



# 2011 DOE Vehicle Technologies

## 2006-2011 GATE program at the Ohio State University:

*Modeling, control and system integration of advanced  
automotive propulsion systems*

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Ohio State University

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Project ID #: ti015\_guezennec

# Program Overview

## Timeline

- Start date: Oct. 1, 2005
- End date: Sept. 30, 2011
- Percent complete: 90%

## Budget

- Total project funding
  - \$670,000 received to date (fully funded)

## Barriers

- Barriers addressed: funding stretched over 1 additional year

## Partners

- Interactions/ collaborations with many automotive OEMs and suppliers
- Project lead: Ohio State University



# Overall Program Objectives

## **Facilitate the education of the best engineers to support the DOE and industry Advanced Vehicle Programs**

- Develop and deploy a world-class curriculum in relevant technologies
- Create value-added research knowledge in relevant supporting technologies
- Support automotive industry competitiveness both with technically-savvy graduates **and** research programs focused on relevant technologies
- Community outreach programs
- **Leverage available resources and maximize benefits**



# History: Past GATE Program (1998-2004)

## *Hybrid Drivetrains and Control Systems*

- Original funding from DOE: \$550,000  
DOE GATE funding supported **22 Graduate student-years**.
- Additional funding at OSU-CAR during the GATE period of performance permitted supporting an additional **96 Graduate student-years**.
- Between 1999 and 2005, the GATE program at Ohio State graduated **38 M.S.** and **12 Ph.D.** students. **45 of these 50** professionals are now employed in the **automotive sector**.
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# Current GATE program (2005-2011)

- The theme of the program is ***System Integration***.
- Such integration is planned at various levels, including curricular integration, integration in teaching and experimental research; and integration in the use of academic, private and government resources.
- The DOE GATE program will continue to serve as a catalyst to leverage other resources and programs towards achieving the objective of educating a new generation of automotive system engineers
- The program focus is on:
  - *advanced combustion engines,*
  - *advanced energy storage systems,*
  - *fuel cell systems,*
  - *sensing and actuation technologies and*
  - *advanced hybrid propulsion and related control systems,*with a strong emphasis on the integration of such systems towards the development of new generation of automotive propulsion concepts.

# Overall Approach

- **Student Recruitment:**
  - **GATE Fellows – Industry GATE Fellows and industrial support**
  - **Visiting scholars**
- **Curriculum Development and Implementation**
  - **New course development and pilot offerings**
  - **Existing courses upgrade and sustained delivery**
  - **Offering of GATE courses to industry via Distance Learning**
  - **Development and upgrade of short courses (primarily for industry)**
  - **Development and delivery of specialized Certificates for industry**
  - **Graduate specialization on Automotive Engineering (ASE)**
- **Fellow achievements in research**
- **Strong linkage to DOE Vehicle competitions**
- **Placement of GATE graduate in industry**
  - **Internships**
  - **Permanent employment**
- **Leveraging of GATE program for Advanced Vehicle Research programs**
- **Proposals for active participation in ARRA programs**

**→ GATE program success: leveraging of fiscal and human resources**

# Success Metrics

- Number of graduates placed in auto industry
- Number of students in the program, including OSU graduate students and industry participants
- Auto companies participating in internship and recruitment programs
- Funded research programs leveraged from GATE activities
- Publications and patents
- Number of specialty courses developed and taught and number of team-taught courses
- Number of participating faculty
- Variety of courses across disciplines
- Outreach and societal impact
- International participation

***Approach 1 – Recruit, educate,  
graduate GATE Fellows  
and other students***

# Current DOE Fellows

Funded 4 graduate students in past year from DOE GATE funds.

Tuition and fees provided by university as part of cost share.

Remaining funds until end of program will allow to support 4/6 students in Sp/Su 2011.

**A total of 20 man years of students will have been supported by DOE funds, impacting in excess of 20 graduate students (MS and PhD), most of which are now working (or accepted employment) in automotive industry**

# Present Industry GATE Fellows

5 additional graduate students in past year from industry-sponsored GATE funds (Honda partnership, GM, etc)

Tuition and fees provided by university as part of cost share.

Remaining funds until end of program will allow to support 5 students in Sp/Su 2011.

**An additional of 20 man years of students will have been supported by industry GATE funds, impacting in excess of 20 graduate students (MS and PhD), most of which are now working (or accepted employment) in automotive industry**

# **GATE International Visiting Scholars**

On a regular basis, the GATE program attracts **many international students to perform internships at Ohio State as part of their degree program in Europe** (mostly Italy, France, Germany and Switzerland) **or Asia** (Japan, Korea). Stays range from 4-18 months. While a part of the deliverables of the GATE program, this **phenomenally successful outreach activity** comes at **no-cost to the GATE program** (leverages other research funds and home institution funding) and these **visiting scholars participate strongly into the GATE technical activities**. This has led to a number of **formal collaborative exchanges and participation of international faculty into some of the GATE-developed courses**.

***Approach 2 – Develop and offer  
GATE courses and related  
offerings***

# GATE Course Offerings

**The course ME 788 “*Fuel Cell Systems for Automotive Applications*”, Spring '10**

The course was offered during the Spring 2010 by Prof. Guezennec (ME/ECE) to over 20 ME and ECE students. This course has now been made permanent as part of the GATE program.

This course is also offered simultaneously via distance learning to over 20 engineers in the automotive industry (primarily GM) in 4 continents.

**This course is currently re-offered (off-cycle) in Sp '11 via distance learning to engineers in the automotive industry (12 students, primarily at GM, multiple international sites).**

# GATE Course Offerings

**Permanent offering of the course ME 631 “*Powertrain Instructional Laboratory*”, Spring 2010 and 2011**

Significant effort went into the development of a new laboratory in the newly inaugurated Scott Laboratory, the new home of the Department of Mechanical Engineering. This (now permanent) yearly course is offered every Sp as part of the GATE program (taught by Dr. Midlam-Mohler (ME/CAR), former GATE fellow).

# GATE Course Offerings

**Pilot offering of the new course ECE-794, “*Power Electronics for automotive Applications in ‘10*”**

This *new* course was offered by Prof. Jin Wang (ECE) to approximately 20 on campus students and was also offered via Distance Learning to over 30 GM engineers

This course will now become part of the standard offering of GATE courses

# GATE Course Offerings

**Pilot offering of the new ME course section in '10-'11 as part of the capstone senior project.**

This *additional offering* within our capstone project ME course *is* offered by Prof. Shawn Midlam-Mohler and is specifically targeted at automotive related projects, motivated by the advanced vehicle competitions (Ecocar, Buckeye Bullet LSR, electric Motorcycle)..

**This capstone offering course will now become part of the standard offering of GATE courses and is a very good recruitment tool for talented undergraduates to participate and eventually join the GATE program.**

# GATE Course Offerings

**Other GATE course offerings (not a stated deliverable, but *integral* part of the program):**

The course ME 784 “*Energy modeling of hybrid Electric Vehicles*”, was offered in Fall '09 by Prof. Guezennec (ME), with an enrollment of 14 OSU students (ME, ECE) and 15 GM distance learning students

The course ME 785 “*Optimization and control of Hybrid and Electric Vehicles*”, was offered in Winter '10 by Profs. Guezennec (ME) and Yurkovich (ECE), with an enrollment of 12 OSU students (ME, ECE) and 4 GM distance learning students.

**These 2 courses were re-offered (off-cycle) in Fa '10 and Wi '11 via distance learning to engineers in the automotive industry (primarily at GM).**

**NOTE:** ME 784 and ME 785 are courses that were developed under the previous GATE award are in their 9<sup>th</sup> offerings having impacted hundred of students at OSU and in the automotive industry !

# Other GATE Course Offerings

**Other GATE course offerings (not a stated deliverable, but and *integral* part of the program):**

The course ME 781 “*Powertrain Dynamics*” was offered during Au’10 by Profs Rizzoni (ME/ECE) and Srinivasan (ME), with an enrollment of 22 OSU students (ME and ECE) and 21 GM distance learning students.

The course ECE 753.01/ME 782D “*Powertrain Control*”, was offered during Winter ‘11 by Prof. Yurkovich (ECE), with an enrollment of 13 OSU students (ME and ECE) and 19 GM distance learning students.

The course ME 730 “*IC Engine Modeling*”, was offered in Wi ‘11 by Dr. Midlam-Mohler (a former GATE PhD graduate), with an enrollment of 8 OSU students (ME).

# Other GATE Course Offerings

**Other GATE course offerings (not a stated deliverable, but an *integral* part of the program):**

The course ME 874 “*Automotive System Diagnostics*” was offered in Wi '10 by Prof. Rizzoni, with an enrollment of 12 OSU students (ME and ECE).

+ **many short courses (8-16 hours)** were developed and offered primarily to industry on specialized topics relevant to GATE program students (Electrical Energy Storage Systems for Traction Applications, Advanced Diesel Engines, Alternative Fuels, Fuel Cell Systems Control...) taught by OSU professors and researchers, with international participation (ETH Zurich, U. Stuttgart...)

***Approach 3 – Fellow  
achievements in research***

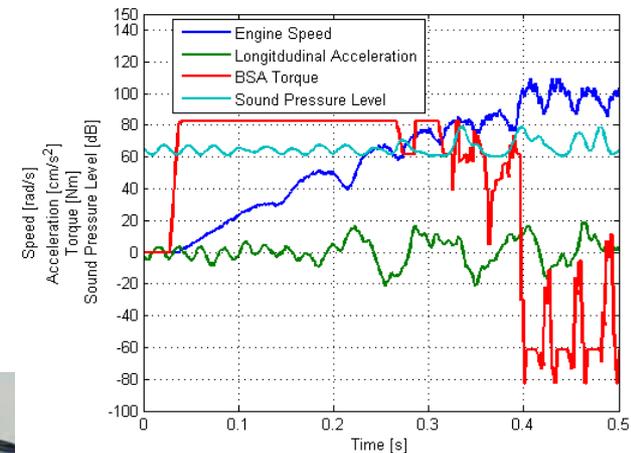
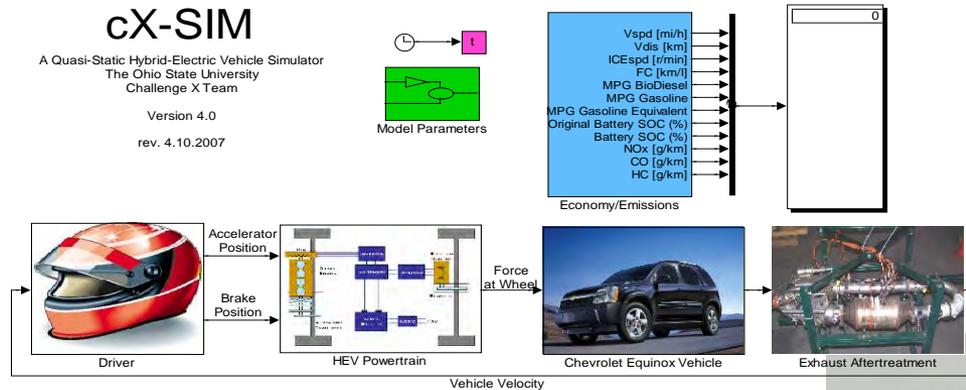
# Technical Accomplishments/ Progress/Results

**EcoCar '10 and '11 competitions**

**Leadership by GATE Fellows**

**All the grad students on team have  
taken all GATE courses**

**Ohio State selected  
in '11 for EcoCAR 2  
competition (Highest  
ranking out of 50  
proposals)**



**→ Multiple papers and  
theses from this work**



**Gate fellows  
involved...**

# Technical Accomplishments/ Progress/Results

In August 2010, the [Buckeye Bullet](#) version 2.5, the team's battery powered, all-electric landspeed racer out to the Bonneville Salt Flats to break the electric car land speed world record, and they did exactly that, hitting a peak speed of 320 miles per hour.



The Buckeye Bullet team -- a collaboration between the Ohio State University Center for Auto Research and a handful of sponsors (Venturi, A123, others...) -- has been racing electric cars for well more than a decade, but the VBB2.5, as it's known, is their first landspeed racer that runs purely on battery power.

In 2009, their hydrogen-fuel-cell-powered VBB2 set a world record for fuel cell-propelled land vehicles by running a mile at an average speed of 302.877 miles per hour (the two-way average was a slightly lower 300.992 miles per hour).

➔ **Multiple papers and  
theses from this work**

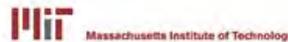
**Gate fellows  
led...**

***Approach 4 – Leveraging or enabling of other research programs aimed at integration of advanced and high efficiency powertrains***

# Leveraged Activities from GATE Program



*Department of Energy  
U.S. - China  
Clean Energy Research Center  
on Clean Vehicles*



# Leveraged Activities from GATE Program



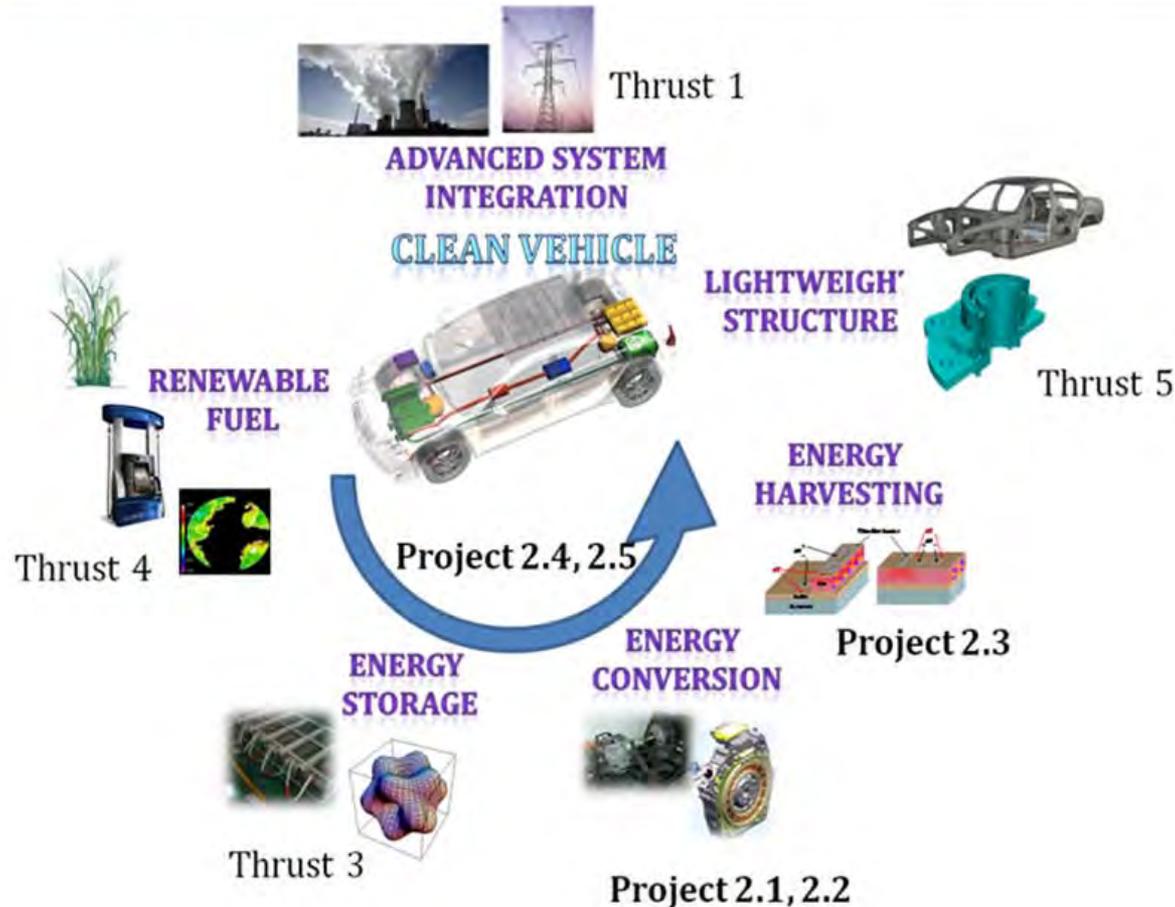
US – China CERC

- Clean Vehicles:
  - “The objective is to contribute to *dramatic improvements in technologies* with the potential to *reduce the dependence of vehicles on oil* and/or *improve vehicle fuel efficiency*.”
- Center awarded to Michigan-Ohio State-MIT consortium.
- U.S. DoE funding \$12.5M over 5 years. With university and Industry cost share, total program funding over 5 years is greater than \$30M.
- Ohio State responsible for over \$7M in programs.

# Leveraged Activities from GATE Program



US – China CERC



# Leveraged Activities from GATE Program



DELPHI



*DOE Advanced Technology Powertrains  
For Light-Duty Vehicles (ATP-LD) Program*

A MultiAir<sup>®</sup>/MultiFuel Approach to  
Enhancing Engine System Efficiency



# Leveraged Activities from GATE Program



## Scope of the Project

### **Objective:**

*To demonstrate a 25% improvement in combined City FTP and Highway fuel economy for a demonstration vehicle (Chrysler minivan), while maintaining comparable vehicle performance to a state-of-the-art gasoline port fuel-injected engine.*

Engine technologies considered will include downsizing, turbocharging, fully-flexible valve actuation, flex-fuel systems.

Combustion improvements have been estimated to achieve up to 20% fuel economy improvement. The desired target of meeting or exceeding 25% improvement will be reached by combining engine combustion improvement with overarching system efficiency improvements:

- *Engine waste heat recuperation and management;*
- *Vehicle electrical energy optimization and management;*

# Leveraged Activities from GATE Program



NSF-CDI: Energy Policy, Investment, and Pricing  
Analysis Driven by Computational Steering

- This research is funded under the NSF CDI (*Cyber-enabled Discovery and Innovation*) program, and is an **outgrowth of the SMART@CAR Consortium program**
- The CDI program aims to increase understanding of science and engineering phenomena, as well as socio-technical innovations in order to enhance the national quality of life.
- The grant from the National Science Foundation will allow researchers to develop a national energy model called ICS-EPP (*Integrated Computational System for Energy Pricing and Policy*).
- ICS-EPP will allow them **to study the impacts of different energy policies and pricing schemes** (including tax incentives and subsidies, carbon taxes, and cap and trade) **on the adoption of different energy technologies**.

# Leveraged Activities from GATE Program



U.S. DOE/NETL National Center of  
Excellence in Energy Storage Technology



- The goal of this program is to establish a national *Center of Excellence in Energy Storage Technology with focus on both mobile and stationary applications.*
- The Center leverages strong relationships with the automotive, electric power and energy storage industries to establish a unique capability to develop and transfer energy storage system technology through a fundamental understanding of *battery electrical and thermal performance, damage and aging mechanisms*, and through the development of *reliable, high-speed processes for joining substrates in battery cell, module and pack assemblies with low manufacturing variability.*

# Leveraged Activities from GATE Program



**Third Frontier**  
Innovation Creating Opportunity

**Aimed at Economic Development,  
supported by thriving educational and  
research GATE program**

## WPP 09-027

### CAR Center of Excellence for Electric and Plug-In Hybrid Vehicle Technology

OSU Center for Automotive Research

March 11<sup>th</sup>, 2009

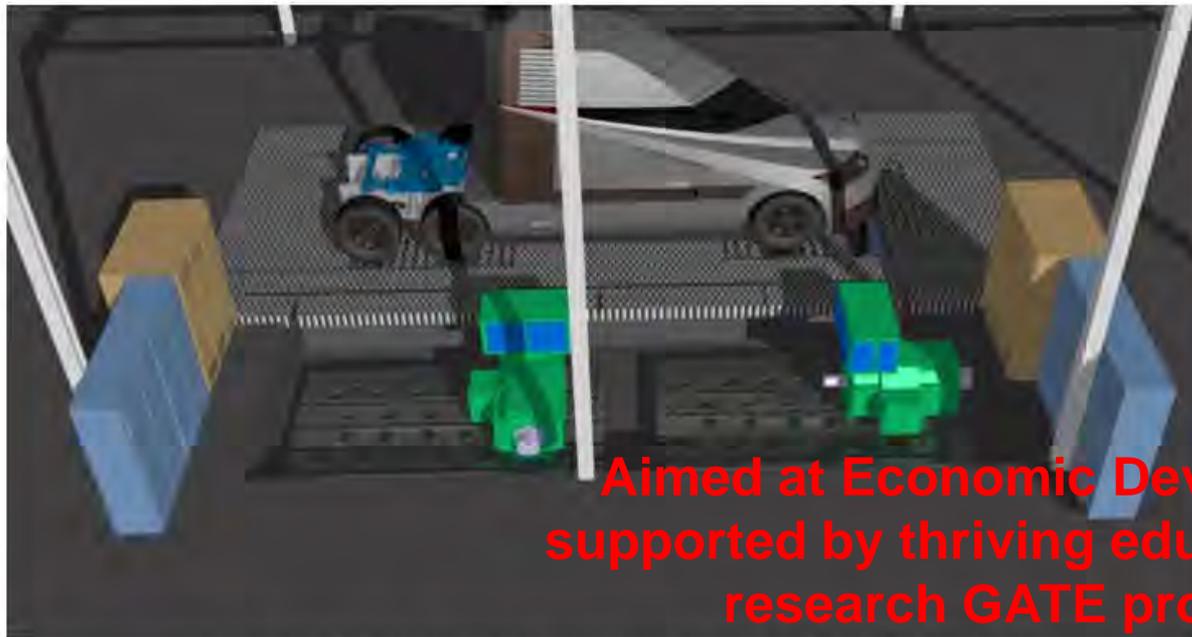


# Leveraged Activities from GATE Program



4WD HD Chassis dynamometer and high-voltage battery emulator and power conversion lab

A \$3M expansion of CAR facilities will **accelerate the introduction of new electric power conversion products** aimed at the **commercial vehicle market**, including transit buses and vocational trucks.



**Aimed at Economic Development, supported by thriving educational and research GATE program**

Heavy-duty chassis dynamometer in high bay of OSU-CAR  
Mustang Dynamometer, Twinsburg, OH

# Leveraged Activities from GATE Program



**Third Frontier**  
Innovation Creating Opportunity

**Aimed at Economic Development,  
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## Center of Excellence for Energy Storage Technology

Wright Projects Proposal 10-525

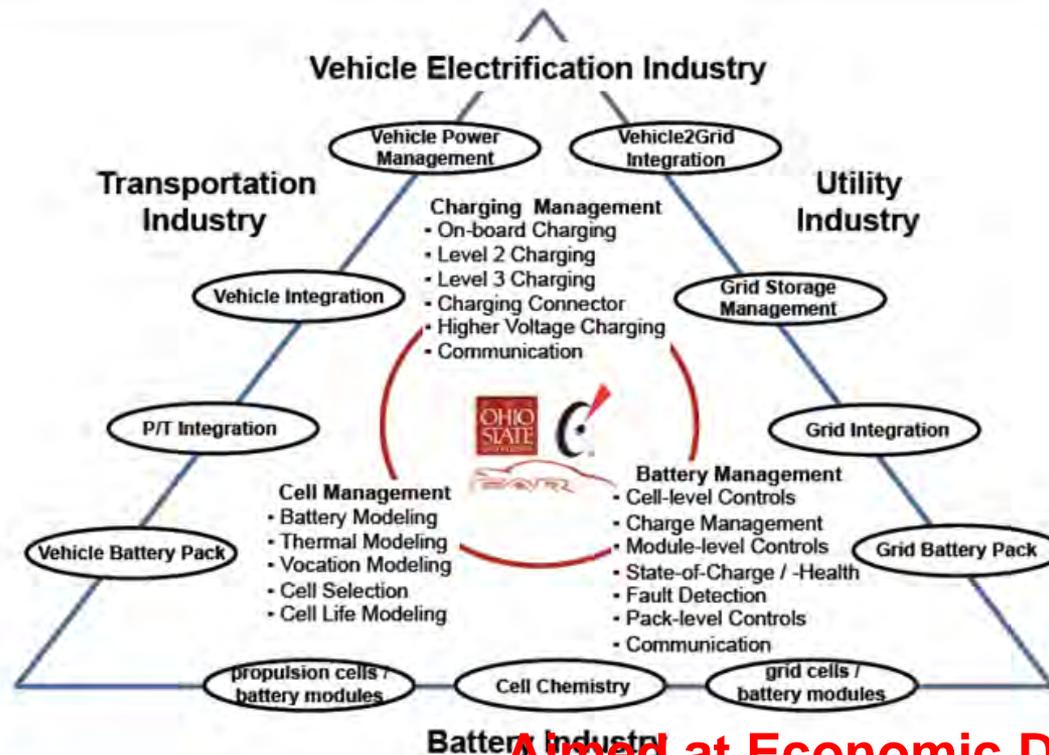
Ohio State University – Center for Automotive Research

CAR Technologies LLC

March 12, 2010



# Leveraged Activities from GATE Program



**Aimed at Economic Development,  
 supported by thriving educational and  
 research GATE program**

# Leveraged Activities from GATE Program



Hubs of Innovation

- Hubs are designed to help regions attract businesses, investments and workers and have their roots in an area's strengths.
- For Central Ohio, that means advanced energy development projects that researchers at OSU and Battelle along with companies such as the Edison Welding Institute and American Electric Power Company Inc. are undertaking solo or through a number of partnerships.
- The Hub recognizes the rapid growth of activities in this area generated by the R&D activities of CAR and EWI, by the recent establishment of **CAR Technologies LLC**, by the proposed establishment of a manufacturing plant by **Lio Energy Systems**, a joint venture between Santa Monica, Calif.-based **Coda Automotive Inc.** and **Lishen** Power Battery of China, and by the arrival of **Venturi North America**. CAR Technologies LLC and Venturi are housed at TechColumbus.

**Aimed at Economic Development,  
supported by thriving educational and  
research GATE program**

# Current and Future Work (2011 and beyond)

- **Finish current offerings of GATE courses and complete theses/dissertations of existing GATE Fellows**
- **Ecocar competition in June '11**
- **Ecocar 2 team build up, Summer '11**
- **Continued design and build efforts of new BuckeyeBullet 3, a Li-ion powered Land Speed Record vehicle (400 MPH target!)**
- **New GATE proposal submitted in early April '11, with significantly expanded scope and faculty participation**
  - **Challenge and opportunity: OSU transitions to semesters in Fall '12!**
- **Final report with detailed employment statistics of GATE Fellows, industry participants impacted through GATE courses and certificates**
- **Documentation of leveraging of DOE funds (estimated 3:1) on education alone, and indirect leveraging through research contracts thematically related to GATE program**

# Summary

- DOE funds are **significantly leveraged by industry \$\$**
- The current GATE program has already graduated 30+ **MS and PhD students** placed in the automotive industry in addition to the 45 students from the first GATE program.
- New courses have been developed and offered at OSU and the automotive industry with significant enrollment. Existing GATE courses (some in their 9<sup>th</sup> offering) continue to see significant enrollment both on campus and in industry
- Program is leveraged with very significant industry-sponsored research – **A very symbiotic and seamless relationship**
- GATE students play a **significant leadership role in student vehicle competitions** (Ecocar, Ecocar 2 in near future) and highly visible high technology vehicle demonstrations (BuckeyeBullett 2, 2.5 and 3, new electric motorcycle racing team, etc...)

# Summary

- The GATE program leverages very extensive research experimental facilities at the Center to **enrich the educational experience of GATE students**, serve as a **magnet for attracting new students** and **international visiting scholars**
- The GATE program has been and continues to be a **catalyst for further curriculum development** (undergraduate technical elective course, specialized graduate courses, short courses..), benefiting not only the **student population**, but also **practicing engineers** in the automotive industry.
- The GATE program has led to **very significant proposed and on-going efforts as part of ARRA.**
- **The GATE program has become one of the cornerstone to support economic development in Ohio through Ohio Third Frontier program and the creation of a Ohio Hub of Innovation for Electric Propulsion Vehicles**

# Summary

- This relatively modestly-funded DOE GATE program creates **unmatched value** for the ‘challenged’ automotive industry, and prepares the work force with unmatched competencies to compete in the new realm of the ‘electrification of the automobile’

➔ **Huge societal benefits**