

# GATE: Energy Efficient Vehicles for Sustainable Mobility

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Center for Automotive Research  
and Departments of:  
Mechanical and Aerospace Engineering  
Electrical and Computer Engineering  
Integrated Systems Engineering  
Materials Science and Engineering  
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Project  
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# Overview

- **Timeline**
  - Start Date: 10/01/2011
  - End Date: 09/31/2016
  - Percent Complete: 40%
- **Budget**
  - Total funding: \$4,420,953
    - DOE share: \$907,026
    - Contractor share: \$3,513,927
  - FY11: \$0
  - **FY12: \$180,000 (DOE)**  
**\$700,000 (partners)**
  - **FY13: \$180,000 (DOE)**  
**\$750,000 (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.

All milestones listed in the PMP have been completed. A summary is given below.

- Milestone 1 – FY 2012 Annual Report:
  - Summary of progress made by the DOE GATE Fellows and other participants in the GATE program (course attendance, graduation data, thesis titles, publications and presentations, etc.)
- Milestone 2 - Reports for completed and/or offered courses
- Milestone 3 - Quarterly updates of Project Management Plan
- Milestone 4 - Report describing proposal to Graduate School for approval of ASE Graduate Interdisciplinary Specialization on the semester calendar
- Milestone 5 - FY2013 Annual Report

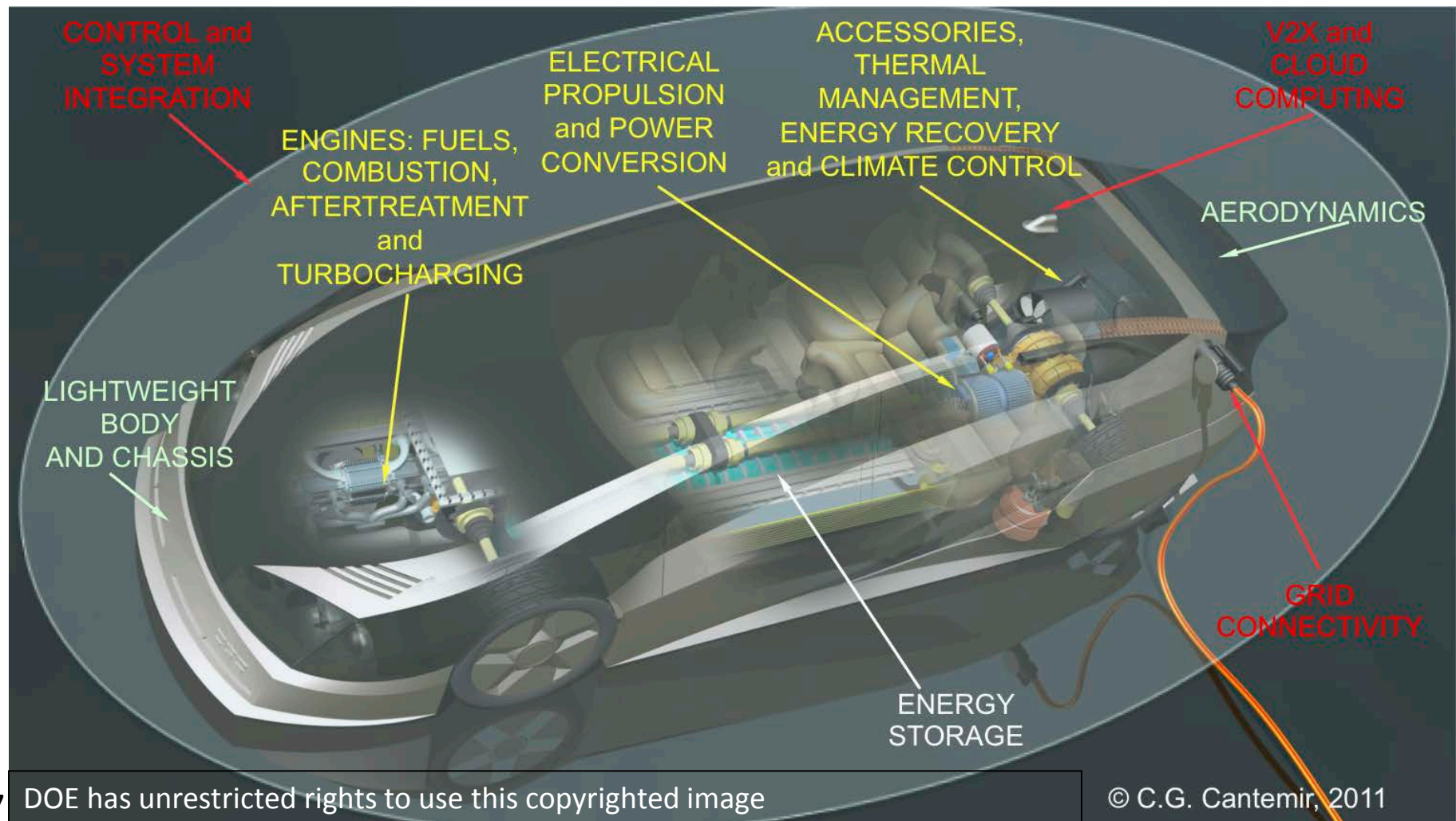
# Approach – 1

- 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***



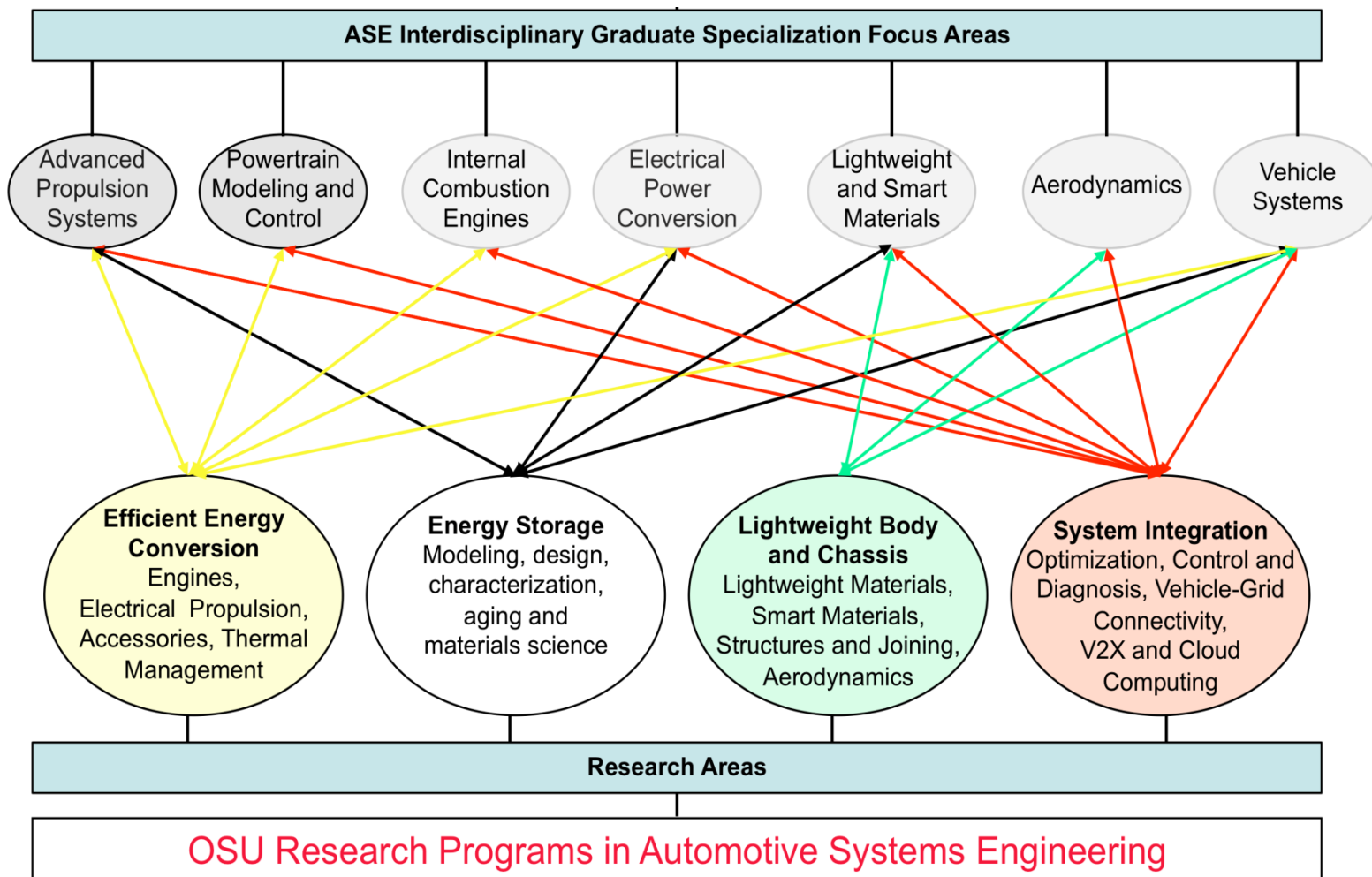
***From basic science to societal impact through system integration***





# 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, motivated by a transition from academic quarters to semesters, began 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 second year of the program;
  - Support from GM, Honda-OSU Partnership Program, CAR Industrial Consortium, SMART@CAR Consortium, and Venturi Buckeye Bullet program has also permitted appointing: 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 FY2012-2013:**
    - DOE: \$180,000
    - Partners: \$750,000      Stipends: \$200,000    Tuition & Fees: \$450,000  
Other: \$100,000 (Faculty & Staff R/T)



# 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
Andrew Garcia	Shawn Midlam-Mohler, MAE	May 2013	Fuel Control in an E85 Fueled SI Engines
Luis Herrera	Jin Wang, Longya Xu, ECE	2014/2015	Networked control of renewable energy integrated vehicle charging
Amanda Hyde	Giorgio Rizzoni, MAE	2014	Traction Control in a PHEV with an Automated Manual Transmission
Jason Johnson	Glenn Daehn, MSE	2014/2015	Development of protocols for testing materials properties.
Pardis Khayver	Ümit Özgüner, ECE	December 2013	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 – 4

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

Fellow Name	Advisor	Est. Graduation	Stipend & Benefits	Tuition & Fees (OSU)
Ricky D. Dehner	Ahmet Selamet, MAE	May 2014	\$25,740	\$17,088
Andrew Garcia	Shawn Midlam-Mohler, MAE	May 2013	\$14,912	\$12,214
Luis Herrera	Jin Wang, Longya Xu, ECE	2014/2015	\$25,202	\$40,892
Amanda Hyde	Giorgio Rizzoni, MAE	2014	\$18,267	\$40,892
Jason Johnson	Glenn Daehn, MSE	2014/2015	\$27,060	\$16,010
Pardis Khayver	Ümit Özgüner, ECE	December 2013	\$25,080	\$40,892
Justin Scheidler	Marcelo Dapino, MAE	2014/2015	\$23,002	\$17,088

# Technical Accomplishments – 5

- GATE Fellows currently funded by **Partners (GM, HPP, CAR Industrial Consortium, SMART@CAR):**

Fellow's Name	Advisor	Est. Graduation	Research Topic
Teng Ma	Shawn Midlam-Mohler, MAE	May, 2013	Shift Control and Fault Diagnosis of a Automated Manual Shifting System
Yan Chen	Junmin Wang, MAE	May 2013	Energy-Efficient Control Allocation for Over-Actuated Systems with Applications to Electric Ground Vehicles
Matthew Yard	Shawn Midlam-Mohler, MAE	May 2014	Control System Integration for a Automated Manual PHEV
Li Tang	Giorgio Rizzoni, MAE	2016	Optimal Energy Management of HEVs with consideration of battery aging
Cong Zhang	Terry Conlisk, MAE	2015/2016	Theoretical and Computational Modeling of Lithium Ion Batteries

# Technical Accomplishments – 5

- GATE Fellows currently funded by **Partners (GM, HPP, CAR Industrial Consortium, SMART@CAR):**

Fellow's Name	Advisor	Est. Graduation	Stipend & Benefits	Tuition & Fees (OSU)
Teng Ma	Shawn Midlam-Mohler, MAE	May, 2013	\$15,972	\$40,892
Yan Chen	Junmin Wang, MAE	May 2013	\$15,972	\$16,010
Matthew Yard	Shawn Midlam-Mohler, MAE	May 2014	\$23,958	\$40,892
Li Tang	Giorgio Rizzoni, MAE	2016	\$23,958	\$40,892
Cong Zhang	Terry Conlisk, MAE	2015/2016	\$24,642	\$40,892



# Technical Accomplishments – 6

- Graduate Fellows currently funded by **Partners: Venturi Buckeye Bullet Program and Ford**

Fellow's Name	Advisor	Est. Graduation	Research Topic
RJ Kromer	Giorgio Rizzoni, MAE/ECE Marcello Canova, MAE	Dec, 2013	Data Acquisition, Simulation, and Control of a Four Wheel Drive Landspeed Vehicle
David Cooke	Giorgio Rizzoni, MAE	Dec, 2014	Design and Implementation of a High Speed Electric Powertrain
LingChang Wang	Giorgio Rizzoni, MAE	Dec, 2013	Design and Optimization of Light Weight Mechanical Systems for a Landspeed Vehicle
Casie Clark	Giorgio Rizzoni, MAE James Gregory, MAE	May, 2014	Aerodynamic development and Verification of a Landspeed Vehicle
Austin Khrohn	Giorgio Rizzoni, MAE/ECE	Dec, 2013	Energy Management and Modeling for an Electric Landspeed Vehicle

# Technical Accomplishments – 6

- Graduate Fellows currently funded by Partners – **Venturi Buckeye Bullet Program and Ford :**

Fellow Name	Advisor	Est. Graduation	Stipend & Benefits	Tuition & Fees
David Cooke	Rizzoni	2015	\$23,958	\$17,088
Austin Krohn	Rizzoni	2015	\$24,314	\$17,088
Robert Kromer	Rizzoni	December 2013	\$24,642	\$17,088
Lingchang Wang	Rizzoni	2014	\$24,642	\$32,236
Casie Clark	Rizzoni/Gregory	2014	11,218	26,129

# Gate Graduates: Spring Semester 2013

- Yan Chen; Adviser: Prof. Junmin Wang, Ph.D., “Energy-Efficient Control Allocation for Over-Actuated Systems with Applications to Electric Ground Vehicles”, Post graduation: **Ford Motor Company**, Internship, Dearborn, MI
- Andrew Garcia; Adviser: Dr. Shawn Midlam-Mohler, MSc, “Feed-Forward Air-Fuel Ratio Control during Transient Operation of an Alternative Fueled Engine”, Post graduation: **General Motors**, Engine Calibration Specialist, Milford MI
- Teng Ma; Adviser: Dr. Shawn Midlam-Mohler; MSc; “Modeling and control of Automated Manual Transmission for PHEV”; Post graduation: TBD

# 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**, and 5 additional Fellows are supported by the Venturi Buckeye Bullet electric land speed record program,
- 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 has offered the course *Powertrain Control* to both UTD and OSU students.
  - In turn, OSU offered the course *Powertrain Dynamics* from the ASE curriculum to both OSU and 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, Cummins, Ford, GM, Honda, Lubrizol, Renault, Samsung, Tenneco, 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**).



# 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, FirstEnergy, PJM, Renault, DNV, TE Connectivity.**
- 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*

# GATE courses offered

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

ME 7384 - Energy Modeling, Simulation, Optimization and Control of Advanced Vehicles (Guezennec, Onori); offered off-cycle sequence to <b>8 distance learning students</b> in Au 2012	ME 7383 - Electrochemical Energy Conversion and Storage Systems for Automotive Applications (Canova, Guezennec); offered off-cycle sequence to <b>8 distance learning students</b> in Spring 2013
<i>Autumn semester odd years</i>	<i>Spring semester even years</i>

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

ME 7236 – Powertrain Dynamics (Rizzoni and Srinivasan); <b>46 students</b> in Fall 2012	Powertrain Control (Yurkovich), UTD distance education offering; <b>14 students</b> Spring 2013
<i>Autumn semester even years</i>	<i>Spring semester odd years</i>

# GATE courses offered

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

ME 5530 – Internal Combustion Engines (Selamet); <b>53 students</b> in Autumn 2012	ME 5531 – Automotive Powertrain Laboratory (Midlam-Mohler); <b>17 students</b> in Spring 2013
<i>Autumn semester</i>	<i>Spring semester</i>
ME 7440 – Internal Combustion Engine Modeling (Guezennec <i>et al.</i> ); <b>8 students</b> in Spring 2013	ME 5427 – Intro. to Turbomachinery (Canova); <b>22 students</b> in 2013
<i>Spring Semester even years</i>	<i>Spring semester</i>

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

ECE 5025 - Power Electronics Devices, Circuits, and Applications (Jin Wang); <b>107 students</b> in Spring 2013	ECE 5041 - Electric Machine Fundamentals (Xu); <b>54 students</b> in Fall 2012
<i>Autumn semester</i>	<i>Spring semester</i>
ECE 5541 Sustainable Energy and Power Systems II (M. Illindala); <b>53 students</b> in Spring 2013	
<i>Autumn semester</i>	



# GATE courses offered

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

ME 5374 - Smart Materials and Intelligent Systems (Dapino); <b>15 students</b> in Sp 2013 <i>Spring semester</i>	MSE 4181: Materials Selection (Daehn); 36 students in Au 2012 <i>Autumn semester</i>
MSE 5605: Quantitative Introduction to Materials Science (Daehn) <i>Autumn semester</i>	WE 7101: Welding Metallurgy I (Babu); <b>40 students</b> in Spring 2013 <i>Spring semester</i>

- Core Focus Area: Vehicle Systems, VS**

ME 5234 Vehicle Dynamics (Heydinger); <b>22 students</b> in Spring 2013 <i>Spring semester</i>	ME 8322 Vehicle System Dynamics and Control (Wang) ; <b>5 students</b> in Fall 2012 <i>Autumn semester; even years</i>
ECE 7855 Large Scale and Cyberphysical Systems (Ozguner); <b>7 students</b> in Fall 2012 <i>Autumn semester; even years</i>	

# 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.**