GATE: Energy Efficient Vehicles for Sustainable Mobility

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Center for Automotive Research
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Mechanical and Aerospace Engineering
Electrical and Computer Engineering
Integrated Systems Engineering
Materials Science and Engineering

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Overview

- Timeline
  - Start Date: 10/01/2011
  - End Date: 09/31/2016
  - Percent Complete: 5%
- Budget
- Total funding: $4,420,953
  - DOE share: $907,026
  - Contractor share: $3,513,927
- FY11: $0
- FY12: $180,000 (DOE)
  $700,000 (partners)

- Barriers
  - Fuel economy
  - Lightweight materials and structures
  - Public acceptance of electric drives
- Partners
  - General Motors Corporation
  - Honda Partnership Program (HPP)
  - CAR Industrial Consortium (see slide 16)
  - Smart@CAR Consortium (see slide 17)

Objectives – 1

- The first objective of the OSU GATE Center of Excellence is to prepare a new generation of engineers capable of leading system integration projects in areas related to energy-efficient vehicles:
  1. *efficient energy conversion*,
  2. *advanced energy storage*,
  3. *lightweight body and chassis systems, and*
  4. *vehicle systems control*, including *vehicle-grid and vehicle-infrastructure connectivity*.
- A second objective is to provide a bridge between traditional engineering education, and the needs of the automotive and transportation industry as our society transitions to sustainable mobility, for students and industry practitioners.

Objectives – 2

- A third objective is to *expand the automotive systems engineering curriculum* created through past DoE Graduate Automotive Technology Education (GATE) programs at The Ohio State University (OSU).
- This effort builds upon the successes of two prior GATE programs (1998-2004 and 2005-2011) and has the support of:
  - OSU *College of Engineering*,
  - *OSU Graduate School*,
  - *Center for Automotive Research (CAR)*,
  - *Ohio Manufacturing Institute*,
  - *Departments* of *Mechanical and Aerospace Engineering*, *Electrical and Computer Engineering*, *Materials Science and Engineering* and *Integrated Systems Engineering*.

Milestones

- Milestone 1 - FY2011 Annual Report:
  - Summary of progress made by the DOE GATE Fellows and other participants in the GATE program (course attendance, graduation data, thesis titles, papers, etc.)
- Milestone 2 - Reports for completed and/or offered courses
- Milestone 3 - Quarterly updates of Project Management Plan
- Milestone 4 - FY2012 Annual Report
- Milestone 5 - Reports for completed and/or offered courses
- Milestone 6 - Report describing proposal to Graduate School for expansion of ASE Graduate Interdisciplinary Specialization to 7 focus areas.

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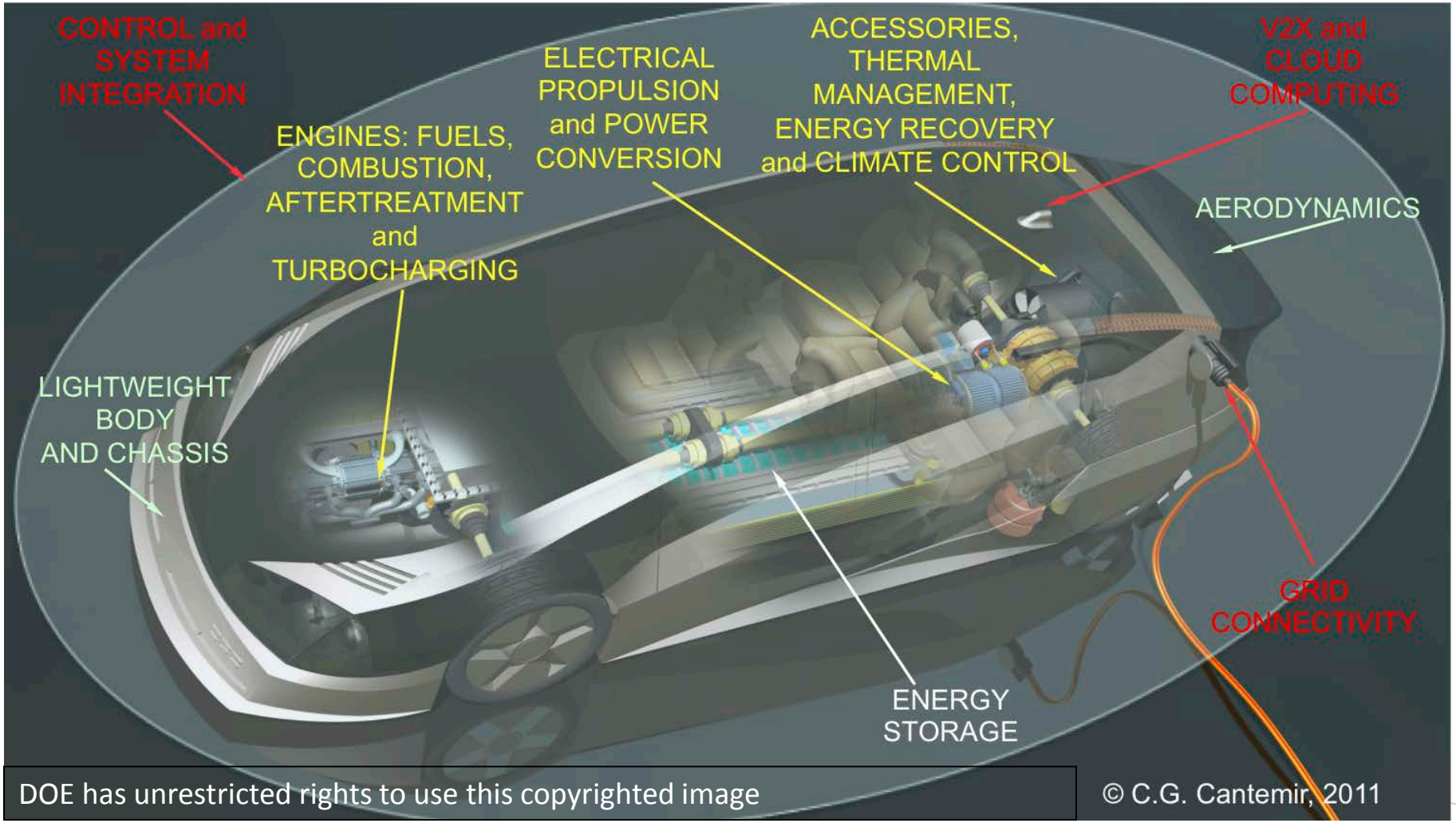
Approach – 1

- The project **GATE: Energy Efficient Vehicles for Sustainable Mobility**, touches on four distinct areas:
  - *efficient energy conversion*,
  - *energy storage*,
  - *lightweight materials for body and chassis systems*,
  - *system integration*.
- Starting from the foundations of scientific and engineering knowledge that are part of the education of our engineering graduates, this project leads to the development of commercial products related to future automotive propulsion, and to their impact on society.

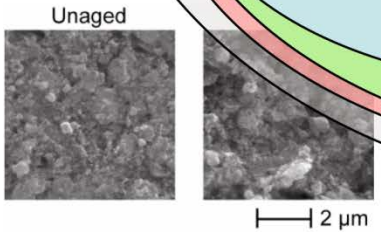
Approach – 2

GATE Topic Areas: efficient energy conversion, energy storage, body and chassis systems and system integration



Approach – 3

From basic science to societal impact through system integration



Emission reduction and efficient energy conversion

"Well-to-wheel" technology assessment

Society

Vehicle demonstrations

Secondary usage of used automotive batteries for grid storage applications

Vehicle impact on grid

Control-oriented modeling

Cloud computing

Real-time control

Hardware-in-the-loop implementation

Thermal synergies, energy harvesting

Optimization design

Optimization of geometry, operating conditions, actuation

Sensor, actuator, hardware implementation

Multivariate optimization

Engine combustion models

Engine flow models, spray dynamics

Turbulent reacting flows, aerodynamics

Material science

Experiments

Control theoretics, control policy, control structure

Experiments

Product Engineering

Multi-dimensional simulations

Electrochemistry, Chemical kinetics

Energy Conversion Efficiency, Advanced Smart and Light Materials

Core Science

Advanced sensing and actuation technology

Experiments

Thermal sciences

Fuel cell and battery modeling

Experiments

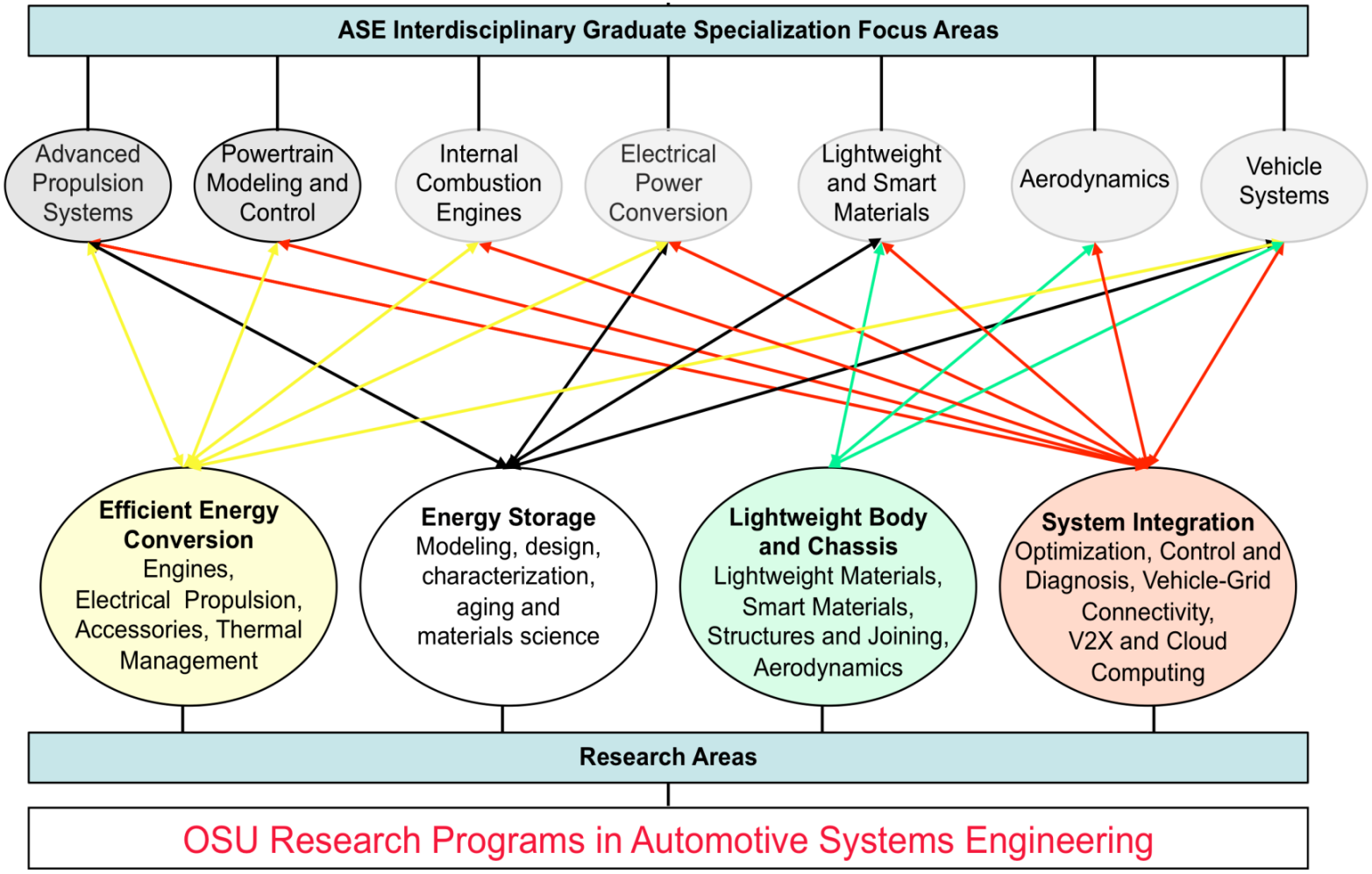
Engineering Science

Battery aging

Advanced Engineering

Approach – 4

Relationship between research expertise and educational program



Technical Accomplishments – 1

- The new GATE Center is built on the outcomes of two DoE GATE Centers of Excellence "*Hybrid Drivetrains and Control Systems*", 1998-2004, and "*Modeling, Control and System Integration of Advanced Automotive Propulsion Systems*", 2005-2011, with significant additional support from the automotive industry.
- These programs leveraged DOE funding by a factor of 5:1 and produced over 70 graduates (roughly two thirds M.S., one third Ph.D.), almost all employed in the automotive sector.
- The graduate course sequences (*Advanced Propulsion Systems* and *Powertrain Modeling and Control*) developed in part thanks to the GATE programs have been completed by over 120 OSU students and 80 industry employees (the latter via distance education), and have been incorporated in an *Interdisciplinary Graduate Specialization in Automotive Systems Engineering* at OSU and in a distance education *Certificate Program* aimed at industry participants.

Technical Accomplishments – 2

- The new curriculum is motivated by a transition from academic quarters to semesters, and begins in Autumn semester 2012.
- The proposed courses, *have all been approved for offering in the semester system*, and are divided into **7 core focus areas**:

1. Advanced Propulsion Systems, APS
2. Powertrain Modeling and Control, PMC
3. Internal Combustion Engines, ICE
4. Electrical Power Conversion, EPC
5. Lightweight and Smart Materials, LWS
6. Aerodynamics, AE
7. Vehicle Systems, VS

Technical Accomplishments – 3

- DOE funding and cost share from industry partners and from the OSU Graduate School have been used as follows:
  - DOE Funds: 7 GATE Fellows (PhD) have been appointed in the first year of the program;
  - Support from GM, HPP, CAR Consortium and SMART@CAR Consortium: 5 Fellows (MS and PhD) have been appointed in the first year;
  - Graduate School: 12 Tuitions and Fees Waivers have been used in support of various student appointments.
  - **Total Value for FY2011-2012:**
    - DOE: $180,000
    - Partners: $700,000

Technical Accomplishments – 4

- GATE Fellows currently funded by **DOE**:

Fellow Name	Advisor	Est. Graduation	Research Topic
Ricky D. Dehner	Ahmet Selamet, MAE	May 2014	Surge in Turbocharger Compressors
Dell Hammond	Marcello Canova, MAE	May 2015	Thermal modeling of Li-Ion batteries
Luis Herrera	Jin Wang, Longya Xu, ECE	2014/2015	Networked control of renewable energy integrated vehicle charging
Chris Jaworski	Joseph Heremans, MAE	August 2012	High efficiency of PbTe materials for automotive waste heat recovery.
Jason Johnson	Glenn Daehn, MSE	2014/2015	Development of protocols for testing materials properties.
Pardis Khayver	Ümit Özgüner, ECE	2013/2014	Control, energy management and grid integration of PHEVs
Justin Scheidler	Marcelo Dapino, MAE	2014/2015	Magnetically-active aluminum for sensing and actuation in harsh environments

Technical Accomplishments – 5

- GATE Fellows currently funded by **Partners**:

Fellow's Name	Advisor	Est. Graduation	Research Topic
Mehmet Tomac	James Gregory, MAE	August 2012	Feedback free type fluidic oscillators for flow control of ground vehicles
Fengjun Yan	Junmin Wang, MAE	August 2012	Nonlinear control of advanced multi-mode combustion Diesel engines
Junqiang Zhou	Marcello Canova, MAE	2014/2015	Control of over-actuated nonlinear systems for advanced turbochargers
Quansheng Zhang	Giorgio Rizzoni, Marcello Canova, MAE	2014/2015	System optimization and supervisory control of vehicle ancillary loads.
Qiuming Gong	Giorgio Rizzoni, MAE	2012/2013	Control and energy management of PHEV/grid interaction

Collaborations

- The GATE program leverages support from General Motors Corporation and the OSU/Honda Partnership Program (HPP). These partners provide support for 3 fellowships/year for the duration of the program.
- Two additional Fellow appointments are supported by the CAR Industrial and SMART@CAR consortia.
- OSU is constantly making efforts to involve other companies in the program, and we expect to add new Partners in 2012.
- A collaboration with University of Texas at Dallas (UTD) was established to support the educational curriculum development.
  - Prof. Stephen Yurkovich, who has retired from OSU and is currently Systems Engineering Department Chair at UTD will offer a course of Powertrain Control and a new Systems Integration course in distance education format to both UTD and OSU students.
  - In turn, OSU will provide a selection of courses from the ASE curriculum to UTD students, further expanding the reach and impact of the program.

Collaborations

- The **CAR Industrial Consortium** focuses on the development of pre-competitive research whose outcomes are shared among industrial partners.
- Current partners: Bosch, Chrysler, CNH, Cummins, Eaton, Ford, GM, Lubrizol, Magnet, Oshkosh Truck, Renault, Samsung, Toyota, TRC Inc. Consortium members have actively recruited among GATE graduates at OSU since 1999.
- Currently, three trust areas concentrate on research areas that are unique to OSU and offer consortium members an opportunity to select research projects:
  - Advanced Propulsion Systems (***APS***);
  - Intelligent Transportation Systems (***ITS***);
  - Lightweight Structures (***LWS***).

Industrial Consortium

Current projects:

- *Life estimation of lithium-ion batteries for PHEVs*
- *PHEV Energy Management: Impact Factors;*
- *Control of diesel engines and aftertreatment;*
- *Thermal modeling of PHEV/EV Li-ion battery packs;*
- *Impact of lubricants on advanced technology vehicles;*
- *Energy and infrastructure analysis (CNG) vehicles.*

Collaborations

- The **SMART@CAR Consortium** is an industry driven research and development program focused on Plug-in Electric Vehicles (PEVs) and intelligent charging.
- Current partners: American Electric Power, Clean Fuels Ohio, Dayton Power and Light, Duke Energy, ECOtality, FirstEnergy, Hitachi, PJM, PlugSmart RechargePower, TE Connectivity, Vanner.
- Topics for research, development, and demonstration are determined by the members on an on-going basis. Currently on-going projects include:

Topics:

- *PEV (Virtual) Fleet Studies*
- *PEV/ Grid Modeling*
- *Residual Life Characterization of PEV Batteries for Secondary Grid Storage Applications*
- *Multiple Vehicles Charging: Circuit and Control*

Future Work – 1: New graduate courses

- **Core Focus Area:** Advanced Propulsion Systems, APC

ME 7384 - Energy Modeling, Simulation, Optimization and Control of Advanced Vehicles (Guezennec, Rizzoni)	ME 7383 - Electrochemical Energy Conversion and Storage Systems for Automotive Applications (Canova, Guezennec)
Autumn semester odd years	*Spring semester even years*

- **Core Focus Area:** Powertrain Modeling and Control, PMC

ME 7236 – Powertrain Dynamics (Rizzoni and Srinivasan)	Powertrain Control (Yurkovich), UTD distance education offering
Autumn semester even years	*Spring semester odd years*
ME 8312 – Diesel Engine Systems Control (Junmin Wang)	
Autumn semester odd years	

Future Work – 2: New graduate courses

- **Core Focus Area:** Internal Combustion Engines, ICE

ME 5530 – Internal Combustion Engines (Selamet)	ME 5531 – Automotive Powertrain Laboratory (Midlam-Mohler)
Autumn semester	*Spring semester*
ME 7240 – Internal Combustion Engine Modeling (Midlam-Mohler)	ME 7520 – Wave Dynamics in Fluids (Selamet)
Spring Semester even years	*Spring semester odd years*
ME 5427 – Intro. to Turbomachinery (Canova)	
Spring semester	

- **Core Focus Area:** Electrical Power Conversion, EPC

ECE 5025 - Power Electronics Devices, Circuits, and Applications (Jin Wang)	ECE 5041 - Electric Machine Fundamentals (Xu)
Autumn semester	*Spring semester*
ECE 5541 Sustainable Energy and Power Systems	
Autumn semester	

Future Work – 3: New graduate courses

- **Core Focus Area:** Lightweight and Smart Materials, LWS

ME 5374 - Smart Materials and Intelligent Systems (Dapino)	MSE 4181: Materials Selection (Daehn)
Spring semester	Autumn semester
MSE 5605: Quantitative Introduction to Materials Science (Daehn)	WE 7101: Welding Metallurgy I (Babu)
Autumn semester	Spring semester

- **Core Focus Area:** Aerodynamics, AE

AAE 6860 - Experimental Fluid Mechanics	AAE 7774 Aeroacoustics
Spring semester odd years	*Spring semester even years*
AAE 7862 Internal Flows in Turbomachinery	AAE 8873 Computational Fluid Dynamics
Spring semester even years	*Spring semester*

Future Work – 4: New graduate courses

- **Core Focus Area:** Vehicle Systems, VS

ME 5234 Vehicle Dynamics (Heydinger)	ME 8322 Vehicle System Dynamics and Control (Wang)
Spring semester	*Autumn semester, even years*
ECE 5553.02 Applications in Control (Autonomous Vehicles) (Ozguner)	ME 8372 Fault Diagnosis in Dynamic Systems (Rizzoni)
Spring semester even years	*Autumn semester, odd years*
ISE 6200 Fundamentals of Optimization (Sioshansi)	ECE 7855 Large Scale and Cyberphysical Systems (Ozguner)
Spring semester	*Autumn semester, even years*
System Integration, (Yurkovich), UTD distance education offering	

Summary

- The proposed program is fully responsive to the DOE GATE FOA:
  - Comprises a broad range of research programs (funded by the automotive industry and by government agencies);
  - Provides outstanding training opportunities for a significant number of graduate students (70 graduate students currently employed at OSU CAR);
  - Facilitates creation of automotive engineering professionals capable of supporting the future needs of the automotive industry.
- The support and cost share provided by OSU and by our industry partners clearly demonstrates the relevance of the proposed program to the industry.
- OSU College of Engineering Career Services office reports that in the past ten years, 11 automotive and commercial vehicle OEMs and 20 suppliers have hired 720 interns and co-ops and 376 full time engineers **from OSU-CAR.**