



**PENN STATE DOE *GRADUATE
AUTOMOTIVE TECHNOLOGY
EDUCATION (GATE)* PROGRAM
FOR
IN-VEHICLE, HIGH-POWER
ENERGY STORAGE SYSTEMS**

Project ID#

DOE Merit Review, May 12, 2010

TI006

Joel Anstrom, Director

“This presentation does not contain any proprietary or confidential information”

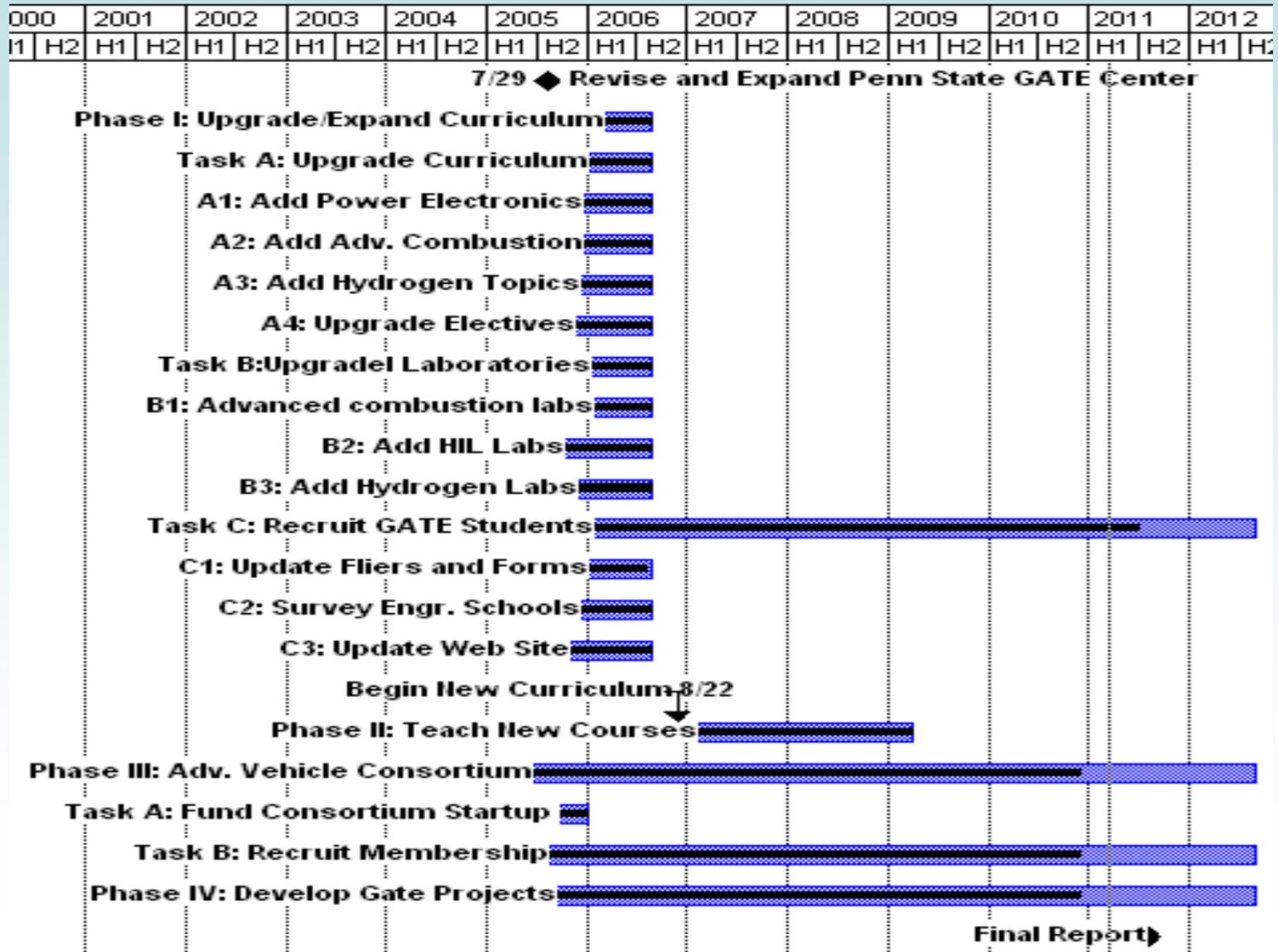


Overview of PSU GATE Center



- Timeline
 - Start Oct 2005
 - No Cost Ext Aug 2012
 - Spending last of match
- Budget
 - DOE \$597,431 obligated of \$597,431 award
 - PSU \$149,358 match
- Barriers
 - None
- Partners
 - Mathworks
 - US DOE and GM via EcoCAR
 - Pennsylvania College of Technology
 - Clemson University
 - Escuela Técnica Superior, Barcelona, Spain

Milestones

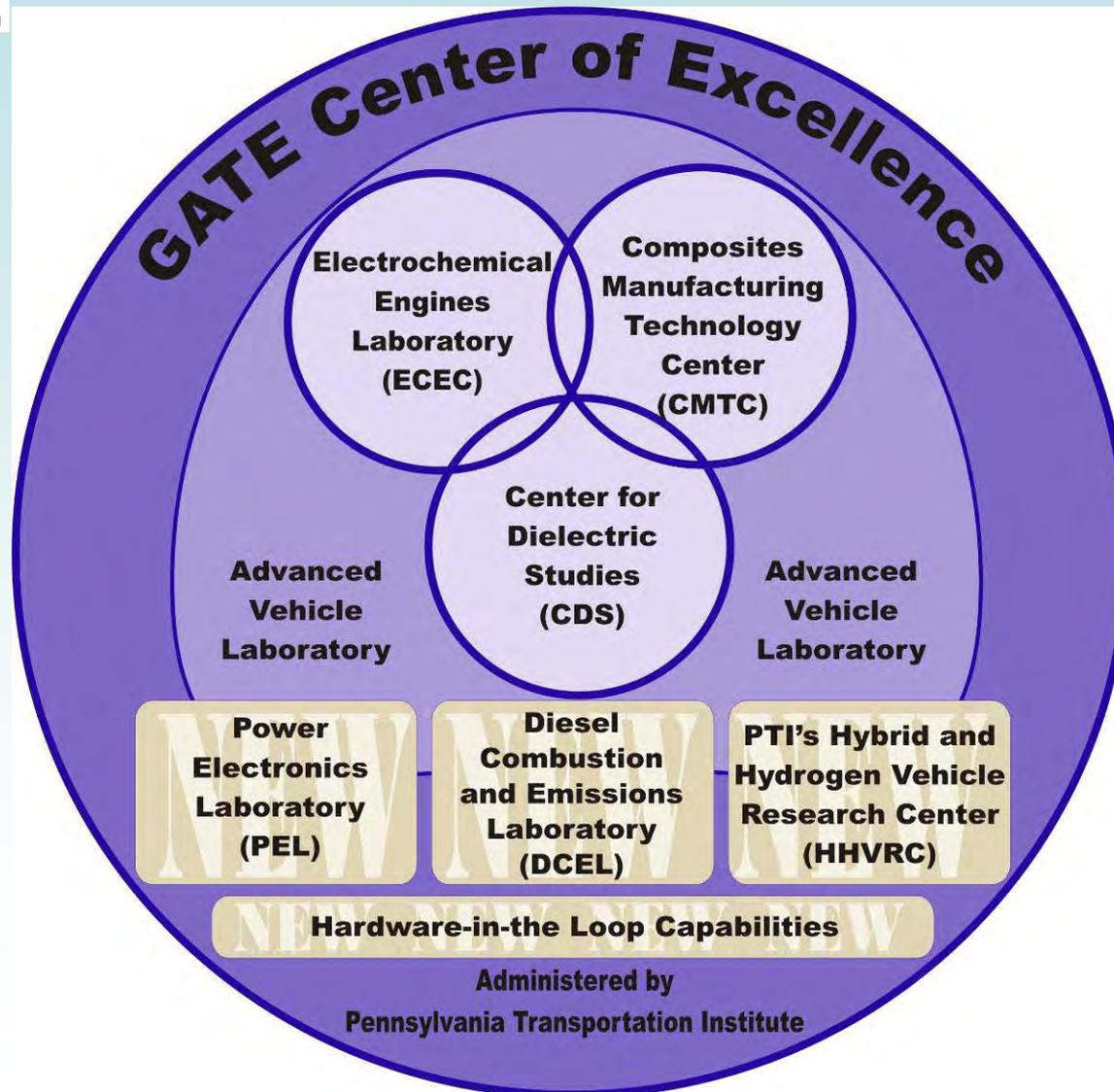


Goals and Objectives

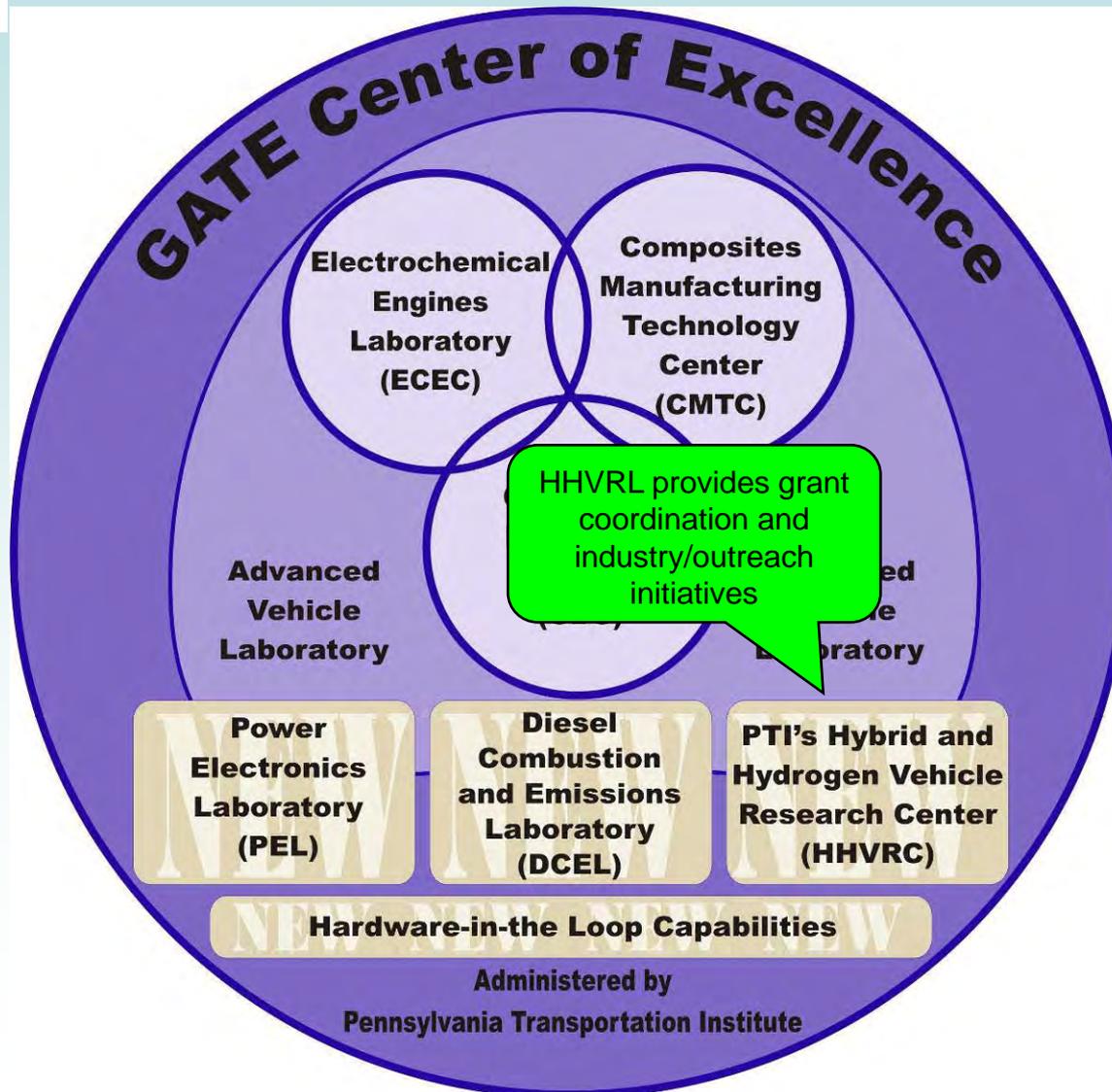
- Provide graduate curriculum focused on high-power in-vehicle energy storage for hybrid electric and fuel cell vehicles covering the fundamental science and models for **batteries, capacitors, flywheels** and their combinations
- Integrate system topics into energy storage curriculum including vehicle configurations, advanced combustion, fuel cells, power electronics, controls, alternative fuels and vehicle fuel efficiency to prepare students for careers
- Develop relationships between GATE students, faculty, industry/research partners, and employers



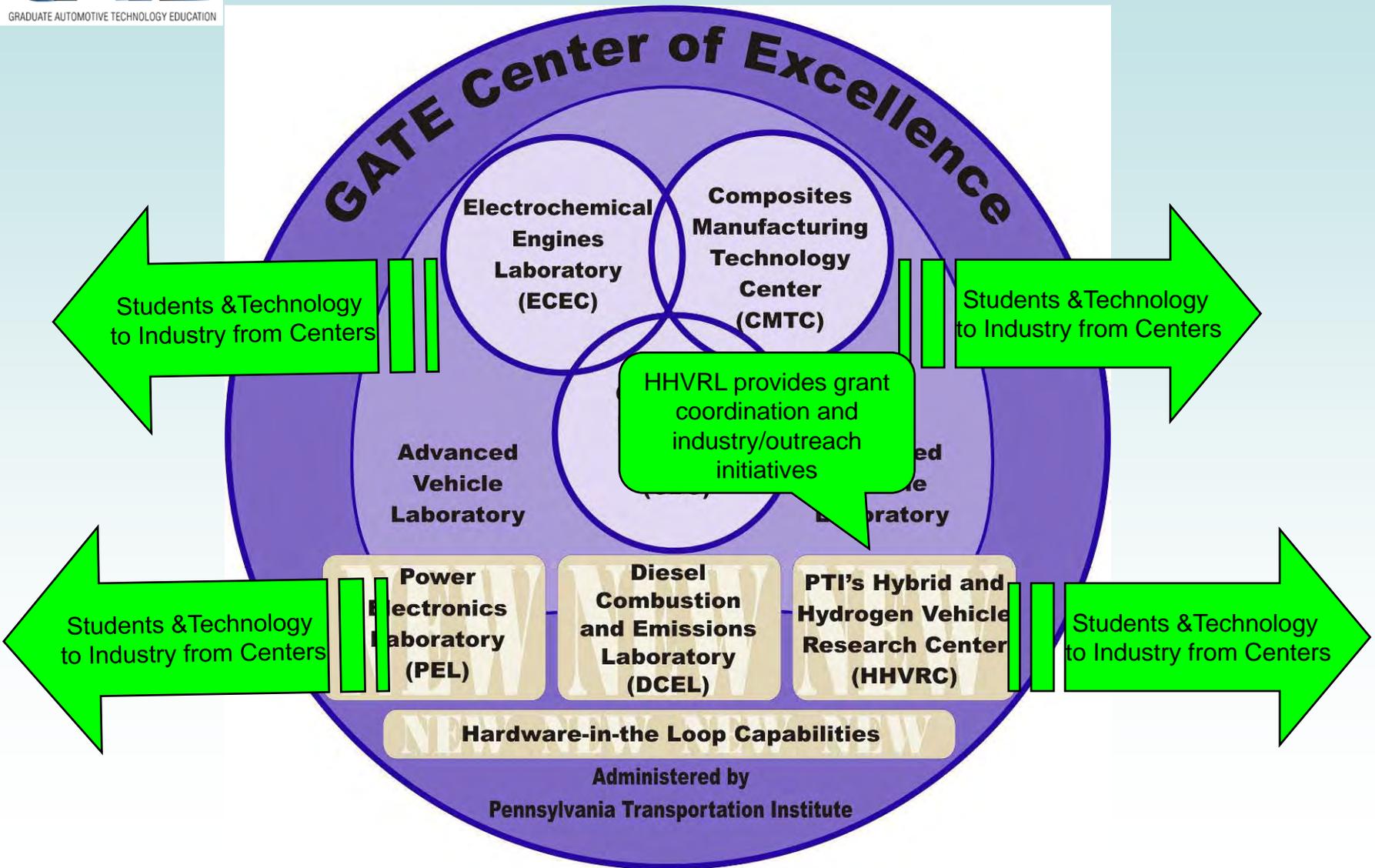
Penn State GATE Program Approach



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Penn State GATE Program Approach



- 1999 PSU GATE Program Faculty
 - Director/Systems - Donald Streit (ME) followed by Joel Anstrom (PA Transportation Institute, Systems)
 - Battery storage – Chao-Yang Wang (ME, ECEC)
 - Ultra-capacitors – Michael Lanagan (ES&M, CDS)
 - Flywheels – Charles Bakis (ES&M, CMTC)
- 2005 Expanded System Theme and Added PSU GATE Program Faculty
 - Adv. Combustion – Andre Boehman (EMS, DCEL)
 - Power Electronics – Jeff Mayer replaces Heath Hofmann in 2009 (EE, PEL)
 - Controls – Sean Brennan (ME, Controls)
 - HEV Lab Instructor, Challenge X Advisor – Daniel Haworth (ME, Advanced Combustion)
- Team planning and teaching of GATE courses
- Research in five Centers, HHVRL coordinates GATE industry outreach
- GATE Fellows follow curriculum and pursue energy storage thesis topic
- Any student in GATE curriculum considered a GATE Student
- Synergy with DOE AVTC Team
- Provide dedicated “focus vehicle” platforms for GATE student research

PSU GATE Faculty Accomplishments

Penn State GATE Faculty Organization 2010

GATE Program Administration

Dr. Joel Anstrom
Director

Robin Talon
Sr. Research Aid

Timothy Cleary
Research Assoc.

Debra Weaver
Staff Assistant

Core Energy Storage Courses

Dr. Chao Yang Wang
ElectroChemical
Engines

Dr. Charle Bakis
Composite Flywheels

Dr. Michael Lanagan
Dielectrics

Advance Vehicle Laboratory and System Courses

Dr. Daniel Haworth, Gary Neal
Hybrid Vehicle Lab - EcoCAR

Dr. Joel Anstrom, Dr. Sean Brennan,
Timothy Cleary
Hardware in the Loop Laboratory

Dr. Andrea Boehman
Advanced Combustion

Dr. Jeffery Mayer
Electric Machines, Power Electronics

PSU GATE Curriculum Accomplishments

Penn State GATE Curriculum 2010

Group I Prerequisites - Nine Credits Required

Select from
Department Math
Requirement (3)

Select Numerical
Methods Course
(3)

Select Advanced
Track Course
(3)

Group II Core Courses - Six Credits Required

ME/EMch/MatSc 597K - In Vehicle High
Power Energy Storage
(3)

ME 442W & 443W - Advanced Vehicle
Design I & II
(3)

Group III Elective Courses - Three Credits Required

ME 597G - Electrochemical Engines with
Laboratory
(3)

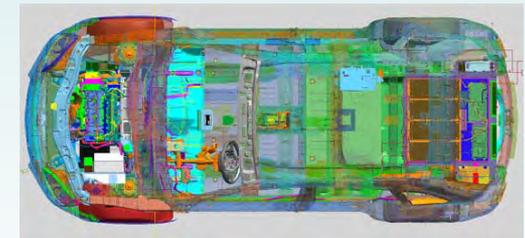
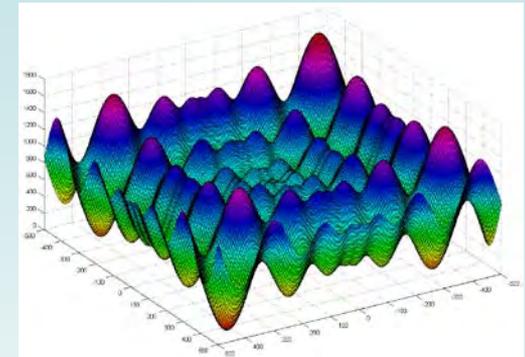
MatSE 597D/ESC 597A - Microwave
Processing of Materials: Theory & Practice
(3)

EMch 471 - Engineering Composite
Materials
(3)

ME 597F - Advance Vehicle Hardware in
the Loop Development Techniques
(3)

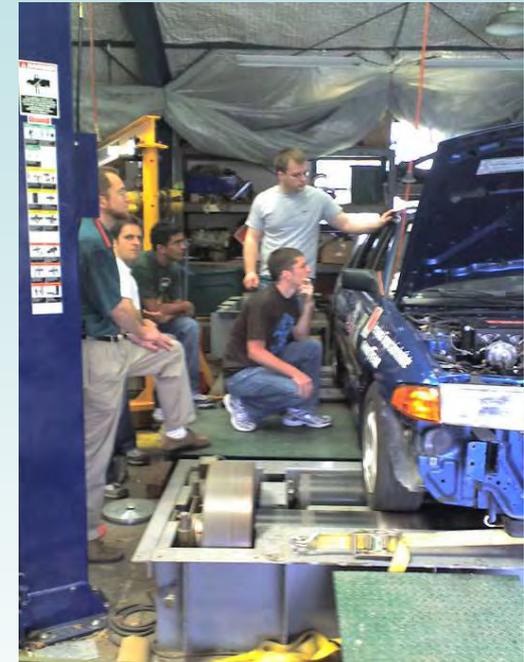
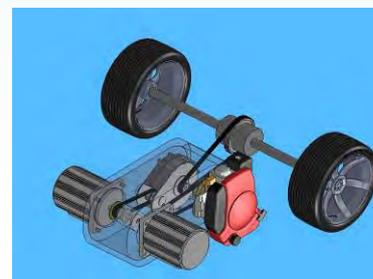
GATE Core Courses

- ME 597K High Power In-Vehicle Energy Storage
 - Fundamental science of energy storage
 - Batteries: NiMH, Lithium Chemistries
 - Capacitors: double layer
 - Flywheels: composite rotor design and motors
 - Introduction to Energy Storage Models
 - Vehicle/Hardware Demos and Lab Tours
 - Team taught by five GATE Faculty
- ME 497A and B HEV Laboratory
 - Develop **DOE AVTC** Competition Vehicles
 - 1999-2004 FutureTruck – Lithium Tech pack
 - 2005-2008 Challenge X – Lithium Tech pack
 - 2008-2011 EcoCAR – A123 pack
 - GATE Students bring energy storage expertise
 - Senior capstone for ME, EE, Chem Eng
 - Available engineering elective or as volunteer
 - Three GATE faculty advise team recruit students



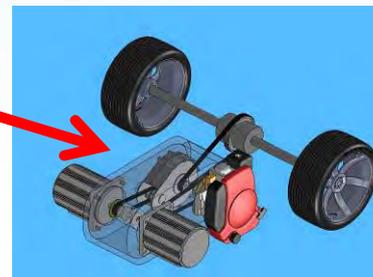
Systems Elective: ME 597F - HIL for Advanced Vehicles

- Hardware-in-the-Loop Development Methods
- **ANL donated licenses for Powertrain Systems Analysis Toolkit (PSAT)**
- **Matlab Sponsored software/hardware ~\$100K**
- Support EcoCAR team goals
- Energy storage focus
 - Battery model & lab
 - Capacitor model & lab
- Other HIL labs
 - Engine model & lab
 - Electric motor & lab
 - Control strategy optimization
 - On track fuel economy
- 2-mode PHEV developed for class
- Economic and Market Forces
- Team taught by four GATE faculty



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PSU GATE



Progress and Deployment

- 18 funded as GATE Fellows with DOE funding
- 37 funded as GATE Students with other funding
- 5 PhD students graduated
- ~450 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
- PSU GATE Graduates placed in FCV/HEV development and testing at Ford, GM, Chrysler, Nissan, NREL, INL, Oakridge NL, Mack Volvo, Aberdeen Proving Grounds



Sample GATE Publications



Publications

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.

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. 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.



Industry/Research Relationships with PSU GATE



- GM annual gift to GATE \$5K
- Hydrogen Station/Fleet Demonstration \$950K PA DEP Grant 2004-2008
 - 12 semesters of GATE Grad support through match
 - Air Products natural gas reformer and station cost shared with DOE ~\$4million
 - Collier Technologies – HCNG and H₂ engines and research
 - CATA – Transit bus use for H₂ demonstration
- Alloy Surfaces –PA DEP grant \$993K 2009-11 onboard hydrogen production module from aluminum/H₂O, four semesters GATE grad support
- The Mathworks & Advantech – ~\$100K in-kind 2007 Matlab Licenses and controllers donated for ME 597F GATE HIL class
- ANL – 13 PSAT 6.1 licenses for GATE HIL class
- Honda – ~\$20K for HIL hardware for visiting scientist Kosuke Orguri investigating Lithium Ion batteries for PHEV
- Mid-Atlantic University Transportation Center – supported GATE students for 15 graduate semesters with transportation thesis topics
- Lithium Technologies – In-kind Lithium battery sponsorship for Challenge X and bench top hybrid drive system for HIL lab
- TACOM – 4 semesters of GATE grad support for HIL of battery/capacitor power systems for heavy trucks through Penn State Applied Research Lab



Penn State GATE - Mathworks First User Video on Homepage



MathWorks - MATLAB and Simulink for Technical Computing - Windows Internet Explorer

http://www.mathworks.com/

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Industrial-Strength Skills at Penn State

Students gear up for careers in automotive design with MathWorks tools.

[Watch the video](#)

Latest News Accelerating Finite Element Analysis in MATLAB with Parallel Computing 30 Nov 2010

Products Events Training

Explore products for **MATLAB**, the language of technical computing, and **Simulink**, for simulation and Model-Based Design.

Featured Products

- Parallel Computing Toolbox
- Data Acquisition Toolbox

Latest Release

R2010b

MATLAB 7.1

Trial Software

Try MATLAB, Simulink and Other

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Industry Outreach Networking Events

- GATE industry networking coordinated by Hybrid and Hydrogen Vehicle Research Lab <http://www.vss.psu.edu/hhvrl/>
- First HHVRL Workshop April 2008, GATE Student Poster Session



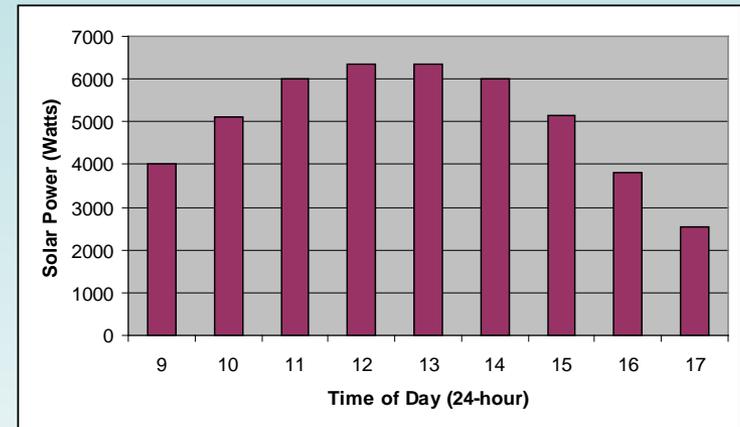
- Second Annual 21st Century Automotive Challenge May 21-23, 2010 at Penn State
 - Battery charging simulated V2G thru Solar Home
 - Consumer driving and fueling choices affect score
 - Scored on mpgge, petroleum displaced, CO²



21st CAC Legacy of Tour de Sol GATE Students Compete and Help Organize Education and Outreach Event Hosted at Penn State

Competition Divisions by Market Segment Rather than Technology

- Production / Independent
- Light Duty / Heavy Duty
- Local / Local and Highway
- Passenger accommodation: 1-2, 3-5, 6+



Carbon footprint score includes solar power fraction from PSU Solar Decathlon home introducing consumer choices of travel and charge time into overall lifestyle efficiency





PSU GATE Academic Collaborations



- Penn State **DOE AVTC EcoCAR** Team
- Pennsylvania College of Technology Advanced Automotive Technology Program
- Escuela Técnica Superior in Barcelona Spain exchange students complete their Masters Project on GATE focus vehicle systems.
- Penn State Center for Sustainability and 2007 **DOE Solar Decathlon** home
- Penn State Applied Research Lab
- Clemson University CU-ICAR



Future Work

- Continue offering GATE core and elective courses
- Continue HEV lab now participating in DOE EcoCAR
- Continual improvement GATE curriculum and labs
- Expand industry involvement, sponsorship, and projects
 - Continue recruitment of GATE partners into Hybrid and Hydrogen Vehicle Research Laboratory Consortium
 - Continue HHVRL Industry Workshops with GATE networking
 - Annual vehicle competitions outreach to public, new students
- Continue focus vehicle use for GATE student thesis
 - HyLion Fuel Cell Vehicle based on EV1 and NiMH pack
 - 1959 Berkeley two-mode HEV powertrain with LiFePO₄ pack
 - Ford Escort hydrogen ICE series hybrid with front wheel motors



Penn State GATE Summary



- GATE funding has been highly leveraged to support many students with other funding sources
- Good progress in energy storage centered curriculum development with system background
- Good progress in obtaining projects and collaborations with industry
- Strong outreach component
- Slightly behind plan in student/semesters supported as GATE fellows



Contact Information

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