

GATE: ENERGY EFFICIENT VEHICLES FOR SUSTAINABLE MOBILITY



PROJECT TI022

Semiannual report, Year 4 – June 2015

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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
June, 2015

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CENTER FOR AUTOMOTIVE RESEARCH



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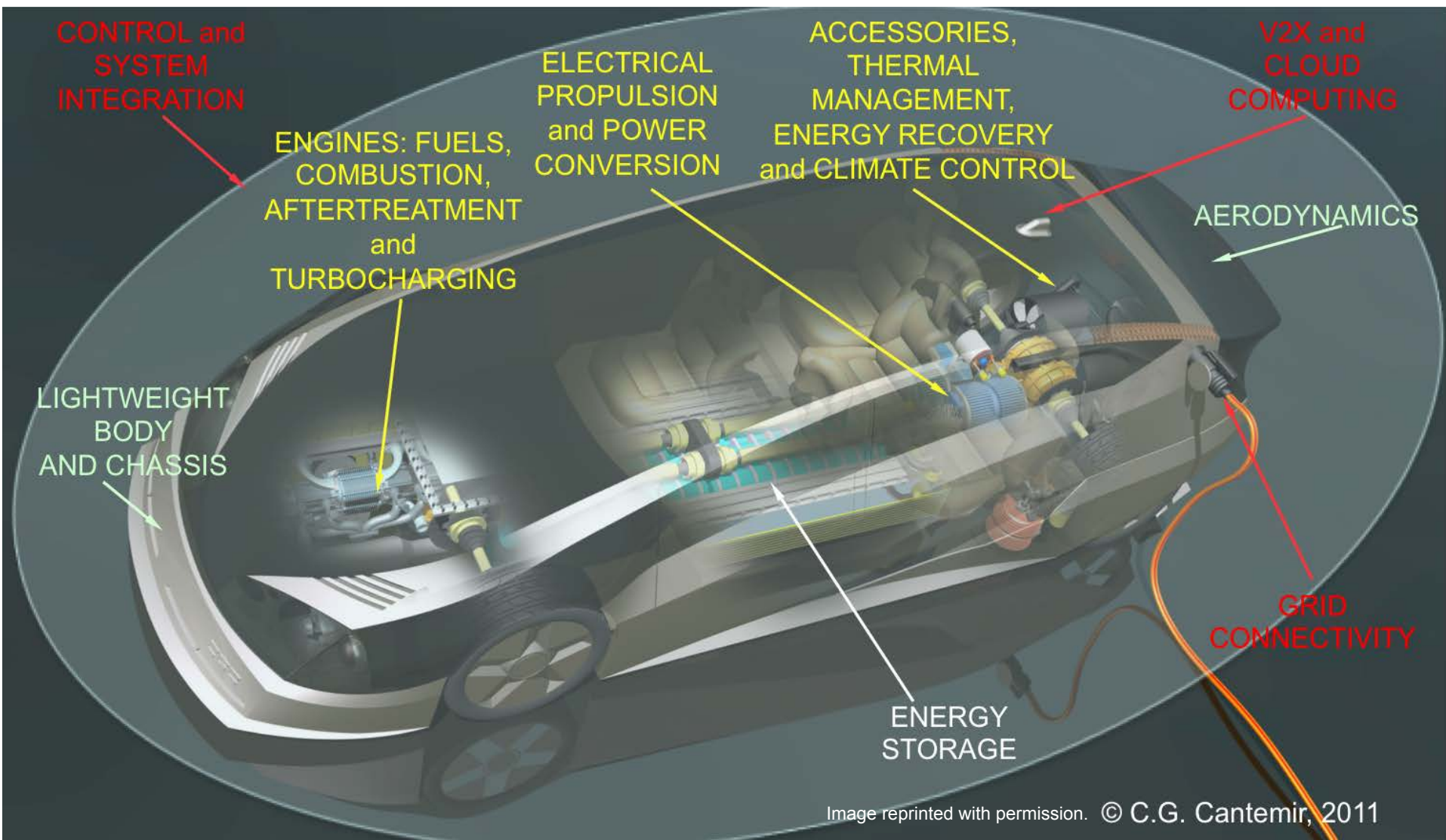
COLLEGE OF ENGINEERING



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

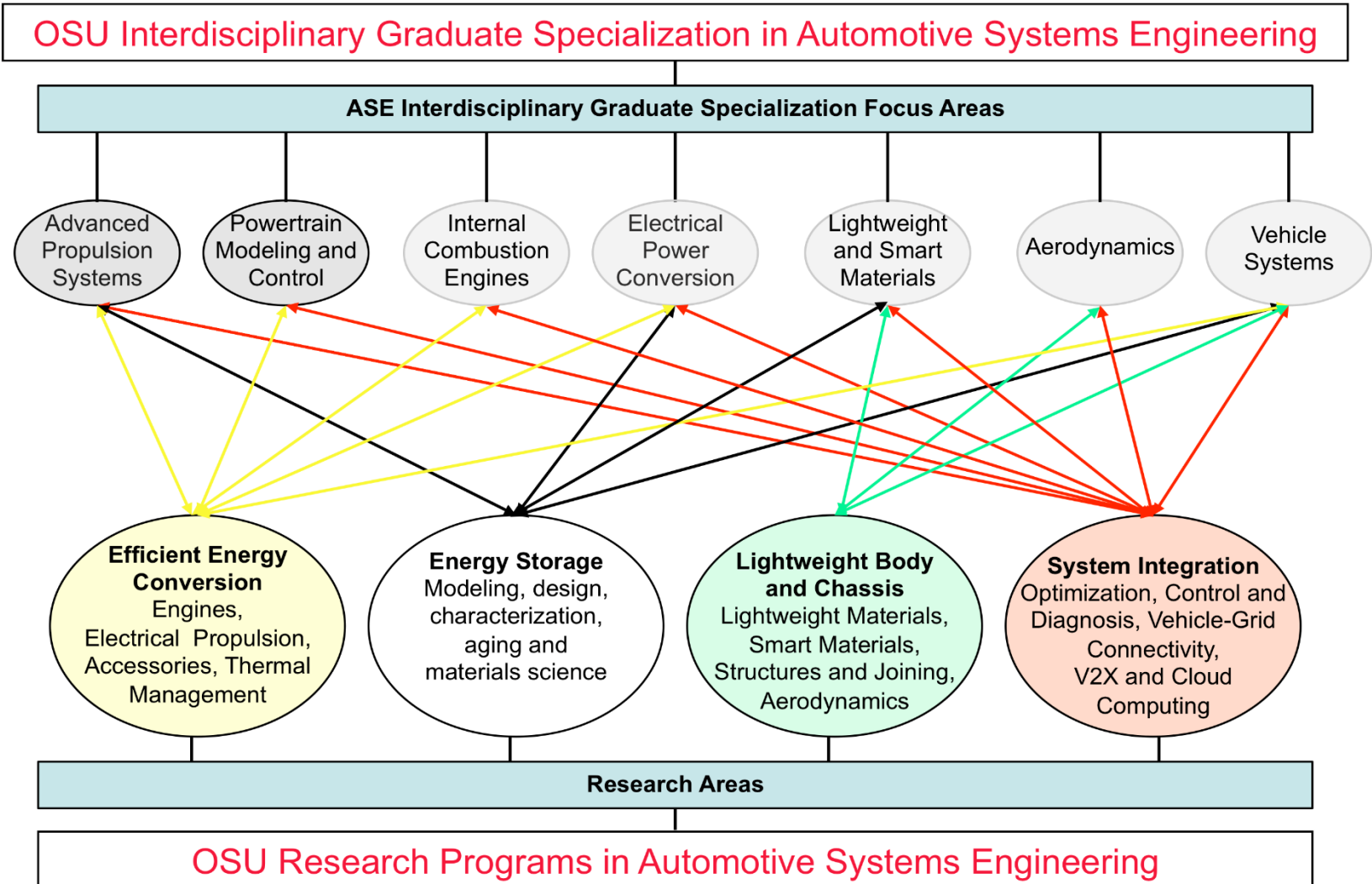


BACKGROUND: TECHNICAL AREAS RELEVANT TO OSU PROGRAM





BACKGROUND: GRADUATE SPECIALIZATION AND RESEARCH AREAS





OVERVIEW, AS OF JUNE 2015

Timeline

- Project start date
10/01/2011
- Project end date:
09/30/2016
- Percent complete: 70%

Budget

- Total project funding:
- \$4,420,951
 - DOE share: \$907,026
 - Contractor share: \$3,513,925
- Funding in FY14: \$501,184
- Funding for FY15: Fully funded
as of FY14 at \$907,026
- \$581,736 spent (64.1%)
 - as of 3/31/2015

Barriers

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

Partners

- General Motors Corp.
- Honda OSU Partnership
- Venturi Automobiles
- CAR Industrial Consortium
- SMART@CAR Consortium



YEAR 4 MILESTONES (FROM PMP)

- Task 4.1: Recruit GATE fellows **completed**
- Task 4.2: Update recruitment material and publicize GATE program **completed**
- Task 4.3: Scheduled course offerings in APS core area (**completed**)
- Task 4.3: Scheduled course offerings in PMC core area (**completed**)
- Task 4.5: Scheduled course offerings in ICE core area (**completed**)
- Task 4.6: Scheduled course offerings in EPC core area (**completed**)
- Task 4.7: Scheduled course offerings in LWS core (**completed**)
- Task 4.8: Scheduled course offerings in AE core area (**completed**)
- Task 4.9: Scheduled course offerings in VS core area (**completed**)
- Task 4.10: Permanent offering of new system integration course (VS core area) (*in progress*)
- Task 4.11: Offering of targeted courses from above core areas to industrial partners via distance learning (**completed**)
- Task 4.12: Increase industrial support by seeking additional fellowship funding (*in progress*)
- Task 4.13: Track graduation and employment of GATE Fellows (**completed**)
- Task 4.14: Report to DOE and Industrial Advisory Board and participation in DOE Merit review (*will be complete when the semi-annual report is presented at AMR*)



TECHNICAL ACCOMPLISHMENTS

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

Summary:

- Currently Funded GATE Fellows: 15 (7 by DOE; 8 by Partners);
- Funded GATE Fellows since beginning of the program: 42 (including current);
- GATE Graduate Employment Records:
 - Ford (4)
 - General Motors (3)
 - Cummins (1)
 - Bosch (1)
 - AVL (1)
 - A123 (1)
 - John Deere (1)
 - Lockheed-Martin (1)
 - Others (2)
 - Academic Positions (3)



TECHNICAL ACCOMPLISHMENTS

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

Fellow Name	Advisor	Est. Graduation	Research Topic
Alexander Bartlett, ME Ph.D.	Giorgio Rizzoni	May 2015	State of charge and state of health estimation of Li-ion batteries using reduced-order electrochemical models
John Frederick, MS, ME	Ahmet Selamet	May 2016	Advanced Engine Combustion
Danielle Fredette, ECE Ph.D. pre-candidate	Ümit Özgüner	May 2016	Human driver modeling and comparison of methods using a driving simulator
Scott Schnelle, ME, Ph.D. pre-candidate	Junmin Wang	May 2017	Electric vehicle control
Meng Huang, ME Ph.D. pre-candidate	Giorgio Rizzoni	May 2020	Battery pack state of health monitoring
Scott Sutton, MSE	Alan Luo	May 2017	Hot compression behavior of lightweight magnesium alloys
Santhosh Tamilarasan, ME	Levent Guvenc	May 2020	Control of driveability in HEVs



TECHNICAL ACCOMPLISHMENTS

- **Five** GATE Fellows, currently funded by **Partners (HPP, GM)**:

Fellow Name	Advisor	Est. Graduation	Research Topic
Margaret Yatsko	Shawn Midlam-Mohler	May 2017	HIL control development of ECOCAR 3
Haoan Wang	Levent Guvenc	May 2019	Vehicle autonomy
Yixian Liu	Ramteen Sioshansi	May 2017	Optimal location of charging stations
Nathan Lord	Marcello Canova	May 2016	Modeling and Control of Electric Racing Motorcycle
Jason Ward	Shawn Midlam-Mohler	May 2016	Model-Based Control for an E85 Engine

- **Three** GATE Fellows currently funded by **Partners (Venturi)**:

Fellow Name	Advisor	Est. Graduation	Research Topic
David Cooke, MS, ME	Rizzoni	August 2015	System Integration of the Buckeye Bullet 3 Land Speed Record electric vehicle
Evan Maley, MS, ME	Rizzoni	May 2015	Design and analysis of the suspension system for the BB3 LSR electric vehicle
Luke Kelm, MS, ME	Rizzoni	May 2015	Design and analysis of the mechanical transmission for the BB3 LSR electric vehicle



TECHNICAL ACCOMPLISHMENTS

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

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



TECHNICAL ACCOMPLISHMENTS

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

Fellow Name	Advisor	Est. Graduation	Funding	Research Topic
Fan, Guodong (Ph.D.)	Canova	August 2016	Ford	Model order reduction for thermal analysis of Li-ion batteries
Johnson, Jason (Ph.D.)	Daehn			
Scheidler, Justin (Ph.D.)	Dapino	May 2015	NASA	Magnetostrictive Variable Stiffness Devices for Vibration Control
Klarner, Andrew (Ph.D.)	Luo			
Yard, Matthew (ME)	Midlam-Mohler	August 2015		Hardware-in-the-Loop simulation development for OSU EcoCAR 2
Bovee, Katherine (Ph.D.)	Rizzoni	April 2016		
Tang, Li (Ph.D.)	Rizzoni	April 2016	Honda	Supervisory control of electrified vehicles
Dehner, Ricky (Ph.D.)	Selamet	April 2016	Ford	Characterization of surge behavior in turbocharger compressors
Herrera, Luis (Ph.D.)	Wang / Xu	April 2017	Air Force Research Lab	Modeling, Analysis and Detection of DC Arc Faults in Power Electronics Systems



AU 2015		
Course #	Course Name	Instructor
ME 7384	Energy Modeling, Simulation, Optimization and Control of Advanced Vehicles	<i>Guvenc / Rizzoni</i>
ECE 5025	Power Electronics Devices, Circuits and Applications	Wang_E
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_M



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



AU 2016

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



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



TECHNICAL ACCOMPLISHMENTS

Collaborations

- The GATE program leverages support from **General Motors Corporation** and the **Honda-OSU Partnership Program** (HPP). These partners provide support for 3 fellowships/year for the duration of the program. General Motors recently increased its support of the program.
- **Venturi Automobiles** has provided support for 7 GATE Fellows, as part of the Venturi Buckeye Bullet 3 Land Speed record Electric Land Speed Record program
- Two additional Fellow appointments are supported by the **CAR Industrial and SMART@CAR consortia**.



CAR INDUSTRIAL CONSORTIUM

- 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, Tenneco, TRC Inc.** Consortium members have actively recruited among GATE graduates at OSU since 1999.

Current projects:

- *Life estimation of lithium-ion batteries for PHEVs*
- *Thermal and electrochemical modeling of PHEV/EV Li-ion battery packs;*
- *Model-based investigation of lean gasoline PM and NOx control*
- *Light-duty natural gas engine characterization*





SMART@CAR CONSORTIUM

- 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, FirstEnergy, SDGE, Renault, Ford, GM, Chrysler, UT Dallas, TE Connectivity.
- Topics for research, development, and demonstration are determined by the members on an on-going basis. Currently on-going projects include:

Topics:

- Electric Vehicle Penetration and Adoption in Ohio
- DC Fast Charging Impact on Electric Grid
- Microgrid Testbed and Installation at CAR
- Secondary Life of Automotive Batteries: Aging and Economic Analysis



CHRYSLER



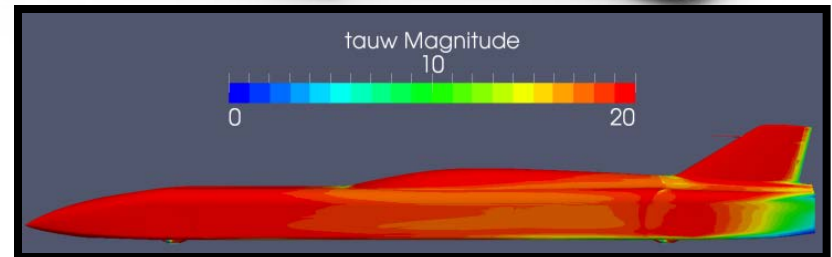
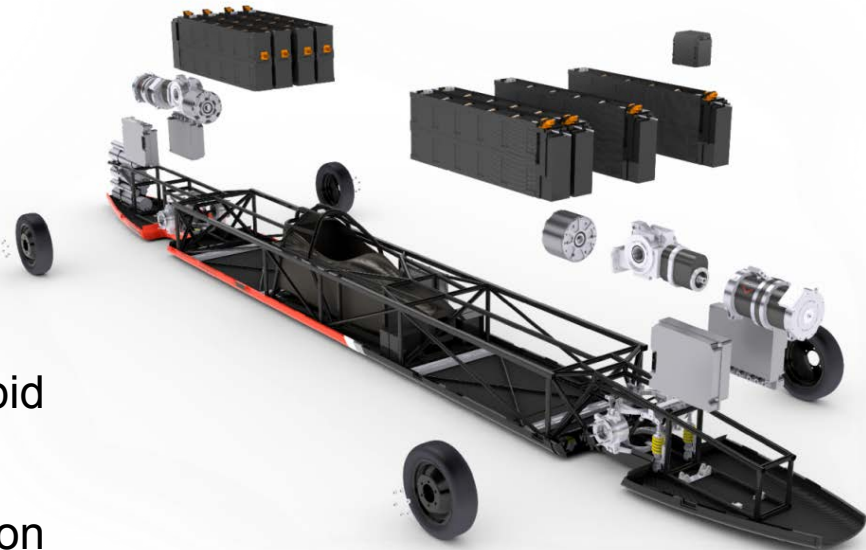


Technical Accomplishments – Venturi Buckeye Bullet 3

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

2014 Accomplishments

- Commissioned Full Power Motor Test Bench
- Test Track Validation of All Vehicle Systems
- Enhanced Control and Power Systems Wiring Harness
- High Performance Coatings
- Initial Salt Flats Testing to 270 MPH



Employers of Recent Graduates

- Ford - SMT
- A123 Systems
- Boeing Co.
- Lockheed Martin
- Northrop Grumman
- Mercedes Formula 1
- Battelle





Technical Accomplishments – EcoCAR 2

1st Place!!





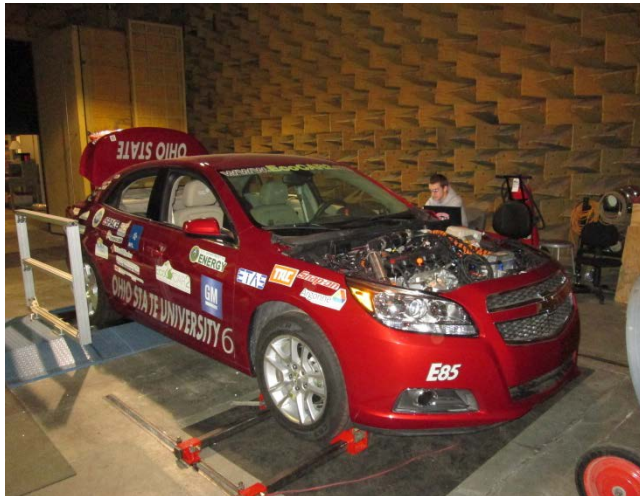
Technical Accomplishments – EcoCAR 2

- ETAS ECU Excellence Award
- dSPACE Embedded Success Award
- Best Outreach Presentation
- Best Communications Program
- Best Communications Plan
- Best Influence Campaign Report
- Best Media Relations Report
- Best Outreach Presentation
- Best Business Presentation
- Best Business Program
- Best Progress Reports
- Best Final Tech Report
- Best Pre-Comp Safety & Tech Inspection
- Best Modeling & Simulation White Paper



Technical Accomplishments – EcoCAR 2

- Best Vehicle Static Consumer Acceptability
- Best Electrical Presentation
- Best Controls Presentation
- Best Technical Report
- Best Petroleum Energy Use
- Lowest Criteria Emissions



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Walked into @OSUCtrAutoRsrch & was attacked by trophies! Impressive haul @OSUEcoCAR21
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Buckeye Current: Electric Motorcycle Racing at Ohio State

The Buckeye Current is an OSU student engineering team that builds electric motorcycles for direct competition against professional racing organizations.

Each of our vehicles has been built for under \$60k. We race against teams with budgets that are totaled in the millions.

The team is barely four years old;

All of our bikes have been record-breakers.



Track Record:

RW-1 Motorcycle: ECTA Land Speed Record at 144 mph

RW-2 Motorcycle: Isle of Man TT Zero 2013 – Third Place

RW-2.X Motorcycle: Isle of Man TT Zero 2014 – Third Place

Other: Motul Award for Technical Performance (2013), IET Best Endeavor Award (2014)

TT University Prize (2013, 2014).



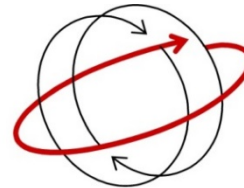


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BUCKEYE CURRENT: SPONSORS

Sponsor Partnerships Established in 2015



Enriching. Expanding. Excelling.

A Partnership of Honda and The Ohio State University



BOSCH

Invented for life



CENTER FOR AUTOMOTIVE RESEARCH

Buckeye Current has announced its intention to develop a new vehicle for competition in the 2015 Pikes Peak International Hill Climb (PPIHC)

Goal: Break The Overall Motorcycle Record



<u>Team</u>	<u>Lap Time</u>
Buckeye Current Goal:	09:45.000
Ducati:	09:52.819
Lightning (Electric):	10:00.694
Ducati:	11:11.329
BMW:	11.46.400

Technical Target for 2015 Motorcycle Design:

Powerful, lightweight racing vehicle

Top Speed 125+ MPH

Battery pack storing 8 kWh minimum

Drivetrain capable of 95 kW peak power



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 (101 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.**



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