Penn State DOE GATE Program
Final Report 2005 through 2012

Submitted November 29, 2012 by Dr. Joel R. Anstrom
on behalf of the Penn State GATE Program Faculty
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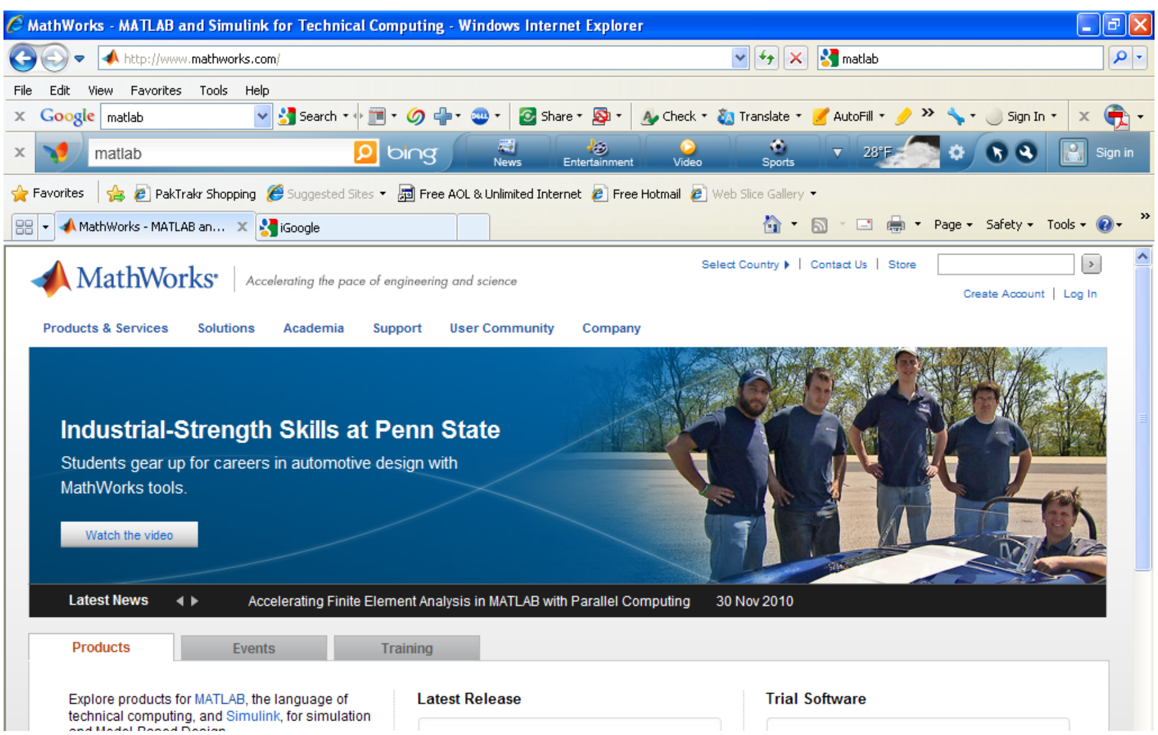

The Mathworks Homepage Featuring a User Story on the Penn State GATE Program

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Introduction

The Graduate Automotive Technology Education (GATE) Program at The Pennsylvania State University (Penn State) was established in October 1998 pursuant to an award from the U.S. Department of Energy (U.S. DOE). The focus area of the Penn State GATE Program is advanced energy storage systems for electric and hybrid vehicles. Major vehicle manufacturers have identified three technologies for in-vehicle, high-power electrical energy storage: batteries, flywheels, and ultra-capacitors. Recently, hydraulic-pneumatic energy storage for hybrid vehicles has received some attention and development especially for heavy vehicles. During the first five years of the Penn State GATE Program, the majority of effort was directed toward recruiting students and sponsors and developing energy storage curriculum of significant breadth and depth. The Penn State GATE curriculum has been offered to all students within the College of Engineering and other colleges meeting the prerequisites. Students completing the Penn State GATE Curriculum have been issued a GATE Certificate.

In 2005, Penn State was awarded a second five year term of support to expand and continue our GATE program. The expanded GATE program retained its focus on electric energy storage for advanced vehicles (batteries, capacitors, and flywheels) but also integrated new curriculum and faculty covering vehicle system topics including power electronics, advanced combustion, hydraulic hybrids, and controls as show Figure 1. The Penn State GATE Program operated on a no-cost extension from September 2012 through August 2012 to provide the last two remaining GATE Fellowships funded under the 2005 award DE-FG26-05NT42618. This final report summarizes the Penn State GATE program activities from 2005 through 2012.

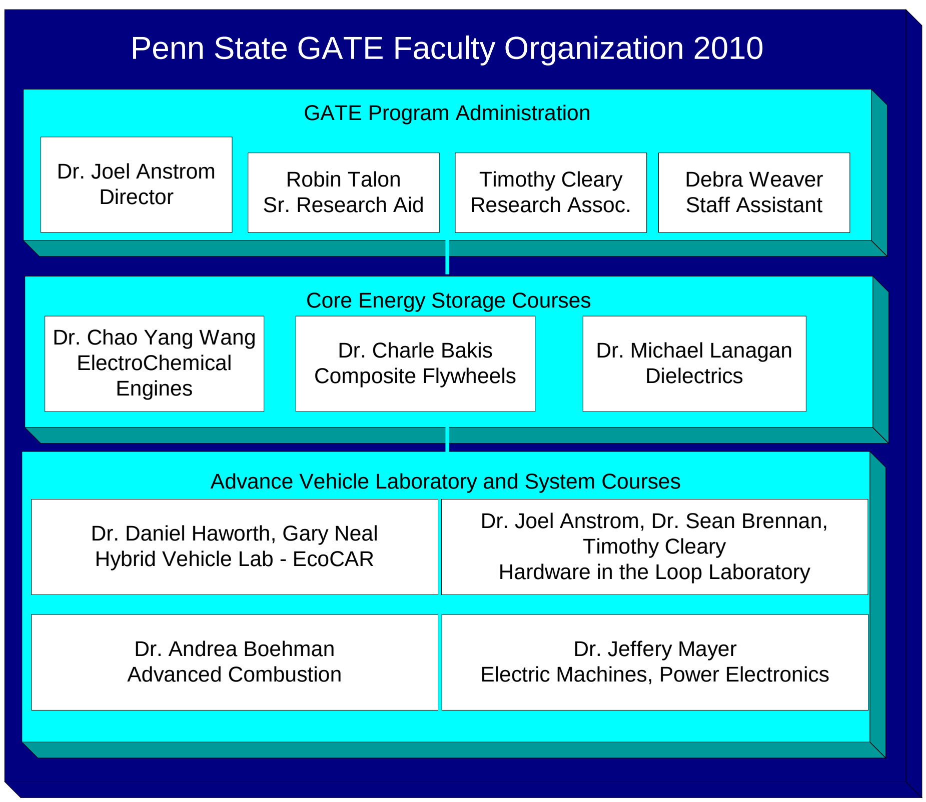

Figure 1: Faculty and Organization of Penn State GATE Program

Penn State graduate students have participated in the Penn State GATE program since 1999 and are now well placed in industry.   Summary statistics for the program are:

- GATE graduates placed with industry GM, Ford, Chrysler, Tesla, Moog, Raytheon, INL, Volvo, and Aberdeen Proving Grounds.
- 20 funded as GATE Fellows with DOE funding
- 37 funded as GATE Students with other funding
- 5 PhD students graduated
- ~400 student-semesters of HEV Lab
- Other GATE students funded by NSF, DARPA, US DOT, NASA, PA-DEP, PA-DCED, US DOE, MAUTC, and Industry
- Hundreds of K-12 students enriched by NSF outreach focused on advanced transportation

In April 2008 and 2009, the Penn State Hybrid and Hydrogen Vehicle Research Laboratory (HHVRL) at the Larson Transportation Institute began sponsoring workshops in support of GATE to engage a broad spectrum of regional industry towards sponsorship of GATE related research, competitions, and fellowships. As a result, several major projects were funded by industry supporting GATE students. In April of 2009 and May 2010, the HHVRL sponsored the 21st Century Automotive Challenge – Legacy of the American Tour de Sol at Penn State. 21st CAC competitors are seen in Figure 2 lining up for the closed track range event at the Penn State Bus Test Center. GATE students and alumni volunteer as scoring officials and technical experts for this advanced vehicle competition. The event provides an excellent opportunity for current and past GATE students to network and establish relationships which can lead to job offers and research opportunities.   It also offers a venue to attract GATE Program sponsors from industry. The GATE Program has also provided several focus vehicles to GATE students to use for thesis research topics and practical experience through team competitions. These vehicles include past several retired competition vehicles from the US DOE Advanced Vehicle Competition (AVTC) series, a donated GM EV1, and a British sports car based hybrid electric vehicle which was developed by GATE students and faculty for teaching GATE courses and competition.

Figure 2: 21st CAC 2010 Lineup for Range Event

Figure 3: Penn State GATE Focus Vehicles

Advanced Vehicle Design ("HEV Lab") is one of two required courses in the Penn State GATE curriculum. It is offered in fall and spring semester sections I and II under course numbers ME 442W and 443W. GATE graduate students can take these 400 level courses as technical electives. This course is based around the DOE AVTC competition. Students taking the course are assigned to component teams for two semesters to develop and implement their subsystems into a completed vehicle by May. The Penn State HEV team then takes the finished vehicle to DOE AVTC Competition in May or June. The first year of EcoCAR in 2009 was the design phase. The second year of EcoCAR was the engineering "mule" phase with a competition in May 2010 held in Yuma Arizona. Penn State placed 3rd overall and also received the following additional awards:

- Third Place Overall
- Third Place in Outreach
- Best AVL Drive Quality
- Best Technical Report
- Second in A123 Battery Design
- Well-to-Wheel Greenhouse Gas Emissions Runner Up
- Best Tailpipe Emissions Runner-Up
- Best Fuel Consumption Runner-Up
- Best Social Media

Figure 4: 2010 Penn State EcoCAR Team

The third and final year of EcoCAR was the 99% consumer phase which ended with a competition in Michigan in June 2011. The Penn State AVTC Team chose an A123 battery system for their series hybrid design for which they designed and implemented their own packaging, cooling, and controls.

Overall the Penn State GATE Program continues to provide graduate engineering students with a world class learning and practicum environment focused on advanced vehicle energy storage technology.

GATE Courses

Figure 5 shows the 2010 Penn State GATE Curriculum. To earn a GATE Certificate from the Penn State Program, a student must first complete a curriculum consisting of nine credits of Group I prerequisites, six credits from the Group II Core Courses, and three credits from the Group III Elective Courses. Core courses provide the GATE student with a broad background in advanced vehicle technology with emphasis in energy storage. GATE electives emphasize one of the energy storage technologies or a systems engineering perspective. What follows are specific course descriptions.

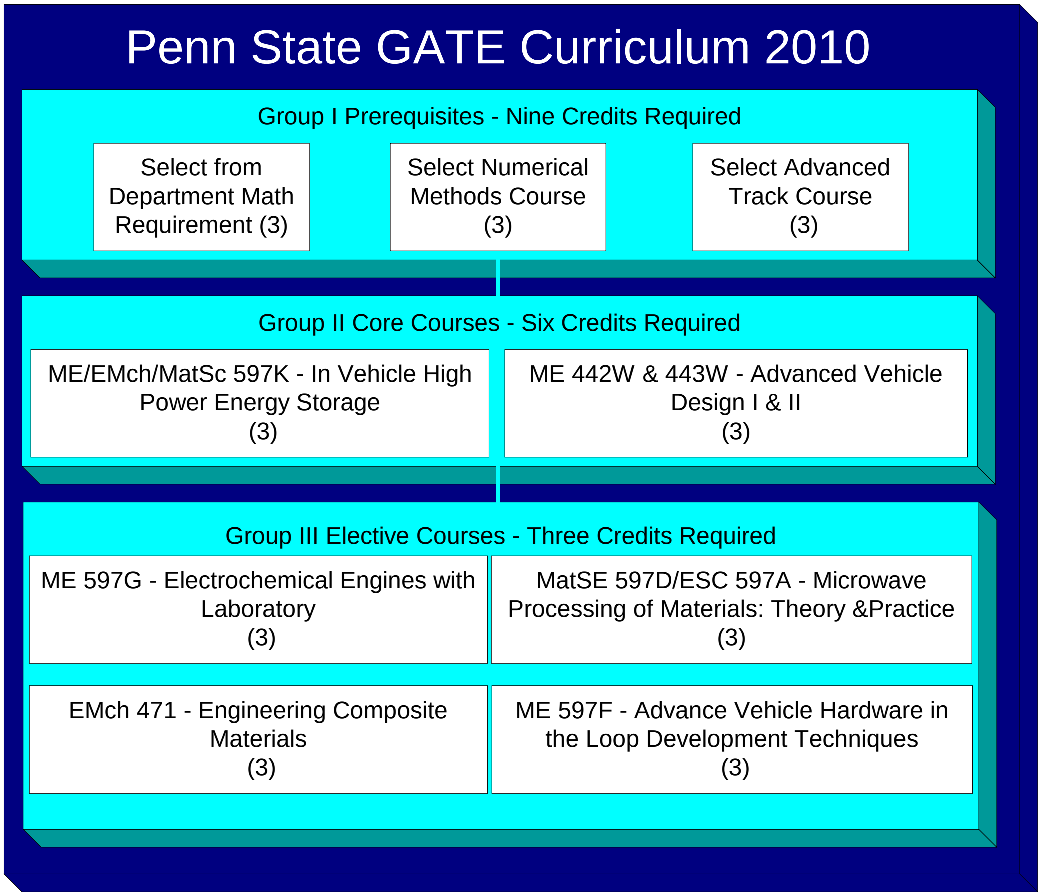

Figure 5: The 2010 GATE Curriculum at Penn State

Group II: ME 597K- High Power In-Vehicle Energy Storage

The first core course in GATE Group II is ME 597K, High Power In-Vehicle Energy Storage. It has been offered each fall semester since 1999. Appendix A is the syllabus for Fall 2010 showing the team of five GATE faculty co-teaching this course with Dr. Joel Anstrom as the official course instructor. Lectures stress fundamental physics and development of energy storage models which can be used for advanced vehicle simulation of fuel efficiency. Grading is based on homework, laboratories, and quizzes assigned by each faculty. Dr. Joel Antrom lectures on fundamental electrochemical relationships within batteries using notes prepared by Dr. Chao Yang Wang. This section covers function of battery plates and electrolytes including lead acid, nickel metal hydride, and lithium chemistries. Dr. Michael Lanagan covers ultra-capacitor theory including double layer capacitor structures and equivalent series resistance. Dr. Charles Bakis lectures on composite flywheel design, methods of manufacture, failure prediction, optimization, and spin testing. Dr. Jeffrey Mayer presents an introduction to high speed permanent magnet motors and power electronics used in flywheel systems. Dr. Anstrom lectures on vehicle system level topics including road loads, hybrid topologies, driving cycles, simulation, and control.

Group II: ME 442W & 443W – Advanced Vehicle Design I&II

The second core course of GATE Group II is Advanced Vehicle Design I & II "HEV Lab" which now has permanent course numbers of ME 442W for two credits each Fall semester and ME 443W for one credit each Spring semester. Appendix B includes the syllabus for both HEV Lab sections. Undergraduates can take HEV Lab as a substitute for their one semester senior capstone design course, ME 415 or EE 413. Graduates can take HEV Lab as a 400 level elective. HEV Lab provides academic credit for students who participate on the Penn State team for the US DOE Advanced Vehicle Technology Competitions (AVTC), currently called EcoCAR. For the 2009-10 academic year, HEV lab developed a Chevrolet SUV into an fully functional series hybrid engineering mule shown in Figure 6. Work continued in Fall 2010 to complete the vehicle for 99% consumer acceptance and competition in June 2011. Dr. Daniel Haworth is the official advisor of the AVTC team and Adjunct Professor Gary Neal is the instructor of HEV Lab and advisor of the permanent competition team. The EcoCAR competition and A123 provided the team with modules of a lithium iron phosphate battery system which the team integrated into their hybrid vehicle with their own designs for packaging, cooling, and control systems. A one credit section of ME 097S freshman seminar is jointly taught with HEV lab. Enrollment in ME 442W/443W and ME 097S for Fall Semester 2010 and Spring Semester 2011 was about 15 students each.

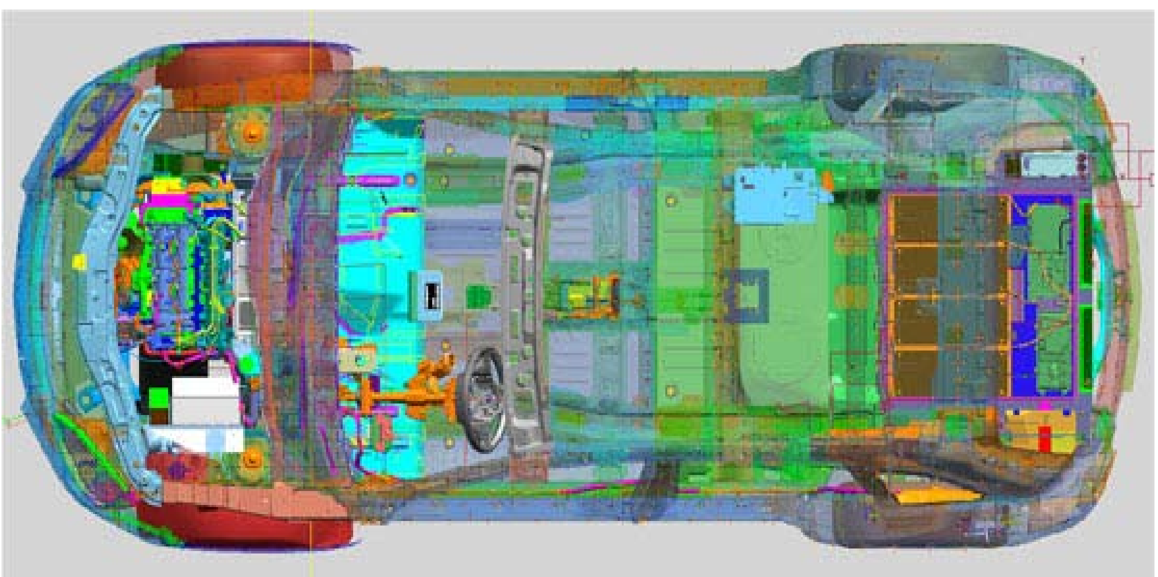

Figure 6: CAC View of Penn State 2010 EcoCAR Design

Group III: ME 597G - Electrochemical Engine Fundamentals

This course provides the theory and practice of electrochemical engines (EC-Engine), i.e. batteries, super capacitors, and fuel cells. Focus is placed on the application of these novel engines to low-CO_2 emission, fuel-efficient vehicles such as fuel cell vehicles, hybrid electric vehicles and plug-in hybrids. The course begins with fundamental principles of electrochemistry and transport phenomena in electrochemical energy systems, followed by design and engineering of specific EC-engines. Lectures are accompanied by two lab sessions in which a battery system and a one-kilowatt hydrogen PEM fuel cell engine will be tested at Penn State Electrochemical Engine Center. The Course Syllabus is shown in Appendix C.

Group III: MatSE 597D/ ESC 597A - Microwave Processing of Materials: Theory and Practice

This GATE elective is intended for specialization in ultra-capacitor materials. MatSE 597D/ESC 597A instructed by Dr. Michael Lanagan of the Penn State Materials Research Lab, Dinesh Agrawal of the Penn State Materials Research Lab, and Elena Semouchkina of Electrical Engineering at Michigan Tech. A syllabus is provided in Appendix D. This course is intended for students that have an interest in microwave interactions with matter. Students with backgrounds in materials, bioengineering, neuroscience, chemistry, food science, electrical engineering, engineering science and mechanics are invited to enroll in this interdisciplinary course. The course focuses on theory and how it is applied to process a variety of materials for diverse applications such as biomedicine, microelectronics and energy. Fundamental dielectric, magnetic, and conduction properties of materials are explored and how these properties influence microwave interactions with a variety of substances. The course introduces the fundamentals of dielectric and capacitor measurements and electromagnetic modeling.

Group III: E.Mch. 471 – Engineering Composite Materials

This GATE elective provides engineering students with a basic knowledge of fiber reinforced composite laminates that can be used for the design of plate- and beam-shaped structural elements subjected to membrane and flexural loadings. Designing with laminated composites entails the selection of fiber and matrix materials and the selection of layer stacking sequence so that certain requirements such as strength, stiffness, or coefficient of thermal expansion are met. Stresses and strains due to mechanical, thermal, and moisture effects and failure criteria are included. These topics will be investigated intensively using computer programs written by individual students. The types of applications where laminated composite beams and plates are found include sporting goods, automobiles, trucks, boats, aircraft, spacecraft, and civil infrastructure. This course is demanding, but is very rewarding for students with a keen interest in the computational stress analysis of laminated composites. A syllabus is provided in Appendix E.

Group III: ME 597F – Hardware in the Loop for Advanced Vehicles

This GATE elective emphasizes energy storage implications on advanced vehicle design from a systems perspective. “HIL Lab” ME 597F was first offered in Spring 2007. The syllabus for Spring 2011 is attached in Appendix F. Hardware-in-the-loop testing combines elements of vehicle computer models with real components under simulated loads to emulate a complete advanced vehicle system under real driving cycles. This technique is a valuable tool used by aerospace and automotive manufacturers to shorten product development cycles by allowing testing of individual components and embedded software without the time and expense of building a complete system prototype. HIL Lab covers theory and laboratory practice of using hardware-in-the-loop techniques to develop electric, hybrid electric, and fuel cell vehicle components and control systems. The five HIL labs include:

1. Battery characterization and co-simulation
2. Capacitor characterization
3. Electric motor characterization and HIL modeling
4. Engine and Fuel Cell characterization HIL modeling
5. Vehicle system level control and optimization

In 2007-2008, the GATE program received significant sponsorship and recognition for the HIL Lab from Matlab Corporation including 12 software licenses and eight target computers valued at approximately $100,000. We were also recognized on the Matlab home page with a user story at http://www.mathworks.com/company/user_stories/userstory17073.html. In Spring Semester 2010, The Mathworks filmed their first ever user videos of the Penn State GATE Program featuring the HIL course. These videos are currently featured on their homepage as shown in Figure 7.

GATE student Timothy Cleary and Advisor Dr. Joel Anstrom have developed a new micro-hybrid vehicle as an HIL test stand to increase the level of hands on experience and safety during HIL Labs of electric motors, engines, and energy storage components. The micro-hybrid HIL test stand is shown in Figure 8 and includes a small utility engine and low voltage electric motors which are less expensive and safer for students than full hybrid components. The micro-hybrid can be quickly re-configured to different hybrid topologies including electric, series, parallel, and two-mode with future plans for power split. Engine and motor HIL Labs can be run in-situ within the 1958 Berkeley chassis. A Lithium battery back and battery management system have been developed for this vehicle and for use in laboratory 1 of 597F. This battery system and the two electric motor controllers use CAN communication which is also covered in the course. The Berkeley also functions as a GATE focus vehicle for student thesis research and team competition. This modular hybrid vehicle design is flexible and inexpensive. We plan to develop this system into a kit intended for high schools and colleges to build their own affordable hybrid vehicle for classroom use and competition.

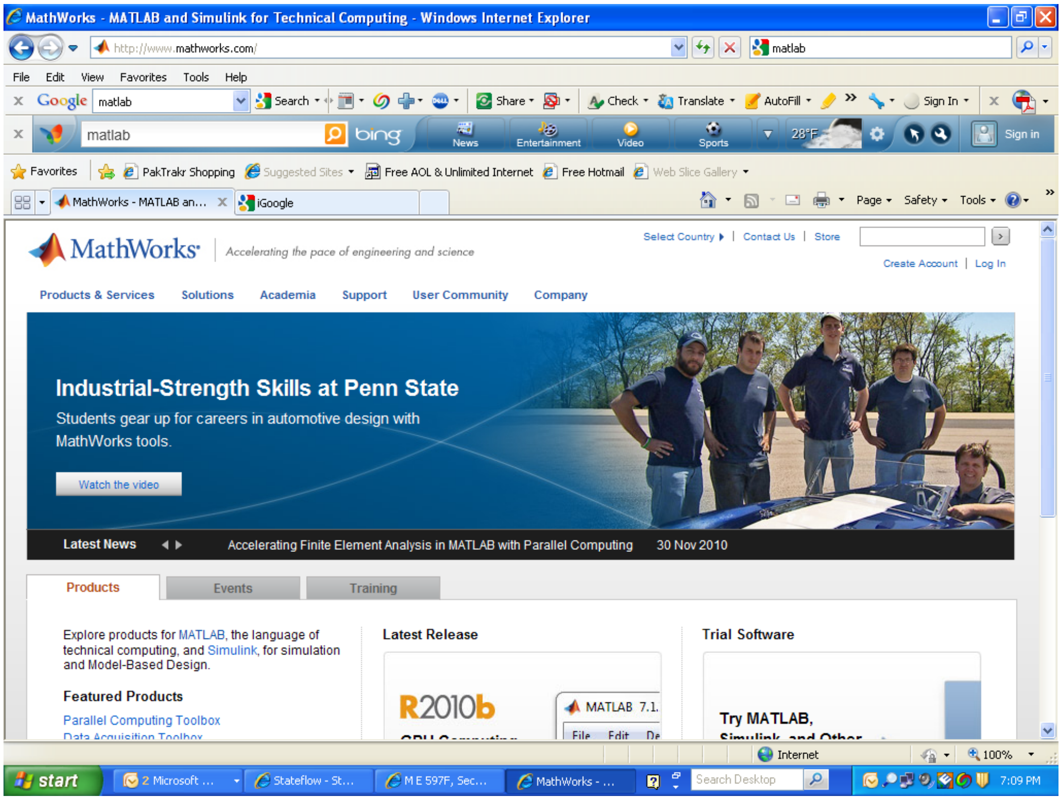

Figure 7: Mathworks Homepage Features Videos of Penn State GATE Program

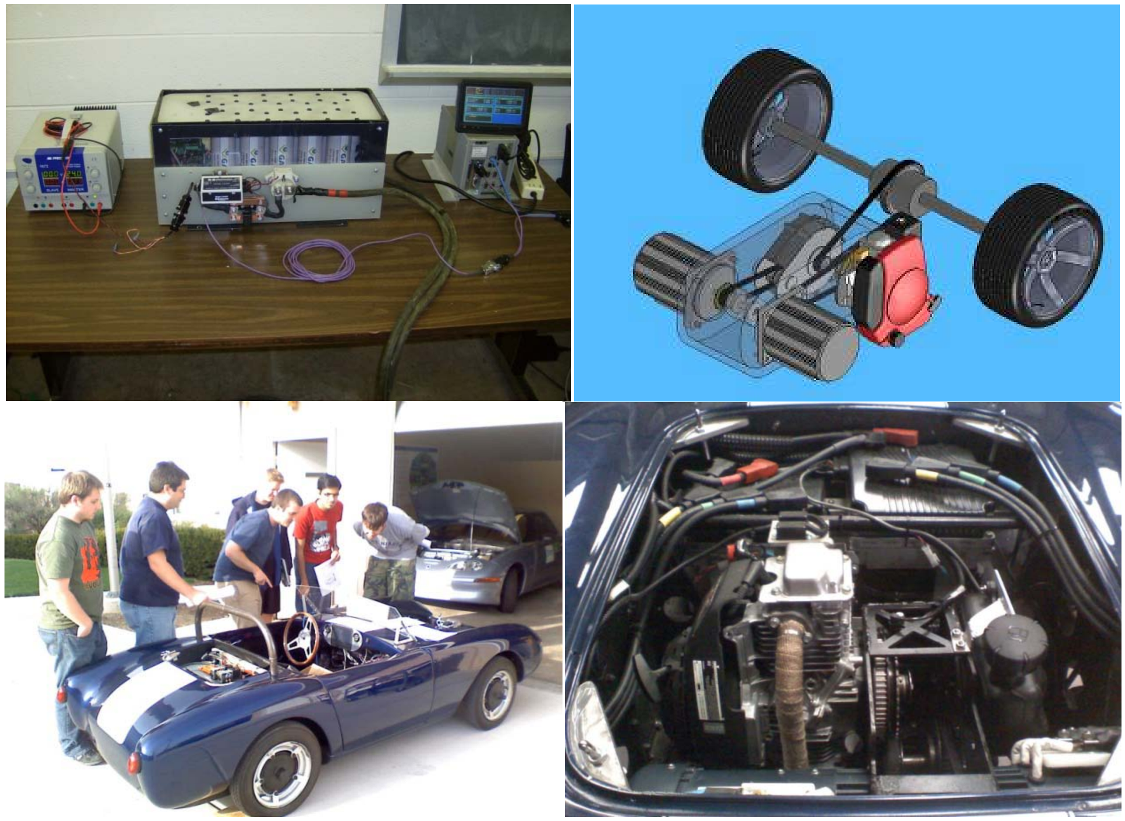

Figure 8: Top Left – Lithium battery pack, top right – drive train schematic, lower left – HIL class during lab 5, lower right – photo of drive train installed

GATE Student PhD, MSE, and BSE Honors Profiles

The following are profiles of students who have been funded by GATE fellowships or participated in the GATE curriculum. This includes PhD and Masters of Engineering students who have participated in the GATE curriculum and may also have been advised by GATE faculty on GATE related research topics. It also includes Bachelors of Engineering Honors students who completed their senior honors thesis on GATE focus vehicles, many of whom also took GATE courses as an elective.

GATE Fellowship PhD Student: Gregory K. Lilik
Funding Source: GATE Fellowship
GATE Advisor: Dr. Andre Boehman
Graduation: Defended PhD March 19, 2012
Thesis Topic: Advanced Combustion of High Cetane Number Fuels and the Impacts on the Combustion Process

Awards:
Mr. Lilik received both the *Robert and Leslie Griffin Award in Fuel Sciences,* and *the Frank* and *Lucy Rusinko Graduate Fellowship in Energy and Geo-Environmental*

Engineering, at the Energy and Mineral Engineering Awards Banquet held on April 15, 2011, Recently, on December 10, 2011, Mr. Lilik was awarded the *EMS Energy Institute Student Achievement Award*, as well as the *EMS Energy Institute Student Service Award*.

Recent Activities:
Mr. Lilik was invited to attend the Volvo Group Tech Show 2011 which was held in Gothenburg, Sweden from the 23 to the 27 of May 2011. The Tech Show highlighted Volvo's "aim to improve fuel efficiency through innovative concepts for energy efficient transportation, solutions to increase the transport effectiveness and uptime”. Specifically, at the Tech Show Mr. Lilik, along with his advisor Dr. Andre Boehman discussed with Volvo scientists research which is now currently being conducted at Penn State. The trip also provided an opportunity to network and expanded Penn State and Volvo relationship.

Mr. Lilik submitted an application to Sandia National Laboratory to participate in the first ever Sandia’s Summer Institute. The Summer Institute was open student across the country who studies energy. Mr. Lilik was selected along with four other students to participate in Sandia’s Summer Institute focusing on combustion. During the week of August $7^{th,}$ he visited Sandia National Laboratory where he worked with Sandia researcher Dr. Mark Musculus to examine measurement uncertainty with imaging detectors. As a result of his visit to Sandia National Laboratory, Mr. Lilik was solicited to return to Sandia to present a seminar of his doctoral research, to be evaluated for a post-doctoral position.

Publications:
Mr. Lilik recently published a journal article in Energy and Fuels under the title of “Advanced Diesel Combustion of a High Cetane Number Fuel with Low Hydrocarbon and Carbon Monoxide Emissions.” The article covers research in advanced diesel combustion where a high cetane number fuel was demonstrated to reduce all major gaseous emissions produced during advanced diesel combustion. The citation of the article is:

Lilik, G.K. and A.L. Boehman, Advanced Diesel Combustion of a High Cetane Number Fuel with Low Hydrocarbon and Carbon Monoxide Emissions. Energy and Fuels, 2011. 25 (4): p. 1444–1456.

Lilik, G. K.; Zhang, H.; Herreros, J. M.; Haworth, D. C.; Boehman, A. L., Hydrogen assisted diesel combustion. International Journal of Hydrogen Energy ***2010,*** *35, (9), 4382-4398.*

Mr. Lilik is also a contributing co-author to two articles currently being drafted. One of the articles exams reaction kinetic pathways of diesel fuel components and involves collaboration between Penn State, Universidad de Castilla-La Mancha in Spain and Universidad de Antioquia in Columbia. The second article will focus on techniques to quantify diesel soot and is being drafted with colleagues from Universidad de Castilla-La Mancha in Spain.

GATE Fellowship PhD Student: Jacob Ross
Funding Source: GATE Fellowship
GATE Advisor: Dr. Charles Bakis
Graduation: Ongoing PhD Candidate
Thesis Topic: Flywheel Design Optimization with Evolutionary Algorithms
In addition to underlying program development, optimization research centered on the flywheel rotor design geometric constraint options and optimization parameters. For a plane stress (2-D flat disk) assumption, there are two parameters for assigning the rotor geometry: the outer and inner radius. For the optimization of the rotor; one, both, or neither of these radii can be constrained leading to four geometric constraint options: (1) unbounded, (2) fixed inner radius, (3) fixed outer radius, and (4) fixed inner and outer radii. There are also the multiple choices for the optimization parameter: (1) total stored energy, (2) energy density, (3) specific energy, and (4) cost. While the cost of the rotor is more difficult to characterize due to combined material and manufacturing factors, the other three are much more straightforward to analyze given the geometric constraints. Research has centered on these 12 optimization design options. A program was constructed to analyze the 12 design options for a rotor that is filament wound (fibers in the hoop direction). The unbounded condition was first analyzed.

The basic results are shown in Figure 9. For an unbounded geometric search based on the total stored energy optimization, the search itself is unbounded, expanding the optimized geometry indefinitely. For an unbounded geometric search based on either the energy density or specific energy, the search converges on an infinitesimally thin ring that at most can realistically be one fiber diameter in thickness. In both cases, the results are non-realistic.

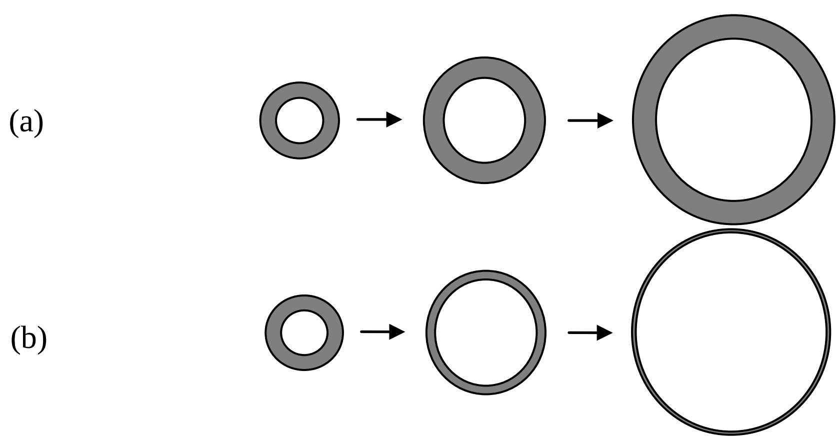

Figure 9: For free boundary conditions, (a) the optimal total stored energy search moves to an unbounded solution with the same overall geometry, and (b) the optimal energy density and specific energy expand the outer radius of the rotor ring to produce a infinitesimally thin ring.

In the case of a fixed outer radius, the results are shown in Figure 10. For total stored energy optimization, the search can center on a physically realistic search that attempts to used as much of the bounded volume as possible. For a fixed outer radius search based either on the energy density or specific energy, the search converges again on an infinitesimally thin ring. The reason for the energy density and specific energy converging on an infinitesimally thin ring can be explained as follows. The most efficient utilization of the mass or volume in a rotor is to place this mass or volume on the highest radial position as possible. Any mass not placed there is not being used as efficiently. Because the highest strength of the composite filament-wound flywheel rotor is in hoop direction, this search is not bounded by the characteristics of the radial/hoop strength ratio.

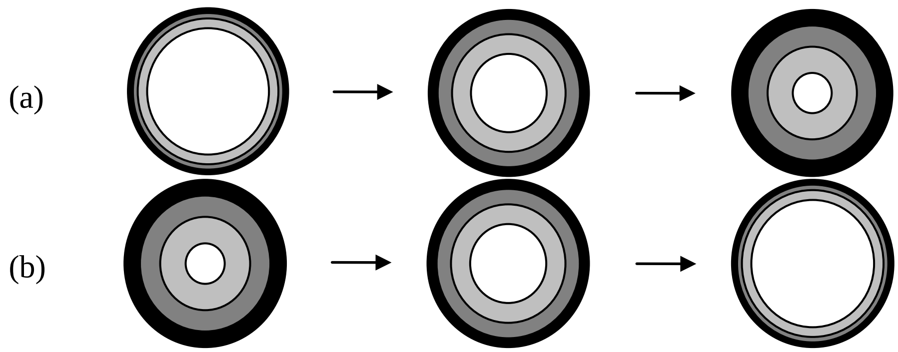

Figure 10: For a fixed outer radius, (a) the optimal total stored energy search converges on a physically realistic solution, and (b) the optimal energy density and specific energy expand the outer radius of the rotor ring to produce an infinitesimally thin ring.

For a fixed inner radius, all three optimization parameters produce physically realistic results as shown in Figure 11. Each of these solutions is distinct based on the differing objectives implied by the different optimization parameters.

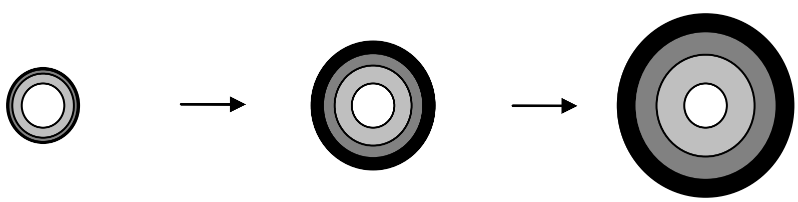

Figure 11: For a fixed inner radius, the three optimization parameters can produce distinct, physically realistic solutions.

For fixed outer and inner radii, there are physically realistic results for all three parameters. However, because the geometry is fixed, so too is the volume. Therefore, the total stored energy and energy density parameters converge on the same solution due to degeneracy in their objectives.

The overall results based on this analysis are shown in Table 1. As can be seen, the possible combinations are reduced from 12 to 6. With these six options combined with the other four concerning the geometric constraint options and cost lead to ten distinct possibilities. The next step of research considers how to select among these ten options using the context of the entire flywheel system.

Table 1: Optimization parameter and geometric constraint validity. The arrow indicates degeneracy with the condition to which it points.

	Unbounded	Fixed Outer Radius	Fixed Inner Radius	Fixed Inner and Outer Radii
Total Stored Energy	Non-physical	Valid	Valid	Valid
Energy Density	Non-physical	Non-physical	Valid	↑
Specific Energy	Non-physical	Non-physical	Valid	Valid

GATE PhD Student: Melanie Fox
Funding Source: Funded by NSF K-12 Science Enrichment GREATT Program and later a non-GATE DOE Research Project for Hydrogen Assisted Combustion
GATE Advisor: Dr. Andre Boehman, Earth and Mineral Science
Graduation: PhD Fall 2011
Employer: General Motors Volt Program and Advance Diesel Research

Melanie investigated hydrogen enriched natural gas combustion using a single cylinder engine to determine effects of timing and swirl on combustion reaction rates, emissions, and torque in a project funded by US DOE. Melanie was earlier supported through the NSF GREATT program which used the advanced automotive technology theme for K-12 outreach to improve science curriculum in regional schools.

GATE Fellowship MSE Student: Joseph Scholz
Funding Source: GATE Fellowship
GATE Advisor: Dr. Michael Lanagan and Dr. Clive Randall, Engineering Science and Mechanics
Graduation: Spring 2009

The phenomenon of aging in a material entails the spontaneous change in electrical and electromechanical properties over time. Automotive elements that suffer from this effect include capacitors and actuators. As their properties change, the capacitors cannot store the same amount of charge, and actuators provide less accurate positioning. Lead zirconate titanate doped with strontium, potassium, and niobium (PZT-SKN) exhibits a high Curie temperature of 350 °C and high d33 values. This makes it a promising material for use as an actuator in diesel fuel injectors. Aging involves defects pinning the domain walls in a material. I am varying the processing conditions for PZT-SKN in order to alter the defects, and thus influence the aging rate. Once the aging rate and its cause are understood, materials can be made with minimal aging. This will improve the reliability and lifetime of devices such as control circuit elements and fuel injectors. There are several automotive companies that are interested in this technology including: Bosch, EPCOS, and NGK/NTK. As diesel and flex fuel combustion engines become more popular in the U.S. this technology will increase in importance.

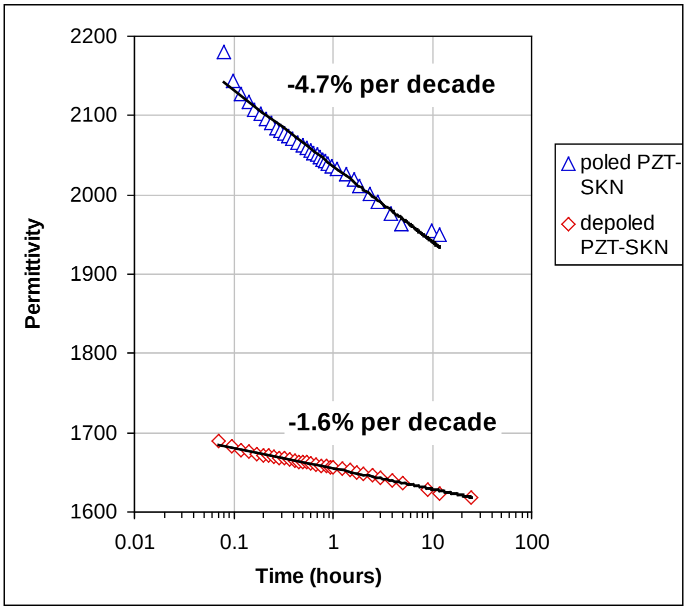

Figure 12: Permittivity of the piezoelectric actuator material (PZT-SKN) decreases steadily and significantly over time

GATE Fellowship MSE Student: Jamie Clark
Funding Source: GATE Fellowship
GATE Advisor: Dr. Andre Boehman, Earth and Mineral Science
Graduation: MSE Spring 2008
Employer: Tesla Motors

Starting summer of 2006, Jamie facilitated development of the new ME 597F HIL course by developing engine lectures and the engine dynamometer laboratory. The lab demonstrated a 2.5 liter Diesel engine and real-time interface to a PSAT based simulation of a series hybrid vehicle on the federal highway drive cycle (FHDS). Engine control was orchestrated by the PSAT program running a portion of the FUDS cycle and generating engine commands for speed and load. These parameters were sent to a local controller for the engine dynamometer commanding speed and load while actual speed and load were returned. Signals are converted within PSAT to an APU current. Setup of this HIL engine laboratory required several weeks and required downtime of the engine and test cell. HIL engine lab can now be performed in-situ within the Berkeley HIL test vehicle.

Jamie's thesis investigated the effect on combustion of HCNG, a blend of 30% hydrogen with natural gas. Jamie collected pressure and crank angle position data on a Ford natural gas engine converted to run on HCNG from which he computed a variety of combustion statistics. Jamie is currently working for Tesla Motors setting up a battery test laboratory.

GATE Fellowship MSE Student: Michael Petersheim
Funding Source: GATE Fellowship
GATE Advisor: Dr. Sean Brennan, Mechanical Engineering
Graduation: MSME Spring 2008
Employer: Spectrum Controls Inc., State College, Pa.

Michael Petersheim investigated real-time network architectures for hardware-in-the-loop testing, selecting UDP network protocol due to its compatibility with existing Ethernet connections and widespread software support. Additionally, Michael developed laboratories for the new HIL course, including characterization of a battery, ultra-capacitor, combustion engine, and electric motor. He investigated problems encountered in developing the labs including time delays, data loss, data transfer bandwidth, hardware scaling effects, and equipment controller instability. Cross-campus real-time networking capabilities were tested and demonstrated.

Michael completed his thesis on HIL testing techniques, specifically allowing a hardware system of one size scale to emulate a similar system of a larger or smaller scale. For example, it can be unclear how to perform HIL testing on a bench-top, small-sized fuel-cell such that performance measurements can be scaled-up to infer performance of a full-sized fuel-cell operating in a hybrid vehicle power-train. To enable such studies, the characteristics of power-train components were investigated for their scaling potential. To this point, Michael established scaling factors for AC induction and permanent magnet DC motors, and these have been tested in simulation. Michael is currently employed at Spectrum Controls Inc. in State College, PA.

GATE Fellowship MSE Student: Nathan Simmons
Funding Source: GATE Fellowship
GATE Advisor:
Graduation: Spring 2008
Employer: Aberdeen Proving Grounds

Nate Simmons followed the GATE curriculum and played a key leadership role during the 2007 and 2008 Challenge X Competitions. Nate graduated in May of 2008 with a Masters of Science in Engineering Mechanics degree. His research focused on the reduction of cavitations erosion via surface coatings and cryogenic treatments to prolong material life. Nate is currently employed at Aberdeen Proving Grounds

Student MSE Student: Nicholas Brannen
Funding Source: Mid-Atlantic Regional Transportation Center (MAUTC), US FTA
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute

Graduation: MSEE Fall 2008
Employer: Raytheon

Nicholas developed and tested a full function battery management system for use in the Penn State HyLion fuel cell vehicle based on a GM EV1 chassis. The BMS circuit monitors battery state of charge, communicates with the main BMS controller, and can charge or discharge a 12V module at 10 amps with energy from the high voltage bus. Nick also assisting in conversion of this and other vehicles to hydrogen as part of a hydrogen station demonstration while participating in the GATE curriculum. Nicholas graduated Fall 08 and was hired by Raytheon developing power systems for the next generation of Presidential helicopters.

GATE MSE Student: Timothy Cleary
Funding Source: Sentech, Inc., Army TACOM through Penn State Applied Research Lab
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute
Graduation: MSME Spring 2010
Employer: Research Faculty Larson Institute, Director of BATTERY Laboratory

Timothy initially was funded to develop a hardware-in-the-loop test stand for Army TACOM to test engine starting systems with ultra-capacitor energy storage. He later began working part time for Sentech, Inc. performing modeling using Power-train Systems Analysis Toolkit (PSAT) to support policy studies for alternative fuel vehicle deployment. His thesis topic was development of a micro hybrid vehicle drive-train as a dedicated teaching tool and was used initially to support the GATE ME 597F Hardware in the Loop elective. This vehicle and curriculum is also being developed for industry extension education through online courses and workshops offered through the Hybrid and Hydrogen Vehicle Research Laboratory. The micro hybrid system is capable of demonstrating important hybrid topologies including series, parallel, and two-mode in any compact vehicle. In our case it has been installed into a 1958 Berkeley British sports car to support on-track testing of various hybrid topologies and control strategies during GATE courses and thesis projects. It is considered a GATE Focus Vehicle which makes it accessible to GATE students. Timothy currently co-teaches the ME 597F Hardware in the Loop course with Dr. Joel Anstrom as part of the GATE curriculum and is shown in Figure 13 instructing GATE students during a laboratory session involving a Pulse Power Characterization Test (PPCT) and HIL test of a high energy nickel metal hydride battery pack using an Aerovironment ABC150 power processing machine at the Larson Transportation Institute.

Figure 13: Timothy Cleary acting as Teaching Assistant of NiMh Battery HIL Lab

GATE MSE Student: James D'Iorio
Funding Source: Mid-Atlantic Regional Transportation Center (MAUTC), US FTA
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute
Graduation: MSME Fall 2008
Employer: Moog

James D'Iorio developed and tested active yaw control algorithms with ABS/traction control strategies integrated into a series hybrid vehicle with independent front wheel motors on very low friction surfaces. This included installation of inertial instrumentation and ground speed sensors into the vehicle along with installation of a 100 Ah Nickel Metal Hydride battery pack. Algorithms were developed and coded into the vehicle embedded controller which command electric drive motor torque to achieve active safety. Vehicle dynamic testing was performed on ice at the Penn State Ice Pavilion. Jim also assisted in conversion of this and several other vehicles to hydrogen including a transit bus, van, and fuel cell vehicle as part of a hydrogen station demonstration while participating in the GATE curriculum. James now employed by Moog in Buffalo NY as a control systems development engineer on next generation launch vehicles for NASA.

GATE MSE Student: Mathew Shirk
Funding Source: NSF GREATT K-12 Science Enrichment
GATE Advisor: Dr. Daniel Haworth
Graduation: MSME Spring 2008
Employer: DOE Idaho National Lab

Mathew participated in the GATE curriculum and was funded through NSF for K-12 science outreach. He completed his thesis on hydrogen enhanced combustion of Diesel engines and is now working for Idaho National Lab in a hybrid vehicle evaluation program. Mathew was supported through the NSF GREATT program which used the advanced automotive technology theme for K-12 outreach to improve science curriculum in regional schools.

GATE MSE Student: Nathan Hobbs
Funding Source: Army TACOM through Penn State Applied Research Lab
GATE Advisor: Dr. Heath Hofmann, Electrical Engineering
Graduation: MSEE
Employer: Penn State Applied Research Lab

Nathan was funded to evaluate alternators for Army TACOM tactical vehicles using HIL methods. Nathan has participated in the GATE curriculum.

GATE MSE Students: Maria Concepcion, Miquel Dominqo, Victor Romero Peralta, and Charles Cornejo
Funding Source: Exchange program with Escuela Téchnica Superior IQS in Barcelona, Spain
GATE Advisor: Dr. Joel Anstrom and Dr. Zoltan Rado, Penn State Larson Transportation Institute
Graduation: Spring 2008-2009

Maria, Miquel, Victor, and Charles developed an electric brake control system for the HyLion fuel cell vehicle based a donated GM EV1. Their goal was to replicate the original EV1 brake controller functions which was removed prior to donation. This system controls regenerative braking effort of the inverter and blends it with the friction braking system to provide antilock braking function. They are part of an exchange program with Escuela Téchnica Superior IQS in Barcelona, Spain and participated in the GATE curriculum.

GATE MSE Student: Jordi Ros
Funding Source: Exchange program with Escuela Téchnica Superior IQS in Barcelona, Spain
GATE Advisor: Dr. Joel Anstrom, Pennsylvania Transportation Institute
Graduation: Spring 2009
Employer: Nissan, Spain

Jordi developed a fuel cell balance of plant controller for the Ballard Nexa Fuel cell used in the HyLion fuel cell vehicle based on a GM EV1 chassis. This controller monitors the fuel cell and performs ventilation and temperature control along with leak detection and other safety functions within the fuel cell compartment. Jordi is part of an exchange program with Escuela Téchnica Superior IQS in Barcelona, Spain. He participated in the GATE curriculum.

GATE BSE Honor Student: Chris Ferone
Funding Source: BSE Schreyer Honors College Thesis
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute
Graduation: Spring 2008

For his senior honors thesis, Chris investigated turbo-charging and supercharging to improve power density of a small displacement hydrogen engine which serves as the generator in a series hybrid vehicle, the H_2Elion.

GATE BSE Honors Student: Scott Jacobs
Funding Source: BSE Engineering Science, Schreyer Honors College
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute
Graduation: MSE Spring 2009

Scott developed a scoring rubric for the 21st Century Automotive Challenge first held at Penn State in April 2009. The electric and hybrid vehicle efficiency competition is a rally format with multiple legs. Called a “Lifestyle Efficiency Competition,” the rally credits electric and pluggable hybrid vehicles with energy and carbon impact based on either grid power or house installed photovoltaic’s on the Penn State MorningStar Solar home built for 2007 DOE Solar Decathlon. Competitors chose when to charge and when to travel on rally legs to perform everyday tasks. Scott developed vehicle categories, rules, scoring equations, and a spreadsheet to score this Energy Lifestyle aspect.

GATE BSE Honors Student: Dan Klodowski
Funding Source: BSE Engineering Science, Schreyer Honors College
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute
Graduation: Spring 2010

For his senior honors thesis, Dan investigated supercharging requirements for a small displacement hydrogen engine for an auxiliary power unit on a range extending pluggable hybrid vehicle.

GATE BSE Honors Student: Wade McCorkel
Funding Source: BSE Engineering Science, Schreyer Honors College
GATE Advisor: Dr. Joel Anstrom, Penn State Larson Transportation Institute
Graduation: Spring 2010

For his senior honors thesis, Wade investigated a fuel injection system for a small displacement hydrogen engine intended as an auxiliary power unit (APU) on a range extending pluggable hybrid electric vehicle (PHEV).

Focus Vehicles and Projects

The Penn State GATE program has reserved four research vehicles and many components dedicated for GATE student thesis research and hands-on experience. Because of the tight schedules involved in DOE AVTC, it is necessary to give GATE students their own vehicle platforms to focus on higher risk or longer term research projects. Some focus vehicles are part of active research projects while others are shared among GATE students as needed. The following gives a short description of some GATE Focus Vehicles as shown in Figure 14.

Figure 14: GATE Focus Vehicles: HyLion FCV EV1 top left, Kurrent NEV top right, Electric Lion series hybrid bottom left, and 1959 Berkeley bottom right

The "HyLion" is a GM EV1 electric vehicle donated in 2001 and has been converted into a pluggable hybrid fuel cell vehicle as part of a Hydrogen Station and Fleet demonstration with Air Products Corporation. About twenty different GATE students and volunteers have worked on the HyLion fuel cell system, hydrogen storage tank, fuel cell boost converter, battery pack and management system, brake controller, and motor inverter. It currently has a 320 V, 100 Ah NiMh battery pack with an in-house designed battery management system.

The Kurrent Neighborhood Electric Vehicle was donated to Penn State by a private individual to be used in research and student projects after the vehicle suffered a mechanical driveline failure which also resulted in damage to the electrical system. The NEV power train is similar to a golf cart with a 48V VRLA battery pack and DC electric drive but it is designed to be street legal on roads 35 mph and under. It has all of the required Federal Motor Vehicle Safety features including rear view mirrors, windshield wipers and defroster, turn signals, brake lights, and headlights. After repairs were completed at Penn State, the Kurrent was made available to Larson Institute staff for on campus trips. It is housed and charged in the HHVRL garage facility.

The Electric Lion is a legacy DOE HEV Challenge competition vehicle with a long history of research projects including advanced battery and ultra-capacitor research, modeling and testing of vehicle dynamic handling, and vehicle to grid power generation. It is a pluggable series hybrid with individual drive motors on each front wheel. It currently has a 144 V, 100 Ah NiMh battery pack. The 620 cc APU engine has been converted to hydrogen fuel and students are working on a supercharger design to increase power.

GATE alumnus Douglas Piccard now works for Ford Motor Company in their Escape HEV program. Doug donated his 1958 Berkeley to GATE as a focus vehicle. GATE student Timothy Cleary has designed and built a micro-hybrid HIL test stand for ME 597F labs that will also fit into the Berkeley and allow several hybrid electric topologies to be tested within this small vehicle with few mechanical changes. The lithium iron phosphate battery pack is only 48 volts which is safer for students than the 140-300 V systems used in production hybrids.

Penn State also participates in DOE Solar Decathlon. Part of that competition involves charging a GEM car from the house for the "Driving Around" competition. GATE faculty and students recently helped the Penn State Solar Decathlon team to instrument and prepare the GEM for efficient operation at competition.

GATE Faculty and students support our Shell EcoMarathon Team with technical advice, components, and testing support. From 2008 to 2010, GATE faculty loaned a 1.5 kW Ballard Nexa fuel cell and supporting equipment to our Shell EcoMarathon Team advised by Professor Leland Engel. This team won 1st place in their division in 2008 achieving 1668 mpgge. In 2009, the team won first place again in the fuel cell division achieving 1912.9 mpgge. In 2010, the team placed second in the fuel cell division achieving 1806 mpgge. During Fall Semester 2011, GATE faculty and students assisted the team with testing of a new lithium ion battery pack to replace the aging fuel cell for the 2011 competition.

Penn State is fortunate to have on-site a hydrogen fueling station developed by Air Products to demonstrate distributed reforming and distribution of hydrogen from natural gas. As part of this demonstration, GATE faculty and students have converted a fleet of vehicles to operate on hydrogen or a 30% blend of hydrogen and natural gas including the HyLion, H_2Elion, a transit bus, and seven work vans. These vehicles are used to place a significant load on the station reformer while offering opportunities for thesis research.

Select GATE Related Publications and Presentations

The Penn State GATE faculty and students have been busy publishing and presenting their work. A sampling of papers and presentations are listed below.

Shi, Y., Prasad, G., Shen, Y., and Rahn, C., “Discretization Methods for Battery Systems Modeling,” 2011 American Control Conference, WeA11.1, San Francisco, CA, June 2011, Invited Paper.
Z. Shen, J. Gou, C. Rahn, and C.-Y. Wang, “Ritz Model of a Lead-Acid Battery with Application to Electric Locomotives,” Dynamic Systems and Control Conference, Arlington, VA, October 31 - November 2, 2011.

Lilik, G.K. and A.L. Boehman, Advanced Diesel Combustion of a High Cetane Number Fuel with Low Hydrocarbon and Carbon Monoxide Emissions. Energy and Fuels, 2011. 25 (4): p. 1444–1456.
S. Kwon, W. Hackenberger, E. Furman and M. Lanagan "Nonlinear Dielectric Ceramics and their Application to Capacitors and Dielectrics," IEEE Dielectric and Insulation 27(2): 43-55, 2011.

M. Mirsaneh, B. Hayden, S. Miao, H. Pokorny, S. Perini, E. Furman, M. T. Lanagan, R. Ubic and I. Reaney, "High-throughput Synthesis and Characterization of the Lead Niobate System on a Single Chip," Acta Materialia, 59(5): 2201-2209, 2011.

G. Sethi, B. Bontempo, E. Furman, M. W. Horn, M. T. Lanagan, S. S. N. Bharadwaja and J. Li, "Impedance analysis of amorphous and polycrystalline tantalum oxide sputtered films," Journal of Materials Research, 26(6): 745-753, 2011.

T. Tomko, R. Rajagopalan, M. Lanagan and H. C. Foley, "High Energy Density Capacitor Using Coal Tar Pitch Derived Nanoporous Carbon/MnO(2) Electrodes in Aqueous Electrolytes," J. Power Sources, 196(4): 2380-2386, 2011.

Z. Li, L.A. Fredin, P. Tewari, S.A. DiBenedetto, M.T. Lanagan, M.A. Ratner, and T.J. Marks, "In Situ Catalytic Encapsulation of Core-Shell Nanoparticles Having Variable Shell Thickness: Dielectric and Energy Storage Properties of High-Permittivity Metal Oxide Nanocomposites," Chemistry of Materials, 22(18): 5154-5164, 2010.

B. Rangarajan, S.S.N. Bharadwaja, E. Furman, T. Shrout and M. Lanagan, "Impedance Spectroscopy Studies of Fresnoites in BaO-TiO2-SiO2 System," J. Amer. Ceram. Soc., 93(2):522-530, 2010.

M. Mirsaneh, E. Furman, J. V. Ryan, M. T. Lanagan, and C. G. Pantano, "Frequency dependent electrical measurements of amorphous GeSbSe chalcogenide thin films," Appl. Phys. Lett., 96, 112907 , 2010.

H. Lee, N. J. Smith, C. G. Pantano, Eugene Furman, and Michael T. Lanagan, "Dielectric Breakdown of Thinned BaO-Al2O3-B2O3-SiO2 Glass," J. Am. Ceram. Soc., 93(8):2346-2351, 2010.

G. Sethi*, R. Sahul, C. Min, P. Tewari, E. Furman, M. W. Horn, and M. T. Lanagan, "Dielectric Response of Tantalum Oxide Deposited on Polyethylene Terephthalate (PET) Film by Low-Temperature Pulsed-DC Sputtering for Wound Capacitors," Journal of Vacuum Science and Technology A, IEEE Trans. Components and Packaging Tech., 32(1), 915-925, 2009.
Z. Lu, M. Lanagan, E. Manias, and D. Macdonald, "Dielectric Properties of Polymer Electrolyte Membranes Measured by Two-Port Transmission Line Technique" ECS Transactions, vol. 28, 95 - 105 2010.

Z. Lu, E. Manias, M. Lanagan, and D. Macdonald, "Dielectric Relaxation in Dimethyl Sulfoxide/Water Mixtures Studied by Microwave Dielectric Relaxation Spectroscopy," ECS Meeting Abstracts, vol. 1001, 2010, p. 1676.

C. Stapleton, M. Lanagan, "Energy Storage Characterization of Nonlinear Dielectrics Near Breakdown," NSF, EE REU Penn State Annual Research Journal, 7:143-152, First Author Supervised by Candidate, 2009.
C. E. Bakis, "High Speed Fiber Composite Flywheels for Energy Storage," presented to Tri-Service Mechanical Energy Harvesting Workshop, Aug. 12, 2009, Blacksburg, VA.

Lilik, G. K.; Zhang, H.; Herreros, J. M.; Haworth, D. C.; Boehman, A. L., Hydrogen assisted diesel combustion. *International Journal of Hydrogen Energy* 2010, 35, (9), 4382-4398.

Anstrom, Joel, September 2007-10, Invited Speaker at the Pennsylvania Renewable Energy Festival, Kempton, PA, Display of HyLion and Berkeley vehicles and presentation on advanced vehicle technologies.

Jessica Serra, Michael Lanagan and Carlo Pantano "Dielectric Breakdown of Alkali-Free Boroaluminosilicate Glass Thin Film," The American Ceramic Society's 2010 Glass & Optical Materials Division Annual Meeting. May 16-20, 2010 Corning, New York.

Mike Lanagan, Clive Randall, Amanda Baker and Eugene Furman, "High Energy Glass Laminates for Pulse Power and Power Electronic Applications," 2010 CICMT Conference, Chiba, Japan April 18-21, 2010

Brian Bontempo* Steve Perini, Mark Fanton, Tim Bogart and Mike Lanagan, "Current Voltage Characterization of Tantalum Oxide Thin Film Dielectrics," 2010 CICMT Conference, Chiba, Japan April 18-21, 2010

E. Furman, G. Sethi, B. Koch, M. T. Lanagan, Monte Carlo Modeling of Heterogeneities in Ceramic, Polymer, and Composite Capacitors , 17th Annual IEEE Pulsed Power Conference, Washington DC, June 28 -July 2, 2009.

Mike Lanagan, Nick Smith, Hoikwan Lee, Badri Rangarajan, Ben Koch, Eugene Furman and Carlo Pantano, "High Energy Density Glass Dielectric for Pulsed Power and Power Electronics Applications," The 14th US-Japan Seminar on Dielectric and Piezoelectric Ceramics., Principal Author, October 2009. (Invited presentation)

Industry and Government Relationships

Industry outreach in support of the Penn State GATE Program is coordinated by the Hybrid and Hydrogen Vehicle Research Lab (HHVRL) which is also Directed by Dr. Joel Anstrom at the Larson Institute at Penn State. Our goal is to develop a strong consortium of companies which engage in funded research programs that support GATE students and provide sponsorship to the Penn State DOE AVTC Team. The HHVRL held an inaugural Workshop for Stakeholders in Hybrid, Electric, and Fuel Cell Vehicle Technologies in April 2008 at Penn State. A number of regional companies attended for two days of GATE faculty research presentations and laboratory tours and a GATE student poster session as shown in Figure 15. A second annual HHVRL Workshop and Exposition was held in April 2009 in conjunction with the 21st Century Automotive Challenge. The outcome has been a number of joint proposals with industry and at least one significant project funded which provided the GATE Program with several student-years of support. However, there is tremendous diversity among companies that are stakeholders in advanced vehicle technology making it difficult to convince industry sponsors to join and support a consortium with such a broad theme. Instead, our emphasis is changing to encourage industry sponsorship of the GATE Program through the existing industry consortiums in batteries and capacitors already established at Penn State and managed by our individual GATE faculty.

Figure 15: Inaugural HHVRL Consortium at Penn State

Other industry support of advanced vehicle research projects has been achieved through individual projects and leveraged to support the GATE Program. Examples include:

- Honda Visiting Scientist Program: Kosuke Oguri from Honda spent one year at PTI and participated in GATE curriculum. $20,000 in Honda support was used to purchase lab equipment to set up the ME 597F HIL course.
- Matlab donated 12 licenses and several xpc target boxes for the ME 597F HIL courses.
- The Mid Atlantic University Transportation Research Center funded two years of research assistantships for James D'Iorio and Nicholas Brannen with matching funding from the Air Products Hydrogen Station. They are completing the GATE curriculum.
- Argonne donated 13 PSAT licenses for the ME 597F HIL course.
- Tank Automotive Command (TACOM) is funding research in battery and ultra-capacitor energy storage for starting tactical trucks. This program is supporting three students in the GATE curriculum.
- GM donated machine shop tools to the HHVRL.

Outreach

In the past, outreach activity of the Penn State GATE Program was accomplished through several channels including invited presentations, site tours, and support of other outreach programs. Advanced automotive technology is a subject of intense interest for the public. Over the timeframe of the GATE program, faculty and students have participated in many tours and invited presentations on the subject to groups on and off campus. A sampling of tour groups hosted here includes:

- The Pennsylvania Towing Association
- Pennsylvania Association of Environmental Professionals
- The Pennsylvania State Park Managers Annual Meeting 2008
- Penn State Distinguished Alumni
- Chungbuk University, South Korea
- A delegation from South Korea interested in hydrogen fueling
- A delegation of International Journalists
- Tom Ryan President of SAE
- Mark Reuss, Vice President GM
- Executives from Volvo

A sampling of invited presentations includes:

- Pennsylvania Engineering Week Council
- Pennsylvania Renewable Energy Festival
- Pennsylvania Concrete and Aggregate Association
- Keystone College Environmental Education Institute
- Penn State Harrisburg IEEE Chapter

The Penn State GATE program collaborated with the Graduate Research and Education in Advanced Transportation Technology (GREATT) project at Penn State funded by NSF until it ended in 2009. The GREATT program provided K-12 teacher workshops and student field trips to Penn State which included advanced transportation technology themes. GATE supported GREATT teacher workshops and student field trips by providing guided tours of our laboratories and demonstrations of research vehicles. Conversely, many of the dozen or so GREATT fellows were enrolled in the GATE curriculum.

In 2009, the HHVRL began hosting an alternative fuel vehicle competition at Penn State Main Campus called the the 21st Century Automotive Challenge which includes a public display component as shown in Figure 16. Competitors display their vehicles in a public setting and explain the technology using the vehicle and visual aids. The 21st CAC is now our main outreach activity.

Figure 16: Public display during 21st Century Automotive Challenge

Schedule

Figure 17 is the Penn State GATE Program Gantt Chart. Black bars represent percent progress towards task completion. We have completed upgrades to the GATE curriculum, adding system topics such as power electronics, advanced combustion, hydrogen, and HIL testing to the core topic of high-power energy storage. The new courses were rolled out in the 2006-07 academic year. GATE course enrollment remains strong averaging about a dozen students per semester. The schedule in Figure 17 reflects the no-cost extension we were granted through August 2012 to spend out the remainder of fellowship funding and complete all tasks by the end September 2012.

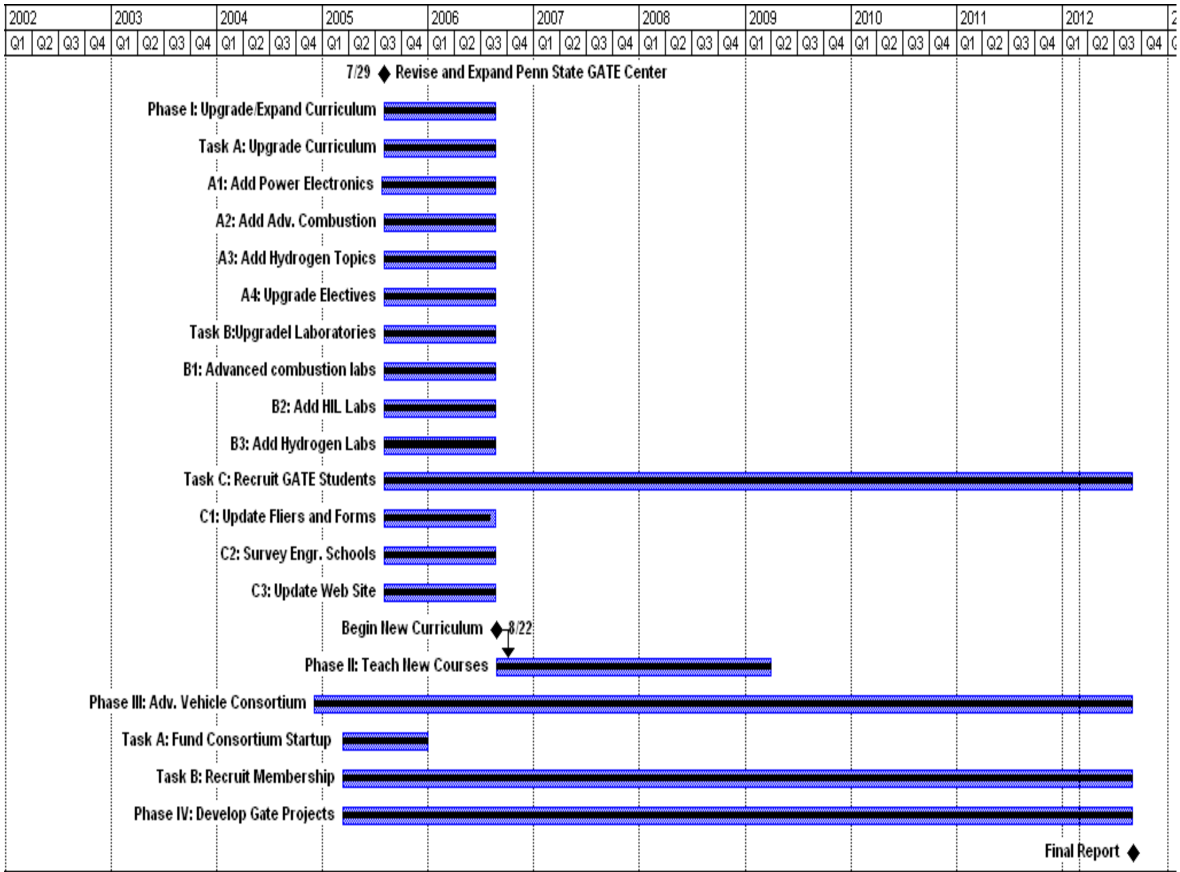

Figure 17: Penn State GATE Schedule and Task Status

Financial

Financial status reported separately.

Appendices

Appendix A: ME 597K

High-Power In Vehicle Energy Storage Fall 2010

Course Objective: ME 597K is one of two required core courses in the Penn State Graduate Automotive Technology Education (GATE) curriculum leading to a GATE certificate. It is an introduction to high-power in-vehicle energy storage technologies used in pluggable and grid independent hybrid electric and fuel cell vehicles including advanced battery chemistries, ultracapacitors, and flywheels. The course also provides an overview of hybrid electric and fuel cell vehicle design, control, and simulation to determine the effect of energy storage components on performance and fuel efficiency.

Section	**Time**	**Room**	**Instructors**
Sec.1	MWF 1:25-2:15	TBD	J. Anstrom, C. Bakis, M. Lanagan, J. Mayer

Faculty	**Office**	**Phone**	**E-mail**
Dr. J. Anstrom	201 Transportation Res.	863-8904	jra2@psu,edu
Dr. C. Bakis	212 Earth & Eng. Sci.	865-3178	cbakis@psu.edu
Dr. M. Lanagan	258 Materials Research	865-6992	mxl46@psu.edu
Dr. Jeffrey Mayer	209G EE West	865-0242	jsmayer@psu.edu

Required Text: Technical papers to be supplied by instructors
Required Notes: Notes to be supplied by instructors
Prerequisites: None.
Homework: Grading of homework will include consideration of the professional manner in which the solution is presented. Homework should be neatly and professionally prepared and is due at the beginning of class.
Grading:

Ultra-capacitor assignments/quizes:	25%
Battery assignments/quizes:	25%
Flywheel assignments/quizes:	25%
Vehicle modeling assignments/quizes:	25%
Total	100%

Academic Dishonesty: (Rule 49-20, Undergraduate Curriculum Information and Planning Manual)
The College of Engineering considers academic dishonesty, including cheating and plagiarism, to be a serious offense. If you are unsure what conditions constitute academic dishonesty, (i.e., if you can collaborate with other students with homework, etc.); ask your instructor. Dishonest incidents should be reported to the course instructor or to the Department Head, who in turn will refer it to the Department Dishonesty Hearing Committee. The departmental committee shall consist of an equal number of faculty and students from the department.

	Date	Topic	Instructor	Lecture Topic
1	8/24	Course Intro	GATE Faculty	**Introduction and technology demonstrations**
2	8/27	Vehicle Modeling	Dr. Joel Anstrom	Vehicle Power and Energy Requirements
3	8/30	Ultra-capacitors	Dr. Mike Lanagan	Introduction to Capacitor Technology
4	9/1	Ultra-capacitors	Dr. Mike Lanagan	Ultracapacitor Systems and Homework discussion
5	9/3	Ultra-capacitors	Dr. Mike Lanagan an Ram Rajagopalan	Capacitor Lab – 214 Materials Research Lab
	9/6	**Labor Day No Class**		
6	9/8	Ultra-capacitors	Dr. Mike Lanagan an Ram Rajagopalan	Capacitor Lab – 214 Materials Research Lab
7	9/10	Ultra-capacitors	Dr. Mike Lanagan	Capacitor Technology and Reliability
8	9/13	Ultra-capacitors	Dr. Mike Lanagan	Inductive energy storage and superconductors
9	9/15	Ultra-capacitors	Dr. Mike Lanagan	
10	9/17	Ultra-capacitors	Dr. Mike Lanagan	
11	9/20	Ultra-capacitors	Dr. Mike Lanagan	
12	9/22	Ultra-capacitors	Dr. Mike Lanagan	
13	9/24	Ultra-capacitors	Dr. Mike Lanagan	
14	9/27	Ultra-capacitors	Dr. Mike Lanagan	
15	9/29	Ultra-capacitors	Dr. Mike Lanagan	
16	10/1	Ultra-capacitors	Dr. Mike Lanagan	
17	10/4	Batteries	Dr. Joel Anstrom	
18	10/6	Batteries	Dr. Joel Anstrom	
19	10/8	Batteries	Dr. Joel Anstrom	
20	10/11	Batteries	Dr. Joel Anstrom	
21	10/13	Batteries	Dr. Joel Anstrom	
22	10/15	Batteries	Dr. Joel Anstrom	
23	10/18	Fuel Cells	Dr. Joel Anstrom	
24	10/20	Fuel Cells	Dr. Joel Anstrom	
25	10/22	Fuel Cells	Dr. Joel Anstrom	
26	10/25	Fuel Cells	Dr. Joel Anstrom	
27	10/27	Battery/Fuel Cell	Dr. Joel Anstrom	
28	10/29	Battery/Fuel Cell	Dr. Joel Anstrom	
29	11/1	Battery/Fuel Cell	Dr. Joel Anstrom	
30	11/3	Flywheels	Dr. Chuck Bakis	
31	11/5	Flywheels	Dr. Chuck Bakis	
32	11/8	Flywheels	Dr. Chuck Bakis	
33	11/10	Flywheels	Dr. Chuck Bakis	
34	11/12	Flywheels	Dr. Chuck Bakis	
35	11/15	Flywheels	Dr. Chuck Bakis	
36	11/17	Flywheels	Dr. Chuck Bakis	
37	11/19	Flywheels	Dr. Chuck Bakis	
38	11/29	Flywheels	Dr. Chuck Bakis	

	11/22-28	**Thanksgiving Break**		
39	12/1	Flywheels	Dr. Chuck Bakis	
40	12/3	Flywheels	Dr. Chuck Bakis	
41	12/6	Flywheels	Dr. Jeffrey Mayer	High-speed Motors and Generators
42	12/8	Flywheels	Dr. Jeffrey Mayer	High-speed Motors and Generators
43	12/10	Flywheels	Dr. Jeffrey Mayer	High-speed Motors and Generators

Appendix B: ME 442W

ME 442W
HYBRID-ELECTRIC VEHICLE LAB I
Fall 2010

https://student.hev.psu.edu

Meeting Times Thursday 8:00 AM – 8:50 AM, 101 Walker
Monday 6:30 PM – 7:45 PM, 189 Materials Research Lab (MRL)

Instructor Gary Neal
239 ARL Science Park Building
814-863-5468 gln103@psu.edu

Office Hours By appointment

Text There is no required textbook. See page 4 for recommendations.

Grading

Attendance	10%
Presentations	10%
Project Work	30%
Written reports	20%
Ecocar events	10%
Peer and customer evaluation	20%

Background The Hybrid-Electric Vehicle (HEV) Lab is designed around Penn State's Advanced Vehicle Technology Competition (AVTC) team: Ecocar. The Lab was created to encourage student participation in the AVTC by providing academic credit for completing an AVTC-related project. Two semesters of HEV Lab (ME442 and ME443 - 3 credits total) can fulfill the normal three-credit writing-intensive senior design requirement for Mechanical Engineering students (ME440W or ME441W) or a Technical Elective Requirement.

Course Objectives The objectives are identical to those of the writing-intensive Mechanical Engineering senior design courses (ME440W/ME441W):

A. Apply academic training and education to provide a professional engineering solution to a real-life problem

B. Implement the design process to a professional engineering problem

C. Work effectively in a team that includes coworkers, customers and vendors

D. Communicate well using verbal, written and electronic methods

Course Outcomes

The expected outcomes are essentially the same as those of the writing-intensive Mechanical Engineering senior design courses (ME440W/ME441W). The mapping of course outcomes to course objectives is indicated in brackets below. Upon completing this course, the student should be able to:

1. Identify and utilize appropriate engineering analysis software during the execution of the project (e.g., Matlab, Mathcad, FLUENT, SolidWorks etc.) [A]
2. Learn to use new evolving engineering tools for analysis, fabrication and management [A]
3. Develop the ability and confidence to make technical decisions based on analysis and research [A]
4. Apply creative ability; i.e. learn to generate ideas focused on solving the identified project technical tasks [B]
5. Conceptualize devices and systems to satisfy design criteria [B]
6. Analyze technical and economic merits of design alternatives [B]
7. Select the most suitable solution that is both useful and feasible by using engineering analysis, modeling and simulation, while keeping in mind any side or long-term environmental and societal effects [B]
8. Learn to use information gained from the first solution to iterate and improve or refine and improve the design and/or solution [B]
9. Face the necessity to wrap up a job or task completely and be able to defend technically each step from broad concept to detailed design [B]
10. Clearly define the project needs and then develop an action plan to organize, schedule and execute the project deliverables in a timely fashion and within budget [C]
11. Cooperate as a group to accomplish a technical task, requiring division of effort and coordination of separate contributions [C]
12. Use resources such as library, patent literature, source people, hardware vendors and support personnel [C]
13. Interact with a customer (boss, coworker, client) to formulate equitable design criteria (time, cost, quality) for a meaningful engineering project [C]

14. Use skills in engineering communications, engineering drawings, graphics, written and oral reports, and shop work [D]
15. Interact with industrial sponsors and produce a working product or a model that satisfies the project needs [D]
16. Demonstrate professionalism in interactions with colleagues, faculty, and staff [D]

Requirements

HEV Lab participants take on a challenging design project that is supervised by the AVTC team student and faculty leadership (the "customer"). In year one (2008-2009) of the Ecocar competition, modeling and simulation were emphasized. In year two, the team designed and built a "mule" vehicle and competed in the June 2010 competition being held in Yuma, AZ. In year three, the team will refine the powertrain and controls for a prototype "production" vehicle that will compete in the 2011 competition. Emphasis will be on vehicle hardware and software refinements, consumer acceptability, and robustness. Each lab student is required to participate in broader aspects of Ecocar (e.g., planning, outreach and public relations, fundraising, report preparation, garage infrastructure, etc.).

To participate in the project, each student is required to complete and submit the following forms: A123 Non-disclosure Agreement, Liability Release (GM), Liability Release (PSU), LTI Student Contract & Emergency Form, Test Track Regulations 2010, a copy of their driver's license and three year driving record, HEV Garage Key Clearance Form, and Skills Survey. Each student is expected to read and to abide by the safety policies enumerated in the handout "Student Policies for LTI Facilities Usage." Students working in the garage are required to receive safety training and machining training through the Learning Factory, and chemical and hazardous waste handling training through Environmental Health and Safety. If for any reason a student feels that they will be unable to comply with these requirements, they should discuss the issue with the instructor immediately (that is, very *early* in the semester).

Students are expected to monitor regularly (e.g., daily) the Ecocar project management website: in particular, the *Calendar* and *Forums*. Students are responsible for any assignments and/or events posted in these areas. Students are expected to participate in the forum discussions. Students also are expected to sign up for the Ecocar listserve.

Grading is based on timely and effective written and oral communication; on design of the team's subsystem or project as part of the overall AVTC effort; and on active participation in the broader aspects of Ecocar. The course schedule is linked to the Ecocar competition schedule, and assignments are tied to Ecocar deliverables.

Attendance Regular attendance is expected and attendance will be taken. Keep in mind that your grade includes peer evaluations by your fellow students ("coworkers") and by Ecocar team leaders ("customers").

Academic Integrity In this course, you are expected to work in teams. A major component of this course is technical writing and communication. In preparing written or oral reports, keep in mind that taking information (*e.g.*, figures, tables, text) from published sources without proper acknowledgement is inappropriate: in fact, it is plagiarism. The commission of any deliberately dishonest act may result in failure of the course with no late drop permitted. Examples of dishonest acts include plagiarism, or signing the attendance sheet for another student. For further information, see http://www.engr.psu.edu/CurrentStudents/acadinteg.aspx.

Some Websites http://www.ecocarchallenge.org - Argonne National Laboratory's Ecocar competition site

http://www.hev.psu.edu - Penn State AVTC team
http://www.sae.org - SAE International
http://www2.mne.psu.edu/sae/fsae - Penn State Formula SAE competition team
http://www.pti.psu.edu - Penn State Pennsylvania Transportation Institute
http://www.lf.psu.edu - Penn State College of Engineering Learning Factory
http://www.ehs.psu.edu/ - Penn State Environmental Health and Safety

Some Books R. Stone and J.K. Ball, *Automotive Engineering Fundamentals*, SAE (2004). ISBN 0-7680-0987-1

J.M. Miller, *Propulsion Systems for Hybrid Vehicles*, IEE (2003). ISBN 0-86341-336-6
J.M. German, *Hybrid Powered Vehicles*, SAE (2003). ISBN 0-7680-1310-0
M. Westbrook, *The Electric and Hybrid Electric Car*, SAE (2001). ISBN 0-7680-0897-2
L.S. Litowitz and R.A. Brown, *Energy, Power, and Transportation Technology*, Goodheart-Wilcox (2007). ISBN 1-59070-221-2

K. Ulrich and S. Eppinger, *Product Design and Development*, 4th edition, McGraw-Hill/Irwin (2007). ISBN 10:0073101427; 13:978-0073101422

Appendix B Continued: ME 443W

ME 443
HYBRID-ELECTRIC VEHICLE LAB
Spring 2011

https://student.hev.psu.edu

Meeting Times Monday 6:30 PM – 7:45 PM, 189 Materials Research Lab (MRL)

Instructor Gary Neal
239 ARL Science Park Building

863-5468 gln103@psu.edu

Office Hours By appointment

Text There is no required textbook. See page 3 for recommendations.

Grading

Attendance	10%
Presentations	10%
Project Work	30%
Written reports	15%
Ecocar events	10%
Peer and customer evaluation	25%

Background The Hybrid-Electric Vehicle (HEV) Lab is designed around Penn State's Advanced Vehicle Technology Competition (AVTC) team: Ecocar. The Lab was created to encourage student participation in the AVTC by providing academic credit for completing an AVTC-related project. Two semesters of HEV Lab (ME497B and ME497A - 3 credits total) can fulfill the normal three-credit writing-intensive senior design requirement for Mechanical Engineering students (ME440W or ME441W).

Course Objectives The objectives are identical to those of the writing-intensive Mechanical Engineering senior design courses (ME440W/ME441W):

E. Apply academic training and education to provide a professional engineering solution to a real-life problem

F. Implement the design process to a professional engineering problem

G. Work effectively in a team that includes coworkers, customers and vendors

H. Communicate well using verbal, written and electronic methods

Course Outcomes The expected outcomes are essentially the same as those of the writing-intensive Mechanical Engineering senior design courses (ME440W/ME441W). The mapping of course outcomes to course objectives is indicated in brackets below. Upon completing this course, the student should be able to:

17. Identify and utilize appropriate engineering analysis software during the execution of the project (e.g., Matlab, Mathcad, FLUENT, SolidWorks etc.) [A]
18. Learn to use new evolving engineering tools for analysis, fabrication and management [A]

19. Develop the ability and confidence to make technical decisions based on analysis and research [A]
20. Apply creative ability; i.e. learn to generate ideas focused on solving the identified project technical tasks [B]
21. Conceptualize devices and systems to satisfy design criteria [B]
22. Analyze technical and economic merits of design alternatives [B]
23. Select the most suitable solution that is both useful and feasible by using engineering analysis, modeling and simulation, while keeping in mind any side or long-term environmental and societal effects [B]
24. Learn to use information gained from the first solution to iterate and improve or refine and improve the design and/or solution [B]
25. Face the necessity to wrap up a job or task completely and be able to defend technically each step from broad concept to detailed design [B]
26. Clearly define the project needs and then develop an action plan to organize, schedule and execute the project deliverables in a timely fashion and within budget [C]
27. Cooperate as a group to accomplish a technical task, requiring division of effort and coordination of separate contributions [C]
28. Use resources such as library, patent literature, source people, hardware vendors and support personnel [C]
29. Interact with a customer (boss, coworker, client) to formulate equitable design criteria (time, cost, quality) for a meaningful engineering project [C]
30. Use skills in engineering communications, engineering drawings, graphics, written and oral reports, and shop work [D]
31. Interact with industrial sponsors and produce a working product or a model that satisfies the project needs [D]
32. Demonstrate professionalism in interactions with colleagues, faculty, and staff [D]

Requirements

HEV Lab participants take on a challenging design project that is supervised by the AVTC team student and faculty leadership (the "customer"). In year one (2008-2009) of the Ecocar competition, modeling and simulation were emphasized. In year two, the team will design and build a "mule" vehicle and competed in the June 2010 competition being held in Yuma, AZ. In year three, the team will refine the powertrain and controls for a prototype "production" vehicle that will compete in the 2011 competition. Emphasis will be on further vehicle hardware and software refinements, consumer acceptability, and robustness. Each lab student is required to participate in broader aspects of Ecocar (e.g., planning, outreach and public relations, fundraising, report preparation, garage infrastructure, etc.).

To participate in the project, each student is required to complete and submit the following forms: A123 Non-disclosure Agreement, Liability Release (GM), Liability Release (PSU), LTI Student Contract & Emergency Form, Test Track Regulations 2010, a copy of their driver's license and three year driving record, HEV Garage Key Clearance Form, and Skills Survey. Each student is expected to read and to abide by the safety policies enumerated in the handout "Student Policies for LTI Facilities Usage." Students working in the garage are required to receive safety training and machining training through the Learning Factory, and chemical and hazardous waste handling training through Environmental Health and Safety. If for any reason a student feels that they will be unable to comply with these requirements, they should discuss the issue with the instructor immediately (that is, within the first two weeks of the semester).

Students are expected to monitor regularly (e.g., daily) the Ecocar project management website (www.student.hev.psu.edu): in particular, the *Calendar* and *Forums*. Students are responsible for any assignments and/or events posted in these areas. Students are expected to participate in the forum discussions. Students also are expected to sign up for the Ecocar listserve.

Grading is based on timely and effective written and oral communication; on design of the team's subsystem or project as part of the overall AVTC effort; and on active participation in the broader aspects of Ecocar. The course schedule is linked to the Ecocar competition schedule, and assignments are tied to Ecocar deliverables.

Attendance Regular attendance is expected, and attendance will be taken. Keep in mind that your grade includes peer evaluations by your fellow ME497A students ("coworkers") and by Ecocar team leaders ("customers").

Academic Integrity In this course, you are expected to work in teams. A major component of this course is technical writing and communication. In preparing written or oral reports, keep in mind that taking information (*e.g.*, figures, tables, text) from published sources without proper acknowledgement is inappropriate: in fact, it is plagiarism. The commission of any deliberately dishonest act will result in disciplinary action. For further information, guidelines, and details of the University's policies, see: http://www.engr.psu.edu/CurrentStudents/acadinteg.aspx.

Some Websites http://www.ecocarchallenge.org - Argonne National Laboratory's Ecocar competition site

http://www.hev.psu.edu - Penn State AVTC team
http://www.sae.org - SAE International
http://www2.mne.psu.edu/sae/fsae - Penn State Formula SAE competition team
http://www.pti.psu.edu - Penn State Pennsylvania Transportation Institute
http://www.lf.psu.edu - Penn State College of Engineering Learning Factory
http://www.ehs.psu.edu/ - Penn State Environmental Health and Safety

Some Books

R. Stone and J.K. Ball, *Automotive Engineering Fundamentals*, SAE (2004). ISBN 0-7680-0987-1

J.M. Miller, *Propulsion Systems for Hybrid Vehicles*, IEE (2003). ISBN 0-86341-336-6

J.M. German, *Hybrid Powered Vehicles*, SAE (2003). ISBN 0-7680-1310-0

M. Westbrook, *The Electric and Hybrid Electric Car*, SAE (2001). ISBN 0-7680-0897-2

L.S. Litowitz and R.A. Brown, *Energy, Power, and Transportation Technology*, Goodheart-Wilcox (2007). ISBN 1-59070-221-2

K. Ulrich and S. Eppinger, *Product Design and Development*, 4th edition, McGraw-Hill/Irwin (2007). ISBN 10:0073101427; 13:978-0073101422

Appendix B Continued: ME 097S

ME 097S
FIRST-YEAR SEMINAR: HYBRID-ELECTRIC VEHICLES
Spring 2011

https://student.hev.psu.edu

Meeting Times Monday 6:30 PM – 7:45 PM, 189 Materials Research Lab

Instructor Gary Neal
239 ARL Science Park Building
863-5468 gln103@psu.edu

Office Hours By appointment

Text There is no required textbook. See page 2 for recommendations.

Grading

Attendance	20%
Outreach Event	10%
Passport to Success	20%
Peer Evaluations	10%
Presentations	10%
Project Work	20%
Written reports	10%

Objectives Engineering First-Year Seminars are designed to *engage* students in learning and to *facilitate* the transition to college life. (See http://www.engr.psu.edu/fys/.)

Overview This seminar is designed around Penn State's Advanced Vehicle Technology Competition (AVTC) team: Ecocar. The Monday evening meeting time coincides with the weekly meetings of the Ecocar team. Students will be provided with basic background on hybrid-electric vehicles (HEV's), Ecocar, and broader transportation energy and emissions issues in a lecture/discussion/demonstration format. In addition, students will be provided with an opportunity to participate directly in Penn State's Ecocar project.

Seminar students will attend the first part of each Ecocar team meeting (general business). For the first few weeks of the semester, seminar students then will break out to meet separately with the instructor. By approximately the fourth week of the semester, students will participate directly in Ecocar by joining one of the project sub-teams and work with the upper-class students. Students will be assessed based on their contribution to their sub-team.

Requirements Each student is required to complete and submit the following forms: a Skills Survey, LTI Student Contract and Emergency form, two Release of Liability forms (one for GM, one for PSU), A123 Non-disclosure Agreement, and HEV Garage Key Clearance Form. Each student is expected to read and to abide by the safety policies enumerated in the handout "Student Policies for PTI Facilities Usage." And students are required to receive safety training and certification through the Learning Factory (www.lf.psu.edu). If for any reason a student feels that they will be unable to comply with these requirements, they should discuss the issue with the instructor immediately (that is, within the first two weeks of the semester).

Students are expected to monitor regularly (e.g., daily) the Ecocar project management (PM) website (www.student.hev.psu.edu): in particular, the *Calendar* and *Forums*. Students are responsible for any assignments and/or events posted in these areas. Students are expected to participate in the forum discussions. Students also are expected to sign up for the Ecocar listserve. Instructions on achieving these required aspects are detailed in the document located on the PM site under FILES/GETTING STARTED/"Getting_Started_cX_2010-2011.doc"

Grading will be based largely on attendance and on active participation. Participation includes in-class participation and project management forum participation. There will be no formal written assignments beyond a brief end-of-semester summary of activities/contributions. A portion of the grade (peer evaluation) will be based on input from Ecocar student team members and leaders.

Attendance Weekly attendance is required, and attendance will be taken. Notify your instructor *prior* to any anticipated absence (email is best).

Academic Integrity The commission of any deliberately dishonest act will result in disciplinary action. For further information, guidelines, and details of the University's policies, see: http://www.engr.psu.edu/CurrentStudents/acadinteg.aspx.

Some Websites http://www.ecocarchallenge.org - Argonne National Laboratory's Ecocar competition site.

http://www.hev.psu.edu - Penn State AVTC team
http://www.sae.org - SAE International
http://www2.mne.psu.edu/fsae - Penn State Formula SAE team
http://www.pti.psu.edu - Penn State Pennsylvania Transportation Institute
http://www.lf.psu.edu - Penn State College of Engineering Learning Factory
http://www.ehs.psu.edu/ - Penn State Environmental Health and Safety

Some Books* R. Stone and J.K. Ball, *Automotive Engineering Fundamentals*, SAE (2004). ISBN 0-7680-0987-1

J.M. Miller, *Propulsion Systems for Hybrid Vehicles*, IEE (2003). ISBN 0-86341-336-6
J.M. German, *Hybrid Powered Vehicles*, SAE (2003). ISBN 0-7680-1310-0
M. Westbrook, *The Electric and Hybrid Electric Car*, SAE (2001). ISBN 0-7680-0897-2
L.S. Litowitz and R.A. Brown, *Energy, Power, and Transportation Technology*, Goodheart-Wilcox (2007). ISBN 1-59070-221-2

K. Ulrich and S. Eppinger, *Product Design and Development*, 4th edition, McGraw-Hill/Irwin (2007). ISBN 10:0073101427; 13:978-0073101422

*Several books have been placed on reference in the Engineering Library on the third floor of the Hammond Building.

Appendix C: ME 597G

Electrochemical Engine Fundamentals

COURSE SCHEDULE
M 3:35 – 5:15 pm; 174 Willard
W 3:35 – 4:25 pm; 171 Willard

INSTRUCTOR
C.Y. Wang, Professor of Mechanical Engineering & Materials Science
338A Reber Bldg, 863-4762
Email: cxw31@psu.edu

TEXTBOOKS
J. Larminie and A. Dicks, Fuel Cell Systems Explained, Wiley, 2000.
C.Y. Wang, "Fundamentals of Electrochemical Engines," Classnotes ©1999-2008 Pennsylvania State University.

References
Handbook of Fuel Cells, Wiley & Sons, 2003.
Linden, D., Handbook of Batteries and Fuel Cells, McGraw-Hill, 1984.

OBJECTIVES
This course is to provide theory and practice of electrochemical engines (EC-Engine), i.e. batteries, super capacitors, and fuel cells. Focus is placed on the application of these novel engines to low-CO_2 emission, fuel-efficient vehicles such as fuel cell vehicles, hybrid electric vehicles and plug-in hybrids. The course begins with fundamental principles of electrochemistry and transport phenomena in electrochemical energy systems, followed by design and engineering of specific EC-engines. Lectures are accompanied by two lab sessions in which a battery system and a one-kilowatt hydrogen PEM fuel cell engine will be tested at Penn State Electrochemical Engine Center. Specific topics to be covered are:

1. Introduction
   - Hybrid Electric Vehicles (HEV) and Fuel Cell Vehicles (FCV)
   - Electrochemical Energy Systems: Batteries and Fuel Fells
2. Electrochemical Fundamentals
   - Thermodynamics
   - Electrode Kinetics
   - Transport Processes: Species, Heat and Charge Transport
3. EC Engines: Basic Concepts, Performance and Durability
4. Lead-Acid Battery Systems
5. Nickel-Metal Hydride Battery Systems
6. Lithium-Ion Battery Systems
7. Proton Exchange Membrane Fuel Cells
8. Diagnostic Techniques (followed by a lab session on battery/fuel cell)
9. Mathematical Modeling
10. Direct Methanol Fuel Cells for Micro and Portable Power

11. Solid Oxide Fuel Cells for Stationary Power
12. Selected Topics: Latest in Battery/Fuel Cell Technologies

The grading will be based on homework (20%), a midterm examination (30%) and a term project (50%). The project will provide students with an opportunity to perform independent reading and work on a topic of contemporary interest. The project topic will be selected by the student in consultation with the instructor. A conference on "EC-Engines" will be held at the end of the semester for oral presentation. Written reports are to be due at the end of classes.

Appendix D: MatSE 597D/ ESC 597A

Microwave Processing of Materials: Theory and Practice

Fall 2010, MWF: 3:35-4:25PM,
Materials Research Laboratory Room 214

Instructors: Dinesh Agrawal, 107 Materials Research Lab, 863-8034 (dxa4@psu.edu)
Mike Lanagan, 278 Materials Research Lab, 865-6992 (mxl46@psu.edu)
Elena Semouchkina, Electrical Engineering, Michigan Tech.

This course is intended for students that have an interest in microwave interactions with matter. Students with backgrounds in materials, bioengineering, neuroscience, chemistry, food science, electrical engineering, engineering science and mechanics are invited to enroll in this interdisciplinary course.

The course will focus on theory and how it is applied to process variety of materials for diverse applications such as biomedicine, microelectronics and energy. Fundamental dielectric, magnetic, and conduction properties of materials will be explored and how these properties influence microwave interactions with a variety of substances will be discussed. The course will introduce the fundamentals of dielectric and capacitor measurements and electromagnetic modeling.

The course will focus on theory and how it is applied to process variety of materials for diverse applications. How does microwave-matter interaction affect the properties and the quality of the final product? What are the advantages/disadvantages, limitations and unique capabilities of microwave technology? The course will also cover microwave heating and processing, which involves polymers, ceramics, metals, composite, food products, glasses and biological systems.

Fundamental dielectric, magnetic, and conduction properties of materials will be explored and how these properties influence microwave interactions with a variety of substances will be discussed. The course will introduce the fundamentals of microwave measurement and electromagnetic modeling and highlight links between electromagnetic field analysis and microwave device design.

Various real examples of case studies will be presented, and the results will be compared with the conventional processing techniques. Microwave processing in separate electric and magnetic field at 2.45 GHz will also be discussed. Issues involving the adaptation of microwave technique for commercialization of various products will also be addressed.

There will also be a laboratory component of the course, where students will have an opportunity to gain hand-on experience in materials processing using real microwave systems or modeling the EM wave configuration. Students will also work on individual projects involving microwave processing of a material of their choice. Student projects will be evaluated on their merit to integrate concepts presented in the course. These projects will be evaluated and graded on the basis of a written report and a formal presentation. Some examples of the student projects are:

- Compare dielectric property measurement and microwave heating of a sample.
- Simulate a near field applicator for a MRI imaging system.
- Simulate microwave field distribution within the brain as a blackbody emitter.
- Model a resonant structure and explore dependence of its characteristics on material properties and/or geometrical parameters.
- Model a cavity structure or dielectric structure by FDTD and compare the results with a microwave measurement.
- Explore the sintering kinetics of a microwave processed sample vs. a thermally processed sample.
- Carry out impedance spectroscopy over a broad frequency range on a sample outlining different relaxation phenomena within the sample. Project and measure results at high frequency.
- Measurement of permittivity and permeability at microwave frequency.
- Use a cavity perturbation method to measure a small sample.
- Ceramic sintering in a multimode cavity
- Selected materials processing in separate E and H fields in a single mode cavity
- (Students can also choose a material related to his/her thesis)

Reading Material: There is no prescribed text book, however, review articles, some reference material and publications of specific topics will be provided or posted on ANGEL.

Course Material: Power point presentations of the most class lectures will be provided using the Penn State's Course Management System ANGEL (http://cms.psu.edu).

Grading Policy:
2 Exams 25% each
Homework and lab write-ups 20%
Final Project 30%

Lecture and Laboratory: There will be two lectures and one laboratory per week. Students will have access under supervision to the microwave facility available at the Microwave Processing and Engineering Center. Students will sign up for specific time slots every week so that only three to four students are using microwave equipment at one time.

Academic Integrity: Following University Policy 49-20, students are expected to maintain a high degree of academic integrity throughout all the course. Accordingly, activities such as cheating, plagiarism, facilitating dishonesty to others, etc., will not be tolerated. This course adopts the College's academic integrity policy. For more information, please check http://www.ems.psu.edu/students/integrity/index.html

Appendix E: E.Mch. 471

Engineering Composite Materials

Fall Semester, 2009, 2:30-3:45 PM, 118 EES Bldg.
Prof. C.E. Bakis

Syllabus

No.	Date	Topic	Assignment**
1	8/25	Introduction -- Objectives, Overview, Applications	Read Ch 1, 2.4-2.5
2	8/27	Definitions and Nomenclature	
3	9/1	Reinforcement Materials	Read Ch. 2.9
4	9/3	Reinforcement Materials and Matrix Materials	
5	9/8	Simple Micromechanical Models for Elastic Properties of Unidirectionally Reinf'cd Laminas	Read selected topics in Ch. 3.4-3.6; HW1
6	9/10	Lamina Elastic Properties (Stiffness & Compliance Matrices)	Read Ch. 4.1-4.3
7	9/15*	Lamina Elastic Properties (Stiffness & Compliance Matrices)	
8	9/17*	Transformation of Stress, Strain, Compliance and Stiffness	Read Ch. 4.4-4.7; HW2
9	9/22	Micromechanical Strength of Unidirectional Fiber Composite Laminas	Read 5.1-5.2, 5.4-5.7
10	9/24	Macromechanical Strength Theories for Laminas	Read Ch. 6.1-6.6
11	9/29	Macromechanical Strength Theories for Laminas	HW3
12	10/1	Classical Lamination Theory	Read Ch. 7.1-7.6
13	10/6	Laminate Elastic Couplings	Read 7.7-7.11; HW4
14	10/8	**Test 1**	
15	10/13	Laminate Engineering Properties	Read 7.12 –7.14
16	10/15	Thermal and Moisture Effects	Read 8.1-8.2, 8.4-8.7;
17	10/20*	Thermal and Moisture Effects: Residual Stress	Read 8.8-8.16
18	10/22*	First Ply Failure Analysis of Laminates without Hygrothermal Effects	Read 9.1-9.6
19	10/27	Progressive Failure Analysis of Laminates with Hygrothermal Effects	Read 9.8-9.9, 9.11-9.12; Scan 9.10
20	10/29	Progressive Failure Analysis	HW5
21	11/3	Laminated Beams	
22	11/5	Sandwich Beams	
23	11/10	I-Beams	HW6
24	11/12	Delamination -- Intralaminar Force and Moment Resultants	
25	11/17	**Test 2**	
26	11/19	Delamination -- Strain Energy Release Rate	
	11/24,26	*Thanksgiving Holiday – no class this wk*	
27	12/1	Delamination	HW7
28	12/3	Stress Concentration Analysis	Read 10.10
29	12/8	Stress Concentration Analysis	
30	12/10	Special topics & Wrap-Up	

*C. Bakis will be out on travel this day.
**Reading assignments are related to the current day's lecture. HW problem sets will be distributed approximately on the days indicated. HW is due at the beginning of class on the day indicated in the assignment.

Appendix F: ME 597F

Advanced Vehicle Hardware-in-the-Loop Development Techniques

Instructor: **Dr. Joel Anstrom**
Email: jra2@psu.edu,
205 Transportation Building
Phone: 863-8904
Office hours: Tues 1-2 pm or by appt.

Topics: Modeling, optimization, and testing of advanced vehicle powertrains and their subsystems using hardware-in-the-loop methodologies.

Textbook: (required) *MATLAB* version 2008a with Simulink, Control System Toolbox, and Stateflow provided by the Mathworks. You can find the student version software at all campus bookstores, at any of the campus computer labs, etc.

Other References: Handouts will be posted on a course website (Angel).

Prerequisites: Assignments will require the use of MATLAB, so knowledge of this software is beneficial but not expected. Knowledge of structured programming as well as some willingness to learn this material is expected.

Course Objectives: Upon completion of the course, students should be able to:

1. Understand the basic principles of hardware-in-the-loop techniques for system development, testing, and optimization especially as these relate to testing and evaluation of advanced vehicle powertrains.
2. Compare mathematical models to physical behavior of energy storage components (batteries, ultracapacitors, and flywheels) coupled with energy conversion components (engines, electric motors, transmissions, and fuel cells). Students should be able to critically evaluate tradeoffs between fidelity versus complexity.
3. Use simulation or hardware-based methods to compare choices of advanced vehicle topologies.
4. Optimize a powertrain design, and particularly the energy storage systems, to maximize efficiency and or performance of hydrogen fuel cell, hybrid-electric, and electric vehicles. Understand the use of HIL to tune system performance for temperature extremes. Students should also demonstrate fundamental understanding of tradeoffs between performance and efficiency.

Grading: In accordance with the policy of this University, all students are encouraged to attend every class period. Because this is a graduate course, the lecture content is supplemental to the student's primary studies outside the classroom. Students are responsible for information disseminated in the required reading and lab exercises, even if this material is not necessarily covered in lectures.

5 labs assignments	= 500
Homeworks, prelabs	= 100
Quizzes	= 50
final project	= 100
Total	**750 points**

ME 597F Spring 2010 – Advanced Vehicle Hardware-in-the-Loop Methods
Course Syllabus (v2)

Lecture Topic:	Assignments:
1 Syllabus, HIL Introduction	R1: HIL Case Studies
2 Hybrid Topologies and Vehicle Demo	H1: Topology Worksheets
3 Hybrid Topologies and Vehicle Demo	
4 Vehicle Components and Test Equipment Demo	
5 Vehicle Components and Test Equipment Demo	R2: Matlab, PSAT
6 Matlab Simulink, xpc, and Stateflow	H1 Due
7 Matlab Simulink, xpc, and Stateflow	
8 Matlab Simulink, xpc, and Stateflow	H2: Simulink
9 PSAT Introduction and Examples	
10 PSAT Subsystems	
11 PSAT Subsystems	
12 Battery, Capacitor, and Flywheel Models	
13 Battery, Capacitor, and Flywheel Models	P1: Prelab 1, H2 Due
14 Lab 1: Battery and HIL Simulation of EcoCAR Model	L1: Battery, P1 Due
15 PSAT Case Studies	R3: PSAT Cases
16 PSAT Case Studies	
17 Transfer Functions and Frequency-response of Systems	
18 Optimization of Hybrid Components and Control Strategies	
19 Optimization of Hybrid Components and Control Strategies	L1 Due, Prelab 2
20 Lab 2: Capacitor and HIL Simulation Lab of EcoCAR Model	L2: Cap, P2 Due
21 AC Inverter and Motor Models	
22 AC Inverter and Motor Models	
23 DC Power Conversion, CAN	
24 DC Power Conversion, CAN	
25 Vehicle Road Load Models	L2 Due, Prelab 3
26 Lab 3: Motor and HIL Simulation Lab, CAN Lab	L3: Motor, P3 Due
27 Engine Models	
28 Engine Dynamics and Transients	
29 Emissions Testing	
30 Fuel Cell Modeling	
31 Hydraulic Hybrids	L3 Due, Prelab 4
32 Lab 4: Engine and Fuel Cell HIL Simulation Lab	L4: Engine, P4 Due
33 Chassis and Driver Dynamics	
34 Chassis Testing Protocols and Standards	
35 Chassis Testing Protocols and Standards	
36 Fundamental Limits on HIL	
37 Fundamental Limits on HIL	L4 Due, Prelab 5
38 Lab 5: Power-train Controller ECU HIL and Optimization	L5: System, P5 Due
39 Business Considerations	
40 Business Considerations	
41 Global Energy Supply and Demand	
42 Global Energy Supply and Demand	
43 Road Test of Optimized Algorithm	
44 Road Test of Optimized Algorithm	
45 Road Test of Optimized Algorithm	L5 Due

R – Reading, H – Homework, L – Laboratory, P – Prelab

Appendix G: Contacts

Dr. Joel R. Anstrom, Penn State GATE Program Director
201 Transportation Research Building
University Park, PA 16802
jra2@psu.edu
Ph. 814 863-8904
Fax 814 863-3707

Ms. Robin Tallon, Penn State GATE Program Administrator
201 Transportation Research Building
University Park, PA 16802
rtallon@engr.psu.edu
Ph. 814 863-1902
Fax 814 863-3707