PENN STATE *DOE GATE* CENTER OF EXCELLENCE FOR IN-VEHICLE, HIGH-POWER ENERGY STORAGE SYSTEMS

DOE Merit Review, February 28, 2008

Joel Anstrom, Director

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

Outline

- PSU GATE Program Goals and Objectives
- Addressing Previous Merit Review Comments
- Approach to Graduate Curriculum
- Performance Measures and Impact
- Publications and Collaborations
- Recent Outreach Events
- Plans for 2008
- Summary

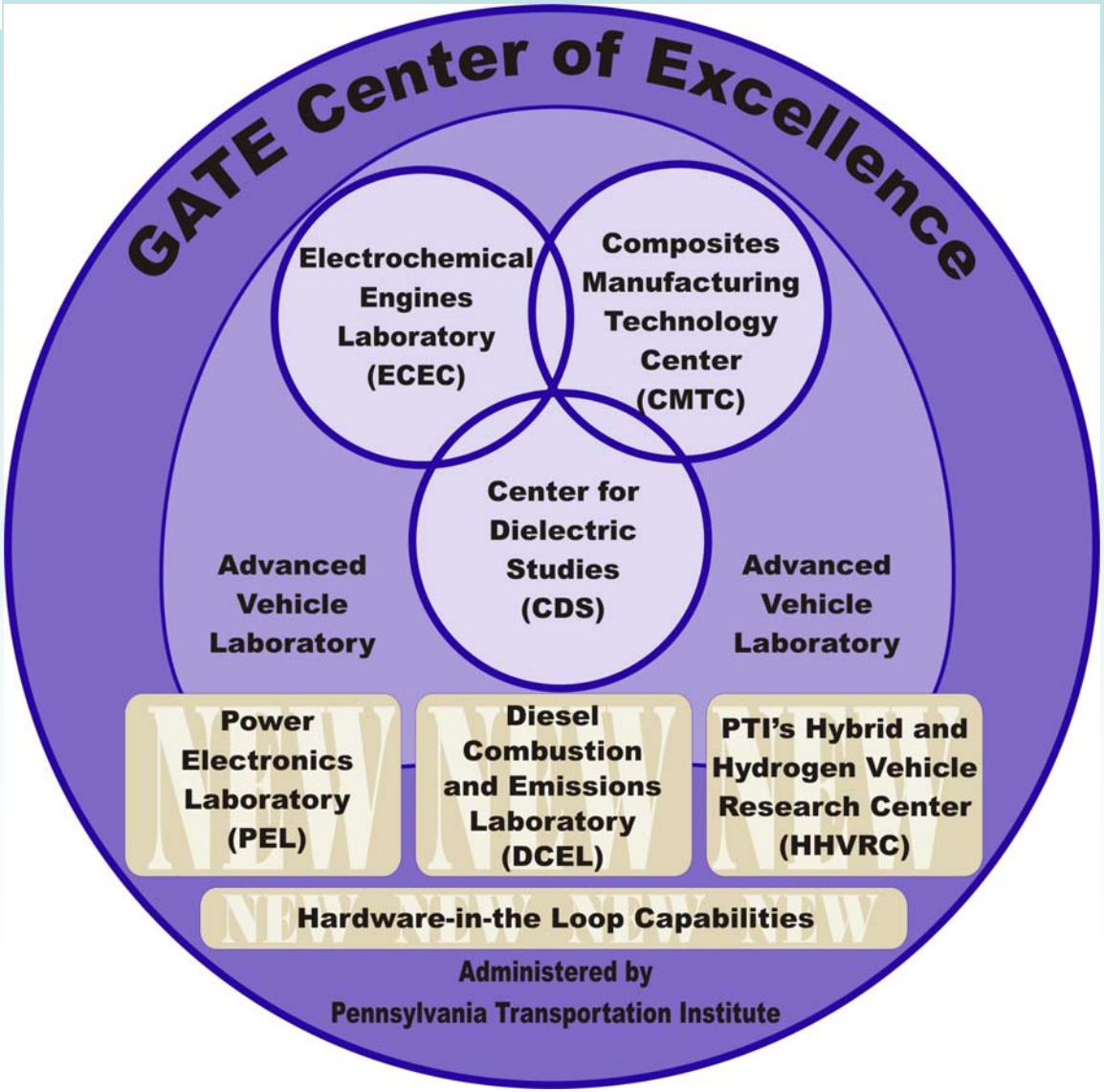
Goals and Objectives

- 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
- Develop relationships between GATE students, faculty, industry/research partners, and employers

Addressing Previous Merit Review Comments

- Competition to recruit GATE students: PSU GATE is back up to plan in number of GATE fellows due to recruitment efforts.
- Highlight GATE value add versus synergies: GATE faculty emphasize energy storage and control algorithms in vehicle system context. PSU is only energy storage GATE school offering a unique curriculum vital to advanced vehicle development efforts.
- GATE presentation seems to emphasize other topics than energy storage: this presentation emphasizes energy storage over 2005 program expansions emphasized in previous review presentation

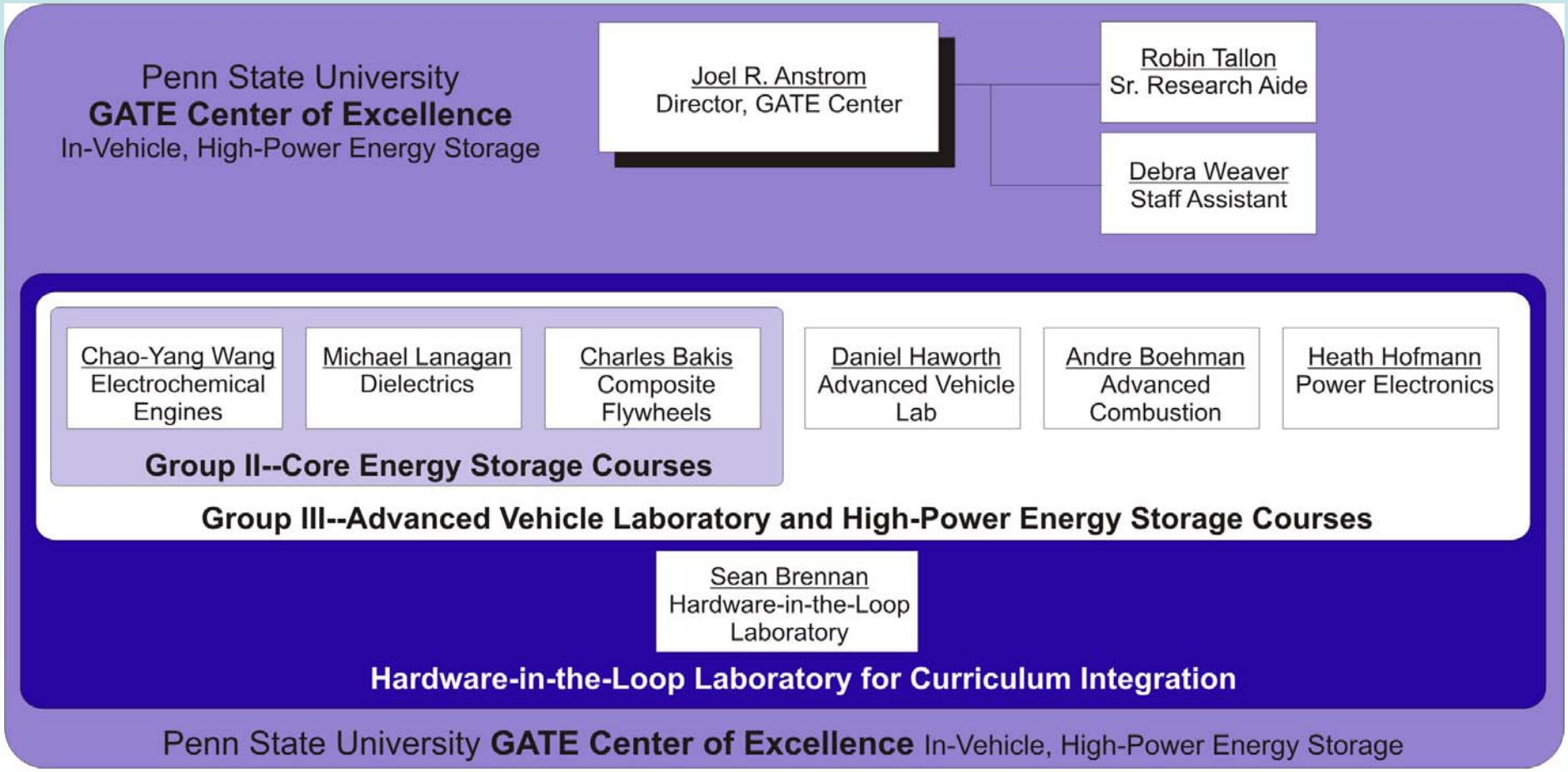
Penn State GATE Program Approach



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 PSU GATE Program Faculty
  - Adv. Combustion – Andre Boehman (EMS, DCEL)
  - Power Electronics – Heath Hofmann (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

GATE Curriculum at PSU



GATE Certificate Issued to Students Completing Curriculum

GRADUATE AUTOMOTIVE TECHNOLOGY EDUCATION

PENNSTATE 1855

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

Group I (9 credits required)

- 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 for Advanced Vehicles (3)

Group IV (Advanced-Track Courses)

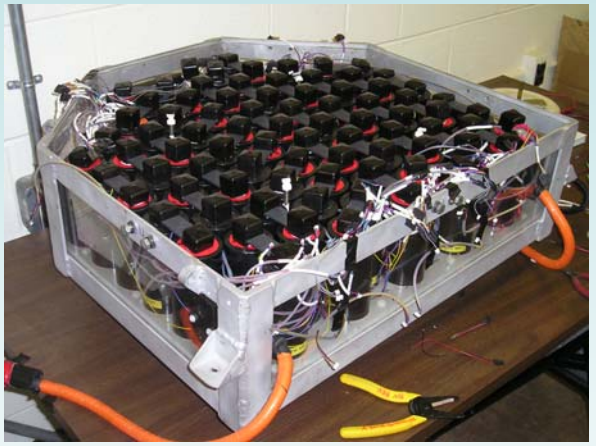
- Group IVa. Mathematics
- Group IVb. Power Electronics
- Group IVc. Dynamics, Vibrations, and Controls
- Group IVd. System Modeling and Design
- Group IVe. Manufacturing
- Group IVf. Business
- Group IVg. Alternative Fuels
- Group IVh. Drive Trains
- Group IVi. Materials
- Group IVj. Advanced Combustion
- Group IVk. Chemistry
- Group IVm. Fuel Cells
- Group IVn. Solid Mechanics

Penn State GATE Program Approach

- Students selected by application for DOE GATE Program funding are considered GATE Fellows. They must follow the GATE curriculum and should pursue a thesis research topic related to our GATE energy storage theme
- All students following the GATE curriculum regardless of funding source are considered GATE Students

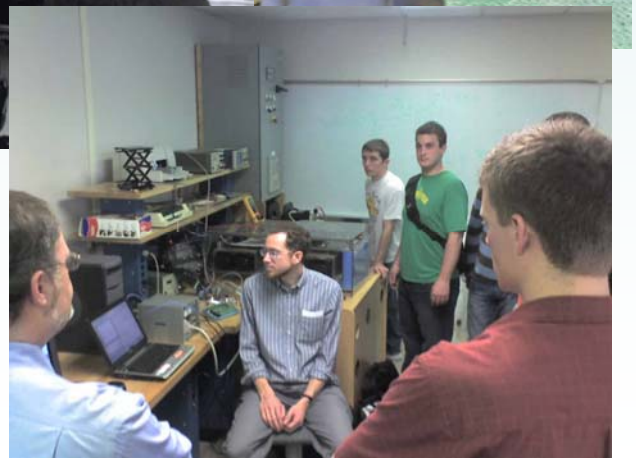
GATE Core Courses

- ME 597K High Power In-Vehicle Energy Storage
  - Fundamental science of energy storage
    - Batteries: NiMH, Lithium Ion
    - Capacitors: Electrolytic double layer
    - Flywheels: Composite rotor design and motors
  - Introduction to Energy Storage Models
  - Vehicle/Hardware Demos and Lab Tours
  - Team taught by GATE Faculty
- ME 497A and B HEV Laboratory
  - Develop **DOE AVTC Competition** Vehicle
    - 1999-2004 FutureTruck
    - 2005-2008 Challenge X
    - 2008-2010 EcoCAR if awarded
  - GATE Students bring energy storage expertise
  - Senior capstone for ME, EE, Chem Eng
  - Available for credit or as team volunteer
  - GATE faculty advise team and help recruit



Example Elective: ME 597F - HIL for Advanced Vehicles

- Hardware-in-the-Loop for Advanced Vehicles
- **ANL donated licenses for Powertrain Systems Analysis Toolkit (PSAT)**
- Matlab Sponsored software and hardware
- Supporting EcoCAR proposal
- Energy storage focus
  - Battery models & lab
  - Capacitor models &, lab
- Engine, fuel cell, motors labs
- Chassis dyno lab
- Models and control
- Economic and Market Forces
- Team taught by GATE faculty



PSU GATE Program Impact

- 18 funded as GATE Fellows with DOE funding
- 36 funded as GATE Students with other funding
- 5 PhD students graduated
- ~300 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

Some Current and Recent GATE Fellows

Student	*Start/End Date*	*Department*	*Faculty Advisor*	*Degree*	*Grad Date*	*Area of Expertise*	*What are they doing now?*
Michael Petersheim	Aug 06-current	ME	Brennan	MS		Scaling battery and other component models for HIL	MSE in progress at PSU. Assisting ME 597 HIL course labs
Jamie Clark	Jan 06-May 08	Earth and Mineral Science	Boehman	MS		Hydrogen assisted combustion of bio-Diesel.	MSE in progress at PSU. Assisting ME HIL labs.
Joesph Sholz	Aug 07-current	Eng Sci	Lanagan	MS		Capacitor materials	MSE in progress at PSU. Taking GATE courses.
Nate Simmons	Aug 07-Current	Eng Mech		MS		Surface corrosion of metals.	MSE in progress at PSU. Taking GATE courses and leader in Challenge X
Ben Zile	Feb 05-May 07	ME	Anstrom	MS	Aug 07	Power electronic systems for fuel cell vehicles	Graduated Summer 2007. Now in Mack/Volvo hybrid development group
Kandler Smith	Aug 06-Dec 06	ME	Wang	PhD	Dec 06	Modeling and Control of Lithium Ion Batteries	NREL, Colorado

Current PSU GATE Students

Michael Petersheim

Jamie Clark

Nate Simmons

Bryan Markovich

James D'Iorio

Nicholas Brannen

Timothy Cleary

Maria Concepcion

Miquel Domingo

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 Manufacuring 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. American Ceramic Society Meeting Presentation: Synthesis of Manganese Oxide Thin Films for Capacitor Electrodes, Do-Kyun Kwon[1], Teppei Akiyoshi[2], and Michael T. Lanagan[1,] *Center for Dielectric Studies, Pennsylvania State University, [2]Murata Manufacuring Co. LTD, Kyoto Japan*

Industry/Research Relationships with PSU GATE

- Air Products – Hydrogen station testing, operation, donation
- The Mathworks & Advantech – 12 Matlab Licences and eight xPC controllers donated for ME 597F GATE HIL class
- ANL – 13 PSAT 6.1 licenses for GATE HIL class
- CATA – Transit bus use for H_2 demonstration
- Collier Technologies – HCNG and H_2 engines and collaboration on hydrogen assisted combustion research
- Doosan – CNG and HCNG engine donated
- Honda – Visiting scientist Kosuke Orguri helped set up HIL course and did HIL testing of Lithium Ion batteries for PHEV
- MAUTC – support for graduate assistants
- Lithium Technologies – Lithium battery sponsorship for Challenge X
- PSU Applied Research Laboratory – Collaboration on advanced vehicle projects, Future Combat Systems and capacitor start
- TACOM – Collaboration on HIL testing of battery/capacitor systems

PSU GATE Academic Collaborations

- GATE faculty and students adapted ME 597F battery and ultra-capacitor HIL labs to provide supporting data for the PSU **DOE EcoCAR AVTC** proposal
- PSU GATE is collaborating with Pennsylvania College of Technology to enhance their automotive technology degrees with advanced automotive technology content
- PSU GATE is hosting two Industrial Engineering exchange students Escuela Técnica Superior in Barcelona Spain who have worked on GATE focus vehicles as their Masters project.
- GATE HyLion focus vehicle will be integrated into energy system of PSU house from 2007 **DOE Solar Decathlon**

Recent Outreach Events

- September 2007, Pennsylvania Renewable Energy Festival display of HyLion cell vehicle and presentation on advanced vehicle technologies. Displayed HyLion fuel cell vehicle.
- March 2007, National Hydrogen Association display of hydrogen research and hydrogen station demonstration. HIL demonstration.
- August 2007, State College Last Cruise car show display of HyLion fuel cell vehicle. Displayed HyLion fuel cell vehicle.

Plans for Next Year

- Continue offering GATE core and elective courses
- Continue HEV lab with new focus on EcoCAR if awarded
- Continual improvement of ME 597F HIL labs and network infrastructure
- Expand industry involvement, sponsorship, and projects
  - Recruit new GATE partners into Hybrid and Hydrogen Vehicle Research Laboratory Consortium
  - Hybrid and Hydrogen Workshop April 24-25, 2008
- Continue HyLion fuel cell vehicle focus project
- For GATE Student Fun!!! Continue ’59 Berkeley HEV project and integrate it as HIL course final project

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
- Back on plan in number of GATE fellows
- Behind plan in number of student/semesters supported as GATE fellows

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