



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

Project ID#

DOE Merit Review, May 20, 2009

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Joel Anstrom, Director

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

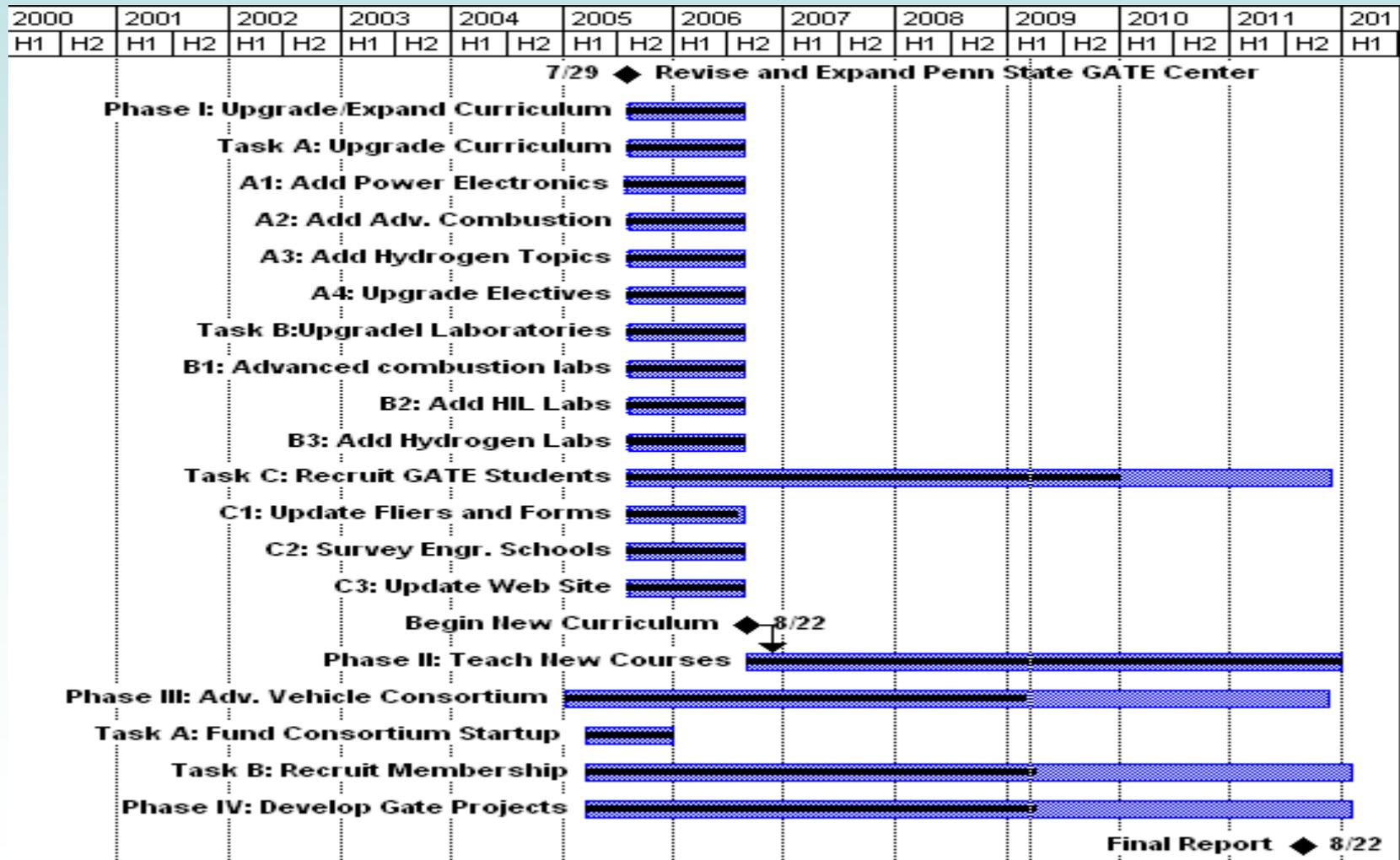


Overview of PSU GATE Center



- Timeline
 - Start Oct 2005
 - Finish Oct 2010
 - 80% complete
- Budget
 - DOE \$416,678 obligated of \$597,431 award
 - PSU \$149,358 match
- Barriers
 - Recruitment of domestic students in previously strong economy
 - Direct industry sponsorship of GATE fellows
- Partners - none

Milestones

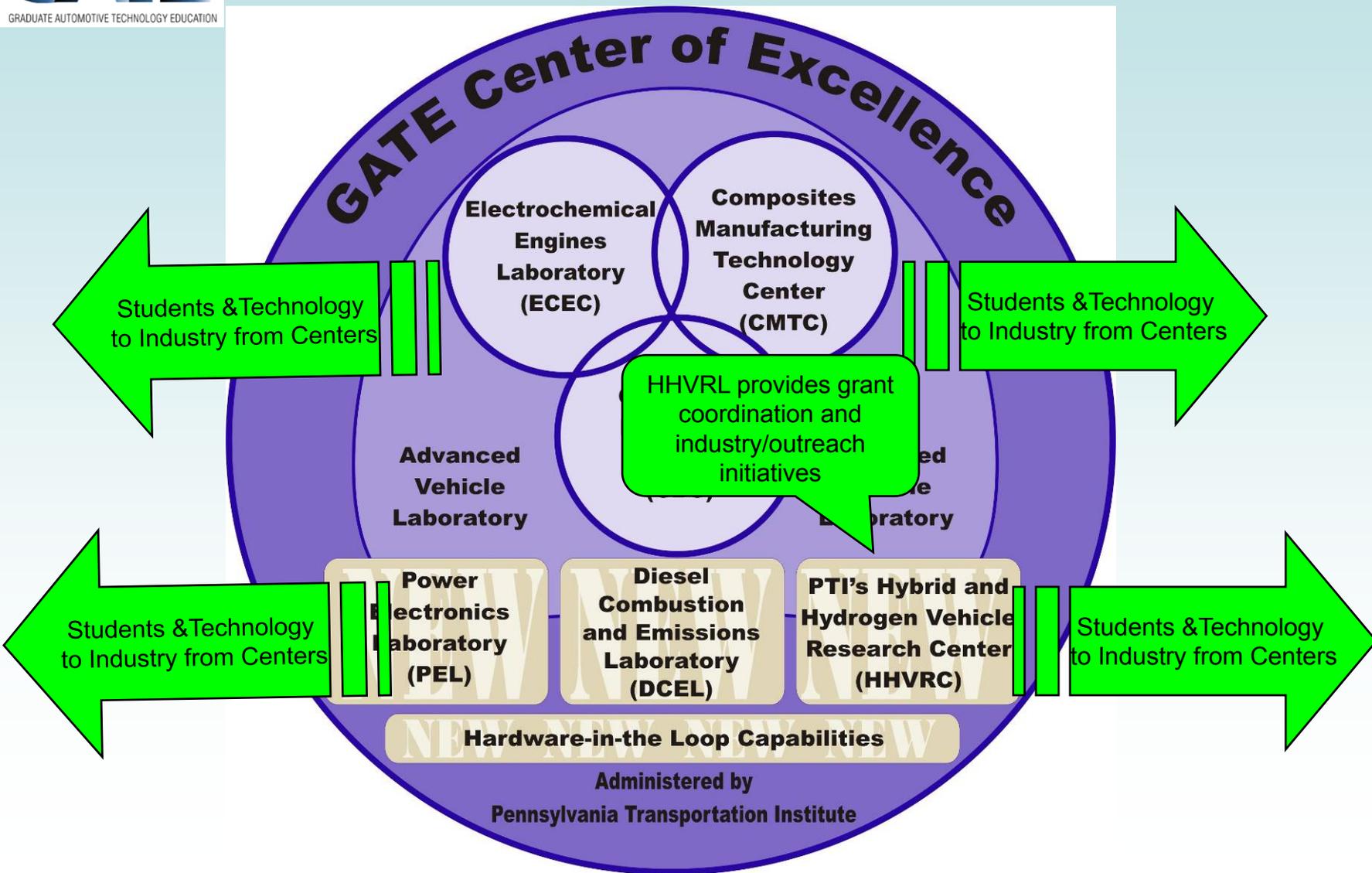


Goals and Objectives

- 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





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 Curriculum Accomplishments



Penn State University
GATE Center of Excellence
In-Vehicle, High-Power Energy Storage

Joel R. Anstrom
Director, GATE Center

Robin Tallon
Sr. Research Aide

Debra Weaver
Staff Assistant

Chao-Yang Wang
Electrochemical
Engines

Michael Lanagan
Dielectrics

Charles Bakis
Composite
Flywheels

Daniel Haworth
Advanced Vehicle
Lab

Andre Boehman
Advanced
Combustion

Heath Hofmann
Power Electronics

Group II--Core Energy Storage Courses

Group III--Advanced Vehicle Laboratory and High-Power Energy Storage Courses

Sean Brennan
Hardware-in-the-Loop
Laboratory

Hardware-in-the-Loop Laboratory for Curriculum Integration

Penn State University **GATE Center of Excellence** In-Vehicle, High-Power Energy Storage

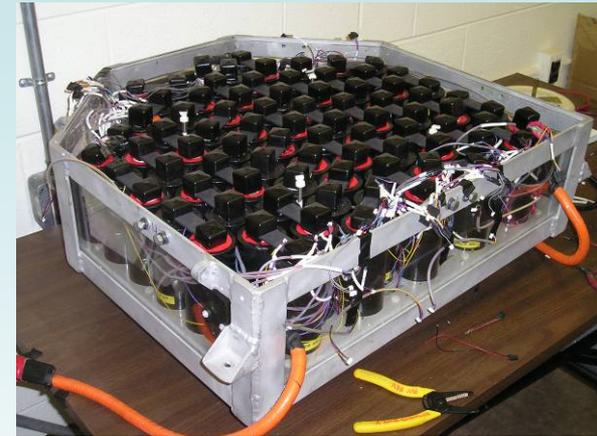
PSU GATE Curriculum Accomplishments

GATE Core Curriculum EMch/ME/MatSc 600 Thesis (6)

Group I (9 credits required)			Group IV (Advanced-Track Courses)
Select from Department Math Requirement (3)	Select Numerical Methods Course (3)	Select Advanced-Track Course (3)	
Group II (6 credits required)			
EMch/ME/MatSc 597F High-Power Energy Storage (3)	ME/EMch/MatSc 597B/A Advanced Vehicle Lab (3)		
Group III (1 course required)			
ME 597G Electrochemical Engines with Lab (3)	Emch 471 Engineering Composite Materials (3)	MatSc 597 Electronic Property Characterization of Materials and Capacitors (1)	
	ME 597F HIL Advanced Vehicles (3)		
			Group IVa. Mathematics
			Group IVb. Power Electronics
			Group IVc. Dynamics, Vibrations, and Controls
			Group IVd. System Modeling and Design
			Group IVe. Manufacturing
			Group IVf. Business
			Group IVg. Alternative Fuels
			Group IVh. Drive Trains
			Group IVi. Materials
			Group IVj. Advanced Combustion
			Group IVk. Chemistry
			Group IVm. Fuel Cells
			Group IVn. Solid Mechanics

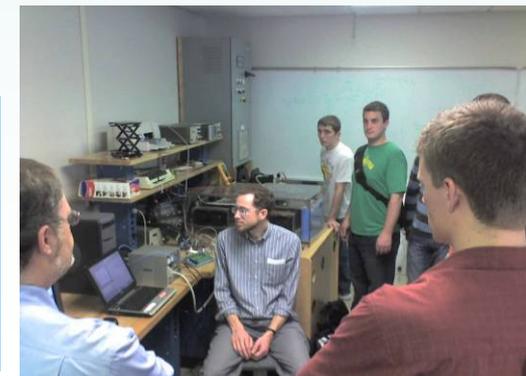
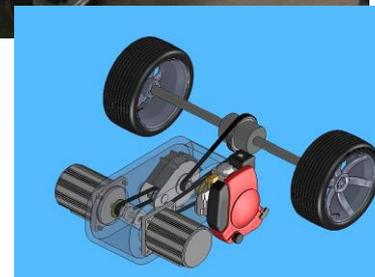
GATE Core Courses

- 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
 - 2008-2010 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 and hardware ~\$100K
- Support EcoCAR team
- Energy storage focus
 - Battery models & lab
 - Capacitor models &, lab
- Other labs HIL simulation of engines and electric motors
- Developing bench-top HEV
- Component models
- Control strategies
- Economic and Market Forces
- Team taught by four GATE faculty





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
- ~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
- 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

- A. Rovnan and H. Hofmann, "Brushless, Self-Excited Synchronous Field-Winding Machine for Variable-Speed Drive Applications," *2006 International Conference on Electric Machines* Chania, Crete Island, Greece, September 2-5, 2006, Paper No. 702
- B. Zile, "Induction Drive for a Hybrid Electric Vehicle," Thesis in Mechanical Engineering, The Pennsylvania State University, 2007.
- K. Smith, C.D. Rahn, C.Y. Wang, "Model Order Reduction of 1-D Diffusion Systems via Residue Grouping," *ASME J. Dynamic Systems, Measurement, & Control*, submitted.
- K. Smith, C.D. Rahn, C.Y. Wang, "Control-Oriented 1D Electrochemical Model of a Lithium Ion Battery," *Energy Conversion and Management*, submitted.
- K. Smith (presenter), C.Y. Wang, C.D. Rahn, "1-D Electrochemical Lithium Ion Battery Model for Real-Time Application," *6th International Advanced Automotive Battery and Ultracapacitor Conference*, May 15-19, 2006, Baltimore, MD.
- American Ceramic Society Meeting Presentation: Synthesis of Manganese Oxide Thin Films for Capacitor Electrodes, Do-Kyun Kwon¹, Teppei Akiyoshi², and Michael T. Lanagan¹, *Center for Dielectric Studies, Pennsylvania State University, 2Murata Manufacturing Co. LTD, Kyoto Japan*
- Joel Anstrom, Modeling Transient Response of Hybrid Vehicle with Stability Algorithm, International Mechanical Engineering Congress and Exposition, IMECE2006-14751, November 5-10, 2006, Chicago, Ill.
- K. Smith (presenter), C.Y. Wang, C.D. Rahn, "1-D Electrochemical Lithium Ion Battery Model for Real-Time Application," *6th International Advanced Automotive Battery and Ultracapacitor Conference*, May 15-19, 2006, Baltimore, MD.
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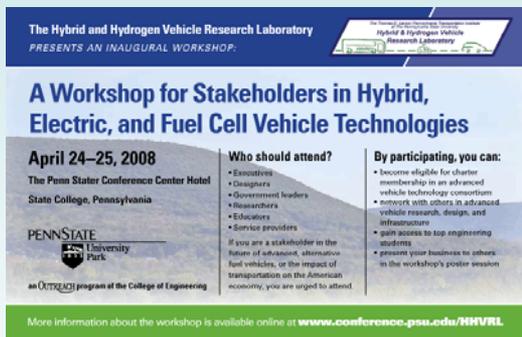
Industry/Research Relationships with PSU GATE



- 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
- MAUTC – support for multiple graduate assistants with transportation thesis
- 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

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 HHVRL Workshop combined with 21st Century Automotive Challenge April 17-19, 2009 at PSU
 - Combined industry expo, EV/HEV competition
 - Battery charging simulated V2G thru Solar Home
 - Consumer driving and fueling choices affect score
 - Scored on mpgge, petroleum displaced, CO²





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



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
 - Recruit new GATE partners into Hybrid and Hydrogen Vehicle Research Laboratory Consortium
 - Annual 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



Summary

- GATE funding is highly leveraged to support many students with other funding sources
- Good progress in curriculum development
- Good progress in projects and collaborations
- Emphasizing more regular publications
- Challenging to recruit qualified domestic students within academic cycle in strong economy
- Back on plan in number of GATE fellows
- Behind plan in number of student/semesters supported as GATE fellows



Contact Information

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