GATE: ENERGY EFFICIENT VEHICLES FOR SUSTAINABLE MOBILITY

PROJECT TI022

DE-EE0005564

Final report, Year 6 – October 2017

PI: Giorgio Rizzoni

The Ohio State University Center for Automotive Research
and Departments of: Mechanical and Aerospace Engineering;
Electrical and Computer Engineering; Integrated Systems Engineering;
Materials Science and Engineering

October 30th , 2017

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Outline

- Overview and Milestones
- Technical accomplishments
  - Graduates and currently funded students
  - Graduate curriculum
  - Partnership
  - Student project team accomplishments

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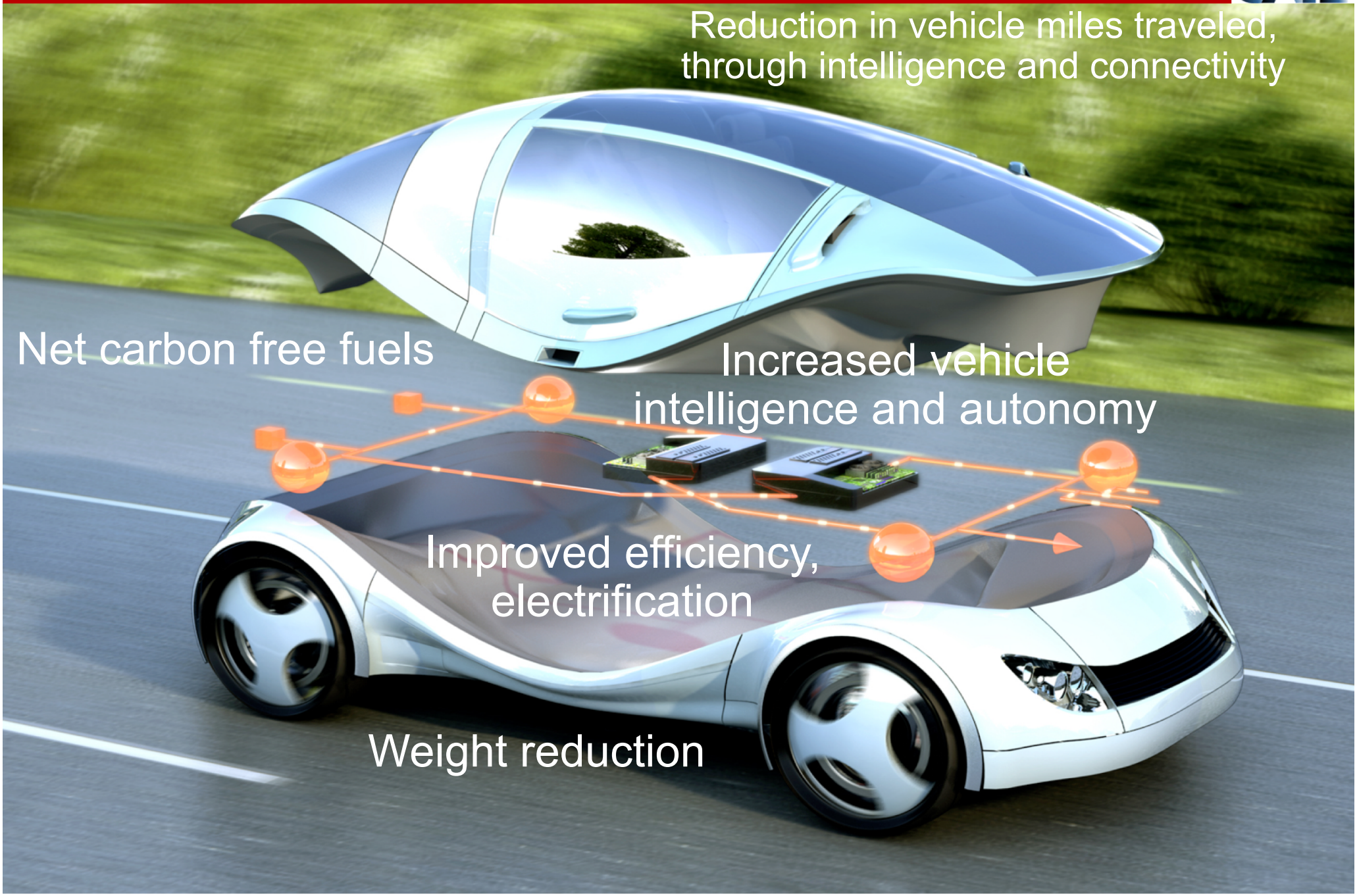
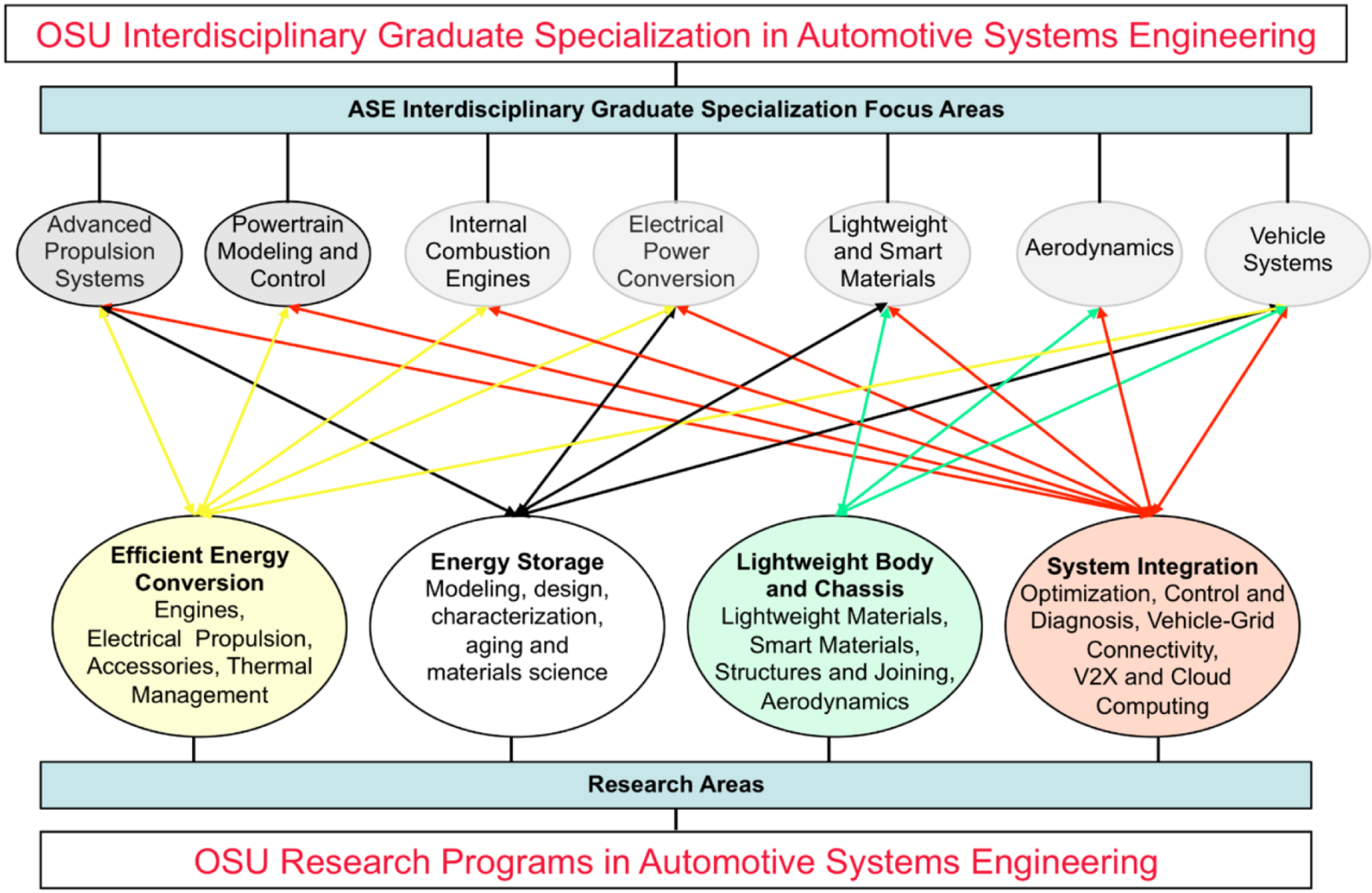
BACKGROUND: TECHNICAL AREAS RELEVANT TO OSU PROGRAM

GATE



BACKGROUND: GRADUATE SPECIALIZATION AND RESEARCH AREAS



OVERVIEW, AS OF SEPTEMBER 2017

Timeline

- Project start date 10/01/2011
- Project end date: 09/30/2017
  Percent complete: 100%

Budget

- Total project funding:
- $4,420,951
  - DOE share: $907,026
  - Contractor share: $3,513,925
- Funding for FY17: Fully funded as of FY14 at $907,026
- $906,673 spent (100%)
  - as of 9/30/2017

Barriers

- Fuel Economy
- Lightweight materials and structures
- Public acceptance of electric vehicles

Partners

- General Motors Corp.
- Honda OSU Partnership
- CAR Industrial Consortium membership program

YEAR 5 MILESTONES (FROM PMP)

5.1 Recruit GATE Fellows and/or renew current GATE fellows **completed**

5.2 Update recruitment material and publicize GATE program **completed**

5.3 Scheduled course offerings in APS core area **completed**

5.4 Scheduled course offerings in MPC core area **completed**

5.5 Scheduled course offerings in ICE core area **completed**

5.6 Scheduled course offerings in EPC core area **completed**

5.7 Scheduled course offerings in LWS core area **completed**

5.8 Scheduled course offerings in AE core area **completed**

5.9 Scheduled course offerings in VS core area **completed**

5.10 Offering of targeted courses from above core areas to industrial partners via distance education **completed.**

5.11 Final report to DOE and Industrial Advisory Board, including final graduation and employment figures. **completed**

CAR CONSORTIUM MEMBERSHIP

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Unique opportunity for industry to engage in original, highly leveraged precompetitive research in automotive and transportation systems, with focus on advanced propulsion systems; fuel economy; vehicle safety, connectivity and autonomy; and advanced driver assistance systems

Additional benefits: prepare graduate students for future careers in automotive industry, reaching undergraduate students through capstone design and other project activities, focused recruitment events

Details: car.osu.edu/industry/car-industrial-consortium

MEMBERSHIP CONSORTIUM: **2017**

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Platinum

DELPHI · Ford · HONDA · RENAULT · TERADATA · TRC · WIND (AN INTEL COMPANY)

Gold

FCA (FIAT CHRYSLER AUTOMOBILES) · GM · TOYOTA · HYUNDAI

BOSCH · Cummins · MERCURY · Rea · TE connectivity

Silver

ST life.augmented · Johnson Controls

2017 CAR CONSORTIUM MEMBERSHIP

• BOSCH	30K
• FIAT CHRYSLER	30K
• CUMMINS	30K
• DELPHI	50K
• GM	30K
• HONDA	50K
• HYUNDAI-KIA	30K
• JOHNSON CONTROLS	10K
• MERCURY MARINE	30k
• REA MAGNET WIRE	30K
• RENAULT	50K
• ST Microelectronics	10K
• T.E.CONNECTIVITY	30K
• TERADATA	50K
• TOYOTA	30K
• TRC	50K
• WIND RIVER	50K
• **TOTAL**	**590K**

TASK 5.10: CONTINUING EDUCATION

- In 2016, OSU launched a continuing education program with ***Fiat Chrysler Automobiles (FCA) Latin America*** in the areas of Computer Aided Engineering and Advanced Powertrain Systems;
- Four certificate programs have been created, each including preparation seminars, two OSU graduate-level courses, and an advanced seminar;
- The certificate program consists of a combination of in-person teaching (prep seminars), and online courses with access to the Instructor and a dedicated Teaching Assistant (TA).

Certificate Program	Prep Seminars	OSU Courses	Advanced Seminars
	August 2016	Autumn 2016 - Spring 2017	Spring 2017
Internal Combustion Engines	ICE Fundamentals	ICE Modeling (ME7440) - Au16	Advances in IC Engines
	Dynamics System Prep	Powertrain Dynamics (ME7236) - Sp17	
	MATLAB/Simulink Prep		
NVH	MATLAB/Simulink Prep	NVH I (ME7260) - Au16	Driveline Systems
		NVH II (ME7262) - Sp17	
Powertrain Systems	ICE Fundamentals	Sim Techs for Dynamic Sys (ME5339) - Au16	Advances in IC Engines
	Dynamics System Prep	Powertrain Dynamics (ME7236) - Sp17	
	MATLAB/Simulink Prep		
Powertrain Controls	Dynamics System Prep	Sim Techs for Dynamic Sys (ME5339) - Au16	Alternative Fuels
	MATLAB/Simulink Prep	Powertrain Controls (ECE5554) - Sp17	

TASK 5.10: CONTINUING EDUCATION

Certificate Program	*Enrolled Students*
Internal Combustion Engines	4
NVH	4
Powertrain Systems	4
Powertrain Controls	4

FCA FIAT CHRYSLER AUTOMOBILES

C . e . S . A . R

Prof. Marcello Canova with FCA LATAM students (Aug. 2016)

TASK 5.10: CONTINUING EDUCATION

- In 2016, OSU organized a series of short courses with ***Honda Research of America***, to provide focused training to their engineers in key technical areas:

Internal Combustion Engine Fundamentals (July 25-26, 2016)

- 14 HRA associates attended two half-day, live sessions at CAR taught by Prof. Yann Guezennec

Introduction to Hybrid Electric Vehicles (August 8-10, 2016)

- 27 HRA associates attended 3-day live short course at CAR taught by Prof. Giorgio Rizzoni
- Hands-on lab sessions included using simulation tools to analyze and design energy management strategies

Advances in Internal Combustion Engine (September 14, 2016)

- 18 HRA associates attended one full-day live session at CAR taught by Prof. Marcello Canova

- In addition, OSU has offered a short course with ***Ford Motor Company***:

Signals and Systems for Control (Oct. 17- Nov. 30, 2016)

- 10 Ford engineers in US and UK enrolled in control seminar
- Seminar is delivered online by Prof. Steve Yurkovich, OSU professor emeritus, and current systems engineering department chair at UT Dallas
- Pilot offering will be evaluated in December 2016 for the development of a customized control seminar in 2017.

SUSTAINABILITY PLAN

Throughout the GATE program, OSU has successfully leveraged industry support to significantly extend the program funding by providing matching funds to support graduate students, and by enrolling in the continuing education program. The requested program extension will insure that the educational programs developed for our key industry partners (leading to certificates of completion in various technology areas) will be in place and will lead to continued funding for the program from the automotive industry. In addition, OSU CAR has recently revised and expanded its industry membership program. Member companies pay an annual membership fee that is largely dedicate to graduate student support through exploratory research projects. Members also receive a discount on the continuing education programs. OSU CAR collected over $500,000 in fees in 2017. We believe that from fiscal year 2018 on the program will sustain itself through membership fees and continuing education receipts.

TECHNICAL ACCOMPLISHMENTS

Since 2011, the GATE program has made an impact on the career of ***58 Graduate Students***

Summary:

- Funded GATE Fellows since beginning of the program: 58;
- GATE Graduate Employment Records (some students are still completing their degrees):
  - Ford (9)
  - General Motors (8)
  - Fiat Chrysler Automobiles (4
  - Cummins (4)
  - Bosch (2)
  - AVL (1)
  - A123 (1)
  - John Deere (1)
  - Delphi (1)
  - Crane Aerospace (1)
  - Academic Positions (4)
  - Other (6)

TECHNICAL ACCOMPLISHMENTS

- ***36*** students graduated since beginning of GATE program:

Fellow Name	Advisor	Grad. Date	Degree	Current Employment
Dell Hammond	Canova	April 2013	MS, ME	John Deere
Junqiang Zhou	Canova	Apr 2015	Ph.D., ME	Mitsubishi Electric Research Labs
Mehmet Tomac	Gregory	Apr 2013	Ph.D., ME	Abdullah Gul University (Turkey)
Chris Jaworski	Heremans	Dec 2013	MS, ME	Tosoh SMD
Andrew Garcia	Midlam-Mohler	May 2013	MS, ME	General Motors
Teng Ma	Midlam-Mohler	May 2013	MS, ME	AVL
Eric Gallo	Midlam-Mohler	Aug 2014	MS, ME	General Motors
Pardis Khayyer	Ozguner	Dec 2013	Ph.D., ECE	Cummins
James Wollaeger	Ozguner	Apr 2012	MS, ECE	Bosch
Engin Ozatay	Ozguner	Aug 2014	Ph.D., ECE	Ford Motor Company
Amanda Hyde	Rizzoni	May 2013	MS, ME	General Motors
Robert Kromer	Rizzoni	Apr 2014	MS, ME	Ford Motor Company
Lingchang Wang	Rizzoni	Apr 2014	MS, ME	A123
Qiuming Gong	Rizzoni	Jun 2013	Ph.D., ME	Ford Motor Company
Austin Krohn	Rizzoni	May 2014	MS, ME	Crane Aerospace
Casie Clark	Rizzoni/Gregory	Apr 2014	MS, ME	Lockheed Martin
Fengjun Yan	Wang	Jun 2012	Ph.D., ME	McMaster University (Canada)
Yan Chen	Wang	May 2013	Ph.D., ME	Ford Motor Company

- ***36*** students graduated since beginning of GATE program:

Fellow Name	Advisor	Grad. Date	Degree	Current Employment
Alex Bartlett	Rizzoni	May 2015	Ph.D. ME	Ford Motor Company
John Frederick	Selamet	May 2015	MS, ME	Fiat Chrysler Automobiles
Eric Lott	Canova	August 2015	MS, ME	Fiat Chrysler Automobiles
Matthew Yard	Midlam-Mohler	December 2014	MS, ME	General Motors
Jason Ward	Midlam-Mohler	May 2015	MS, ME	Ford Motor Company
Luis Herrera	Wang, Jin	August 2015	Ph.D. ECE	Rochester Institute of Technology
Justin Scheidler	Dapino	August 2015	Ph.D. ME	
Quansheng Zhang	Rizzoni	August 2015	Ph.D. ME	Ford Motor Company
Katherine Bovee	Rizzoni	December 2015	Ph.D. ME	General Motors
MJ Yatsko	Midlam-Mohler	May 2016	MS, ME	General Motors
Aaron Bonnell	Canova	May 2016	MS, ECE	Bosch
Nathan Lord	Canova	August 2016	MS, ME	Eaton Corp.
Sam Yacinthe	Midlam-Mohler	August 2016	MS, ME	Earnst & Young
Guodong Fan	Canova	August 2016	Ph.D. ME	Cummins, Inc.
Ricky Dehner	Selamet	December 2016	Ph.D. ME	The Ohio State University
Li Tang	Rizzoni	May 2017	Ph.D. ME	Delphi
Derek Riddle	Canova	August 2017	MS, ME	Cummins
Kshitij Shah	Rizzoni	August 2017	MS, ME	Cummins

TECHNICAL ACCOMPLISHMENTS

- ***Thirteen*** graduate students currently working on sponsored research programs, and initially supported by the GATE program:

Fellow Name	Advisor	Est. Graduation	Funding	Research Topic
Andrew Klarner (Ph.D.)	Luo	December 2017	Am Lightweight Materials Innovation Inst	Lightweight materials
Jianzhe Liu (Ph.D.)	Zhang, Wei	December 2017	NSF - CAREER	Hierarchical Coordination of DER's in future distribution
Brian Rahman (Ph.D.)	Rizzoni	May 2019	Parker Hannifin	Fault diagnosis in complex systems
Mustafa Ridvan Cantas (Ph.D.)	Levent Guvenc	May 2021	National University Transportation Center	Vehicle autonomy
Nitish Chandramouli (Ph.D.)	Levent Guvenc	May 2020	Hyundai	Vehicle autonomy
Yuxing Liu, ME, Ph.D. pre-candidate	Marcello Canova	May 2019	General Motors	Control strategies for boosted engines
Shreshta Rajakumar Deshpande (Ph.D.)	Marcello Canova	December 2017	ARPA-E	Powertrain control

TECHNICAL ACCOMPLISHMENTS

- ***Thirteen*** graduate students currently working on sponsored research programs, and initially supported by the GATE program:

Fellow Name-	Advisor	Est. Graduation	Funding	Research Topic
Tong Zhao (Ph.D.)	Giorgio Rizzoni	May 2021	DOE-Truck	HEV energy management
Sukru Gelbal (Ph.D.)	Levent Guvenc	May 2019	NSF - EAGER	Vehicle autonomy
Adithya Jayakumar (Ph.D.)	Giorgio Rizzoni	December 2017	Ford Alliance	HEV fuel economy improvements using computational optimization
Kaveh Khodadadi Sadabadi (Ph.D.)	Giorgio Rizzoni	May 2020	Ford Alliance	Diagnostics and prognostics of automotive systems
Ke Pan (Ph.D.)	Marcello Canova	December 2017	Univ of Akron PRESIDES	Electrochemical models of Li-ion batteries
Ruochen Yang (Ph.D.)	Giorgio Rizzoni	May 2018	Cummins	On-board diagnostics for engine emissions control systems

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Course offerings AU2015

AU 2015		
Course #	**Course Name**	**Instructor**
ME 7384	Energy Modeling, Simulation, Optimization and Control of Advanced Vehicles	*Guvenc / Rizzoni*
ECE 5025	Power Electronics Devices, Circuits and Applications	Wang, Jin
ME 7260	Automotive Noise and Vibration Control I	Singh
ME 8372	Fault Diagnosis in Dynamic Systems	Rizzoni
ME 5339	Simulation Techniques for Dynamic System Analysis and Design	Canova
ME 5194	Project Management	Midlam-Mohler
ME 5530	Internal Combustion Engines	Selamet
ME 8312	Diesel Powertrain Systems Control	Wang, Junmin

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Course offerings SP2016

GATE
GRADUATE AUTOMOTIVE TECHNOLOGY EDUCATION

SP 2016		
Course #	**Course Name**	**Instructor**
ME 7383	Electrochemical Energy Conversion and Storage Systems for Automotive Applications	Canova / Guezennec
ECE 5041	Electric Machine Fundamentals	Xu
ECE 5127	Power Electronics Lab	Xu
ME 7262	Automotive Noise and Vibration Control II	Singh
ME 5234	Vehicle Dynamics	Heydinger
ECE 5553	Autonomy in vehicles	Ozguner
ME 5531	Automotive Powertrain Laboratory	Midlam-Mohler
ME 5427	Introduction to Turbomachinery	Canova

Course offerings AU2016

AU 2016		
Course #	**Course Name**	**Instructor**
ECE 5025	Power Electronics Devices, Circuits and Applications	Wang, Jin
ME 8322	Vehicle System Dynamics and Control	Wang, Junmin
ME 5339	Simulation Techniques for Dynamic System Analysis and Design	Canova
ME 7236	Powertrain Dynamics	Rizzoni / Srinivasan
ME 5530	Internal Combustion Engines	Selamet

Course offerings SP2017

SP 2017		
Course #	**Course Name**	**Instructor**
ECE 5041	Electric Machine Fundamentals	Xu
ECE 5127	Power Electronics Lab	Xu
ME 5234	Vehicle Dynamics	Heidinger
ECE 5554	Powertrain Control	Guvenc
ME 5531	Automotive Powertrain Laboratory	Midlam-Mohler
ME 5427	Introduction to Turbomachinery	Canova
ME 7440	Internal Combustion Engine Modeling	Canova
ME 7520	Wave Dynamics in Fluids	Selamet

SUMMARY

- The proposed program has been fully responsive to the DOE GATE FOA:
  - Comprised a broad range of research programs (funded by the automotive industry and by government agencies);
  - Provided outstanding training opportunities for a significant number of graduate students;
  - Facilitated creation of automotive engineering professionals capable of supporting the future needs of the automotive industry.
  - Provided and continues to provide advanced continuing education to numerous automotive industry partners
- The support and cost share provided by OSU and by our industry partners clearly demonstrates the relevance of the proposed program to OSU academic programs and industry partners.

REPORT ON OSU MOTORSPORTS STUDENT PROJECTS

THROUGH APRIL 2017

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- Ohio State secured its ***fourth consecutive First Place finish*** in Year Three of EcoCAR 3!

- Scores (out of 1000 points)
- **1. Ohio State – 853**
- 2. Embry-Riddle Aeronautical University – 761.7
- 3. Georgia Tech – 727
- 4. West Virginia University – 676
- 5. University of Tennessee – 666
- 6. Virginia Tech - 576

Technical Accomplishments – EcoCAR 3

- 1st Place Project Management Program
- 1st Place Project Management Presentation
- 1st Place Electrical and ADAS Presentation
- 1st Place Innovation Report
- 1st Place Vehicle Design Review
- 1st Place Energy Consumption
- 1st Place Well to Wheels Petroleum Energy Use
- 1st Place Well to Wheels Criteria Emissions
- 1st Place Well to Wheels Greenhouse Gas Emissions
- 1st Place dSPACE Embedded Success Award

Technical Accomplishments – Venturi Buckeye Bullet 3

Venturi Buckeye Bullet Racing is a land speed racing project with the goal of exceeding 400 MPH with an electric vehicle for the first time in history. Project partners include OSU-CAR and Venturi Automobiles.

Key Thrust Areas

- Electric powertrain development, integration, and control
- Aerodynamic optimization for drag reduction and stability
- Li-ion battery management and rapid charging technology
- Advanced energy storage integration
- Lightweight structures
- High speed wheel package development (custom bearing, cv joint, wheel, and tire)

Technical Accomplishments – Venturi Buckeye Bullet 3

FIA World Record – 341.264 MPH

Top Speed – 358 MPH

United States Auto Club

USAC

Certificate of Performance

The undersigned certify in the name of the United States Auto Club That

on August 21st, 2015, Roger Schroer driving the "Venturi VBB3" streamliner at the Bonneville Salt Flats, established new American Category A Group VIII Class 8 records in the kilometer and mile distances by averaging the following two way flying start speeds:

DISTANCE	TIME	SPEED	SPEED
KILOMETER	9.298	387.180 KM/H	240.582 MPH
MILE	14.980	240.320 MPH	386.757 KM/H

- 5 Days of testing
- Salt conditions much Improved from previous years

RECORD ACHIEVED

- Run time 108 s
- Record Average Speed 341 mph
- Peak speed 358 mph
- 100% maximum torque
- Peak output power 1.75 MW
- Motor speed 7,870rpm @ 2nd gear
- Maximum motor temperature 140° C
- Maximum IGBT temperature 48° C

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BUCKEYE CURRENT

Track Record:

***RW-1** Motorcycle: ECTA Land Speed Record 2012 at 144 mph*
***RW-2** Motorcycle: Isle of Man TT Zero 2013 – Third Place*
***RW-2x** Motorcycle: Isle of Man TT Zero 2014 – Third Place*
***RW-3** Motorcycle: Pikes Peak International Hill Climb 2015 – Second Place in Electrics*
***RW-3x** Motorcycle: Pikes Peak International Hill Climb 2016 – Third Place in Electrics*
***RW-3x2** Motorcycle: Pikes Peak International Hill Climb 2016 – **FIRST** Place in Electrics*

Buckeye Current is an OSU student engineering team that builds electric motorcycles in order to educate its members and compete against the best in the world.

The team is six years old and has already raced at the prestigious Isle of Man Zero TT and Pikes Peak International Hill Climb with great success.

2017 RW-3x2

BUILT FOR THE RECORD BOOKS

200 kW	***7.7 kWh***	***120 mph***	***520 lb***	***9:45 Lap Goal***
Peak Power At The Wheel	*Custom Made Battery Pack*	*Top Speed At Pikes Peak*	*Student-designed Student-built*	*To Break Record At PPIHC*

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Contact:

Giorgio Rizzoni

Director, OSU CAR

Professor, MAE and ECE

rizzoni.1@osu.edu

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