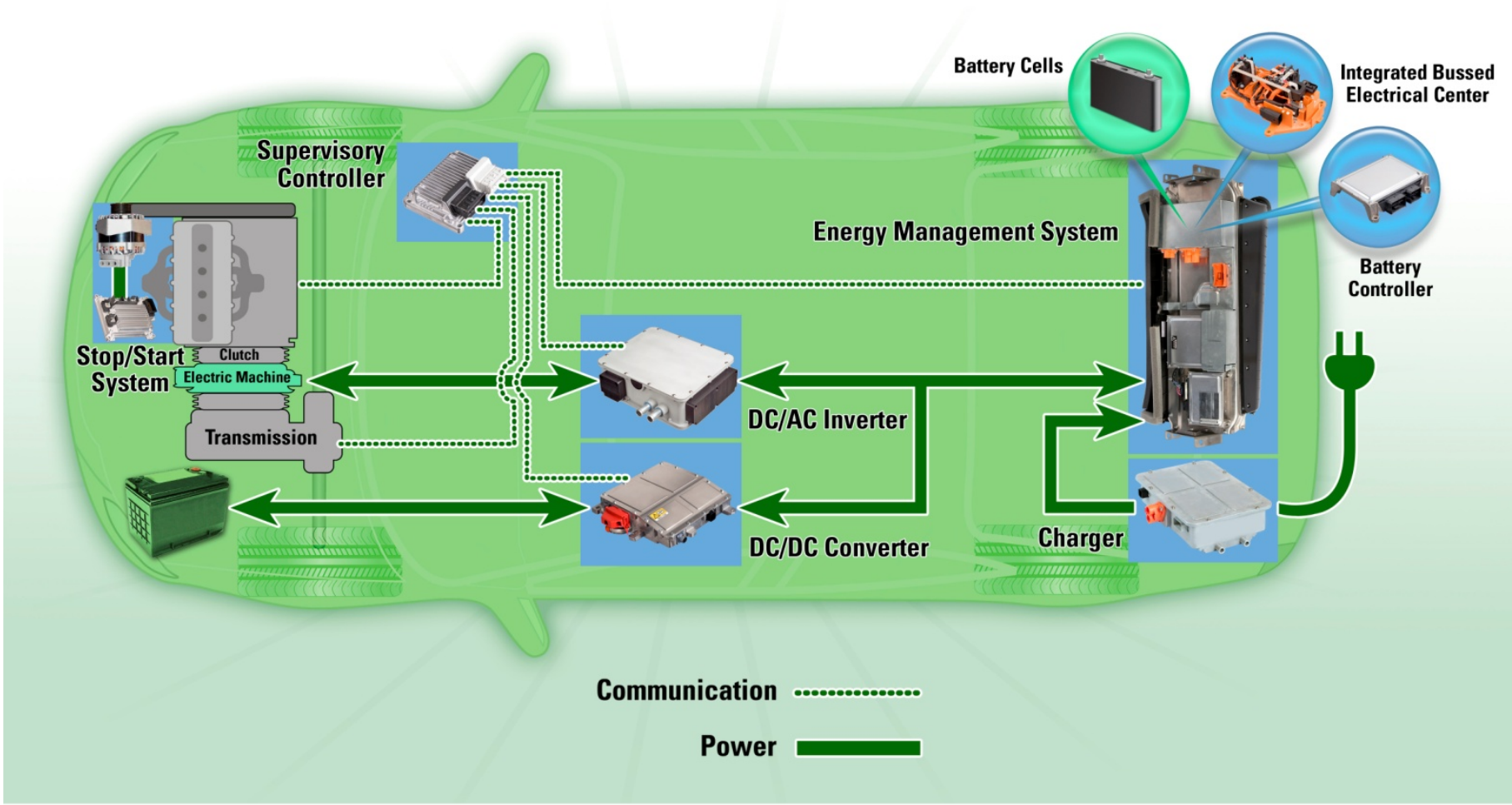
Collaborators

- Vehicle and Powertrain OEM Customers
  - GM®, Ford, 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

DELPHI

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



Market Drivers: Performance - Emissions - Fuel Economy

DELPHI

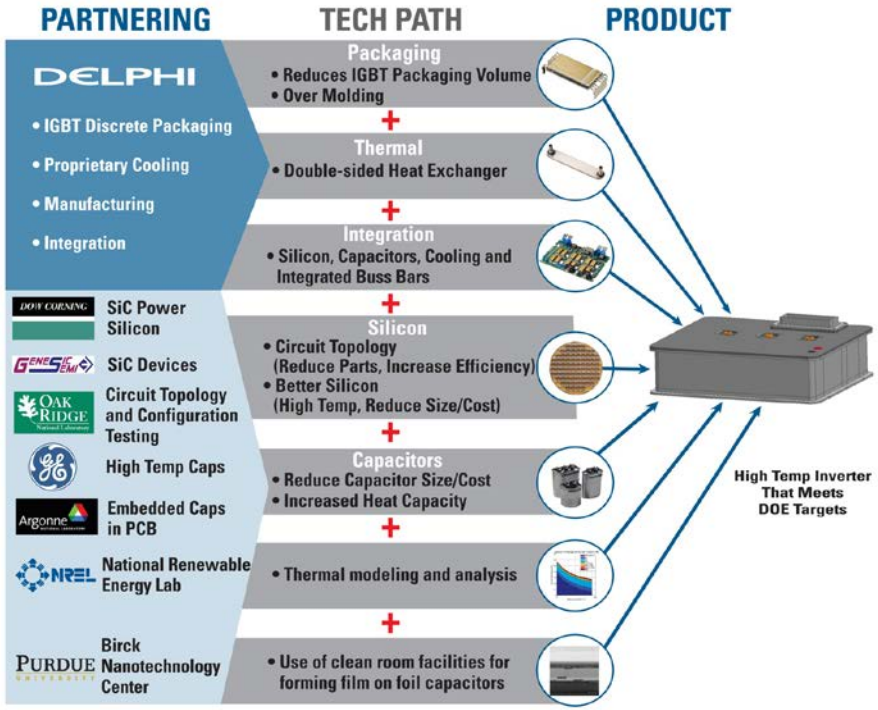
Relevance: Establishes a U.S. power electronics volume production capacity

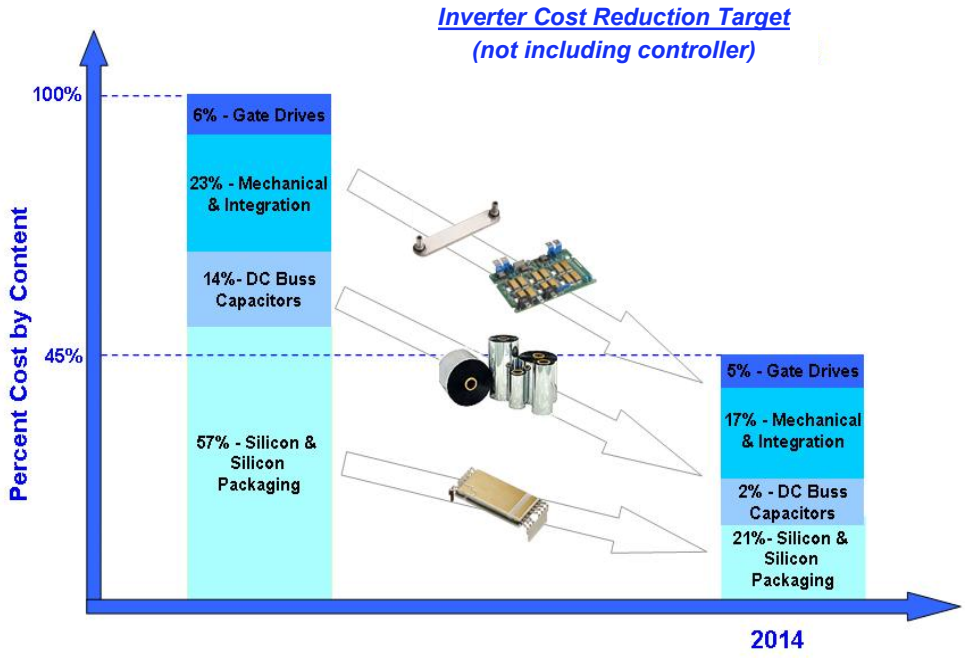
- Establish a globally competitive, U.S.-based production source for power electronics
  - Automobiles
  - Commercial vehicles
  - Off-road / industrial equipment
- Build upon Delphi's core capabilities
  - Rapid, concurrent product/process design optimization for production
  - Based on power electronics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

Delphi Power Electronics Manufacturing Site Kokomo, Indiana

DELPHI

Relevance: Provides a commercial path for future power electronics technology





– October 2007 –

DOE awarded $5.4M to team led by Delphi for the Development, Test and Demonstration of a Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Propulsion Inverter

– November 2009 –

DOE awarded $7.0M to a team led by Delphi to develop GaN devices for HEVs/PHEVs/EVs/FCVs

DELPHI

Approach: Apply more than 20 years of Delphi experience with vehicle electrification 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 – Increasing Usage of Electrified Vehicles that Reduce U.S. Dependence on Foreign Energy, Create U.S. Jobs and Reduce Emissions

DELPHI

Approach: Focus on three major areas

- Optimizing Delphi's power electronics component and system designs for volume production for a broad range of vehicular and equipment applications
- Retrofitting existing and install required new equipment and tools
- Validating the readiness of Delphi's component and system designs for volume production

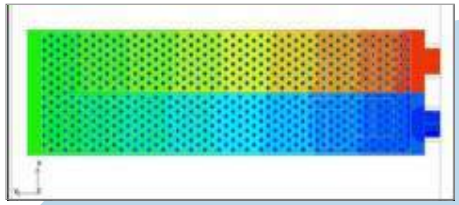
DELPHI

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

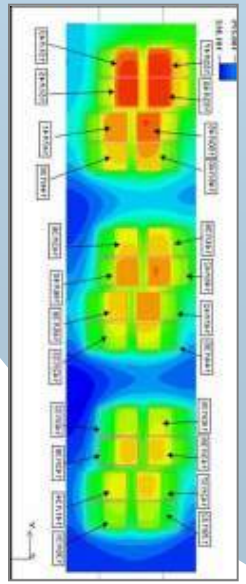
DELPHI

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



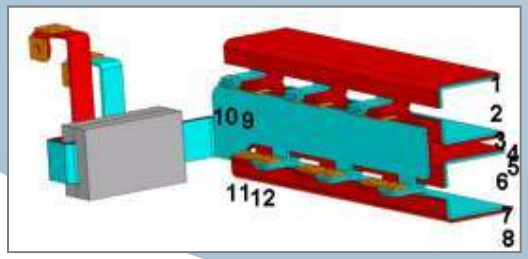
Heat Exchanger Fluid Dynamics Modeling

Vehicle Integration

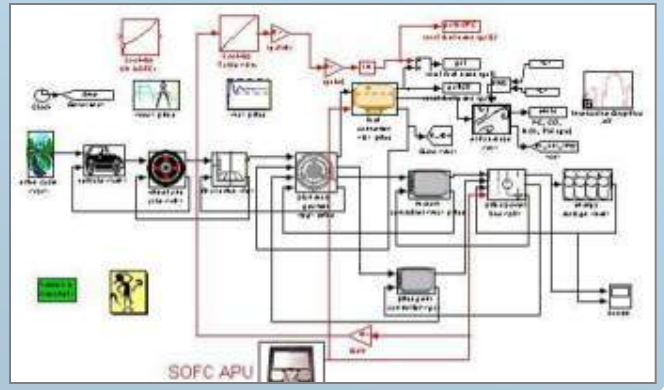


Power Module Thermal FEA

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**

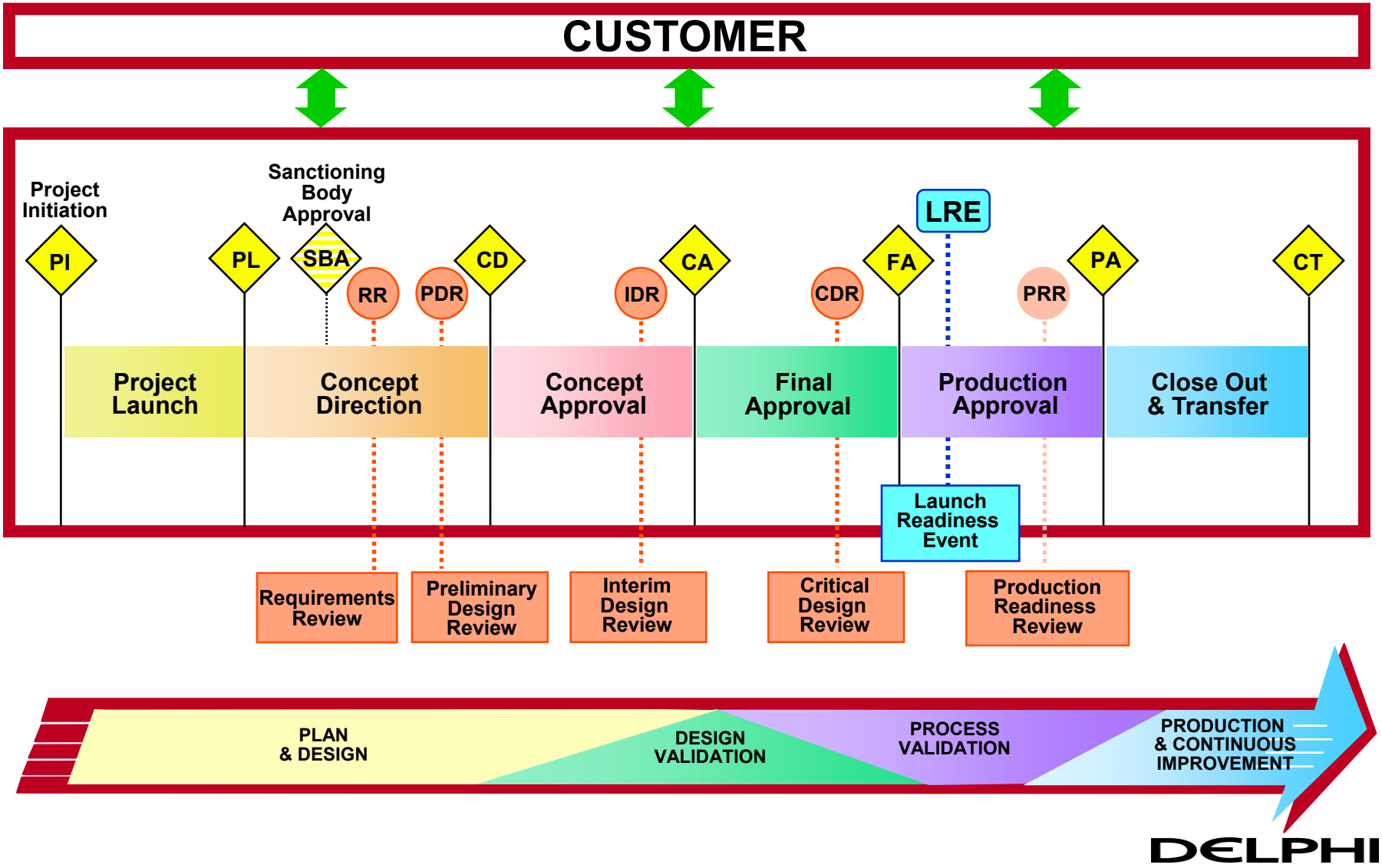
Environmental
- **Humidity**
- **Dust**
- **Corrosion**

Powered Temperature Cycling

Highly Accelerated Life Test

DELPHI

Approach: Utilize Delphi's Product Development Process



DELPHI

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
- 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
- Jun 2012: High volume conformal coat and final assembly installed
- July 2012: 1st complement of high volume test capacity installed
- Aug 2012: Added plant air capacity and lower cost lighting fixtures
- Sep 2012: Recertification of TS 16949 & ISO 14001
- Nov 2012: SOP for lithium-ion battery controller
- Dec 2012: Achieved annual production capacity of 244,000 units

DELPHI

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
- Mar 2012: Cost optimized production design successfully validated and proceeding to production

DELPHI

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

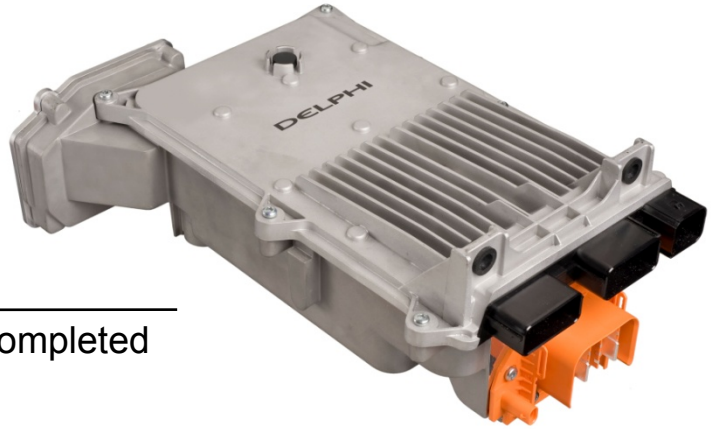
---

- Jan 2012: Long lead validation equipment ordered
- Feb 2012: Third generation production prototype design initiated
- July 2012: Third generation prototype delivered to European customer
- Aug 2012: Third generation charger validation started
- Sep 2012: Third generation production design improvements initiated
- Dec 2012: Third generation production design completed

DELPHI

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 evaluation 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
- Sep 2012: Completed third phase customer deliveries
- Sep 2012: Customer driven requirements changes included in next design turn
- Dec 2012: Units with updated design built and delivered for customer evaluation

DELPHI

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

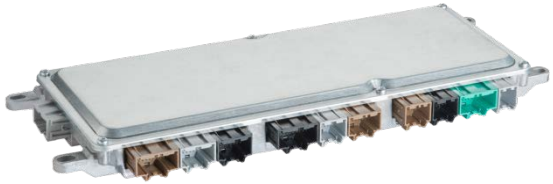
- Feb 2011: First vehicle test complete with inverter, converter and battery system
- Aug 2011: Delivered second design turn hardware to customer
- Aug 2011: Design validation testing initiated
- Dec 2011: ESS Design validation testing completed

- Feb 2012: Converter design validation testing completed
- Feb 2012: First customer reliability testing started for the battery controller, converter, inverter and energy storage system
- Jun 2012: Inverter design validation completed
- Sep 2012: Converter production design completed
- Oct 2012: Inverter production design completed
- Oct 2012: Converter product validation build starting
- Nov 2012: Battery system controller production started

Converter

Allison Transmission H3000 System

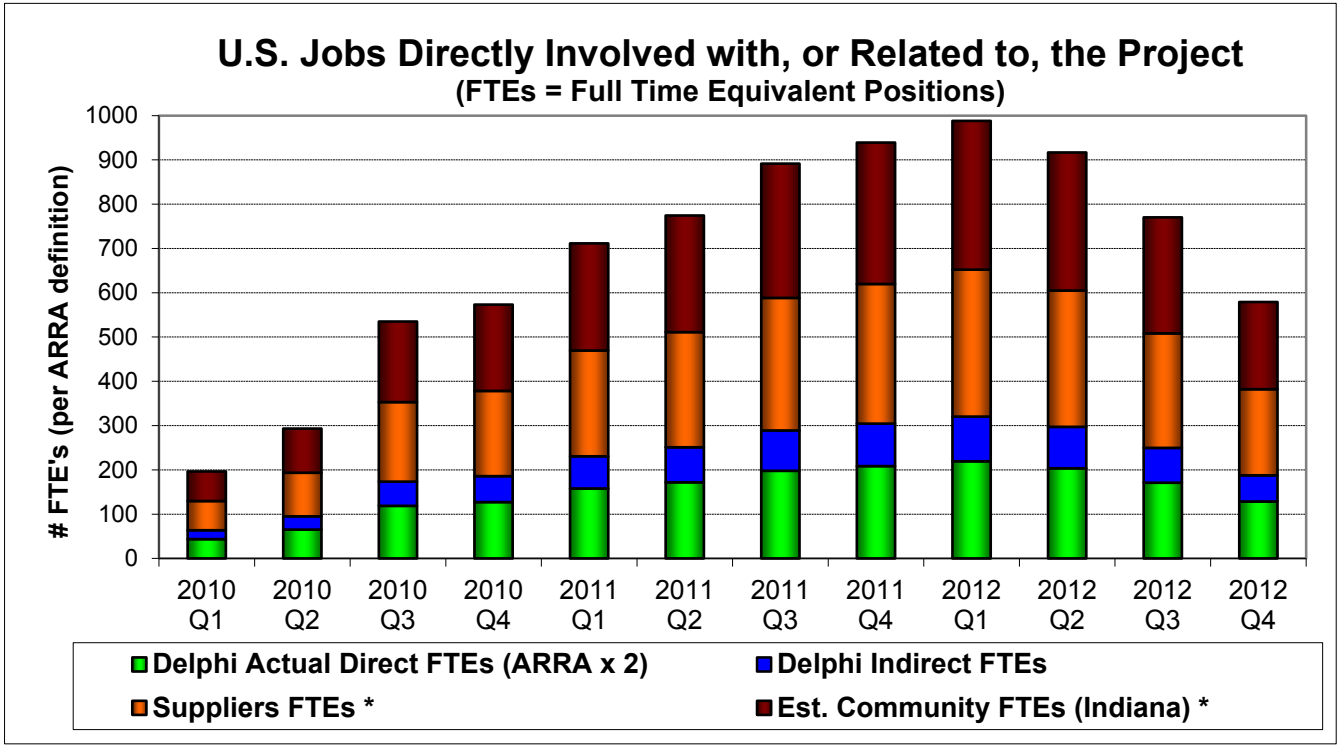
Inverter



Battery System Controller

DELPHI

Accomplishments:
An estimated 1000 U.S. jobs attributable to the project at its peak



*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.

The project resulted in over 300 jobs at Delphi and many more U.S. jobs indirectly

DELPHI

FY13 Summary of Achievements
(Oct 2012 – Dec 2012)

- Sep 2012: Completed third phase customer deliveries for Passenger Car Inverter
- Sep 2012: Completed re-certification to TS 16949 and ISO 14001 standards
- Oct 2012: Completed inverter and converter production designs for Commercial Vehicle Hybrid System
- Nov 2012: Production started for Battery System Controller (Ford PHEV)
- Dec 2012: Completed third phase production design for 110/220 AC to DC Charger
- Dec 2012: Production process validation builds and testing
  - Commercial Vehicle Systems: build May/12 - Jun/12, testing July/12 - Dec/12
  - Passenger Car Inverter: build Aug - Oct/12, testing Oct/12 - Dec/12
- Dec 2012: Completed DOE review verifying achievement of the project's targeted capacity for power electronics products

DELPHI

Project Summary

From 2010 to 2012, this project has achieved its objectives, by:

- Implementing a scalable, lean and cost-effective volume manufacturing processes that can be rapidly expanded to meet increases in demand for power electronics component and systems
- Establishing an ISO/TS16949 quality certified U.S. power electronics production facility
- Establishing 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 EDV power electronics components and systems
- Establishing a U.S. test and remanufacturing operation for power electronics components and systems
- Establishing a U.S. production capacity established for power electronics components and systems capable of supporting annual production of at least 200,000 units (achieved 244,000 units of capacity by 31Dec2012)
- Ensuring that vehicle OEMs and power system integrators have a globally competitive U.S. source for power electronics

DELPHI