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

Joel Anstrom, Director of GATE Program
The Pennsylvania State University
DOE Merit Review, May 15, 2013

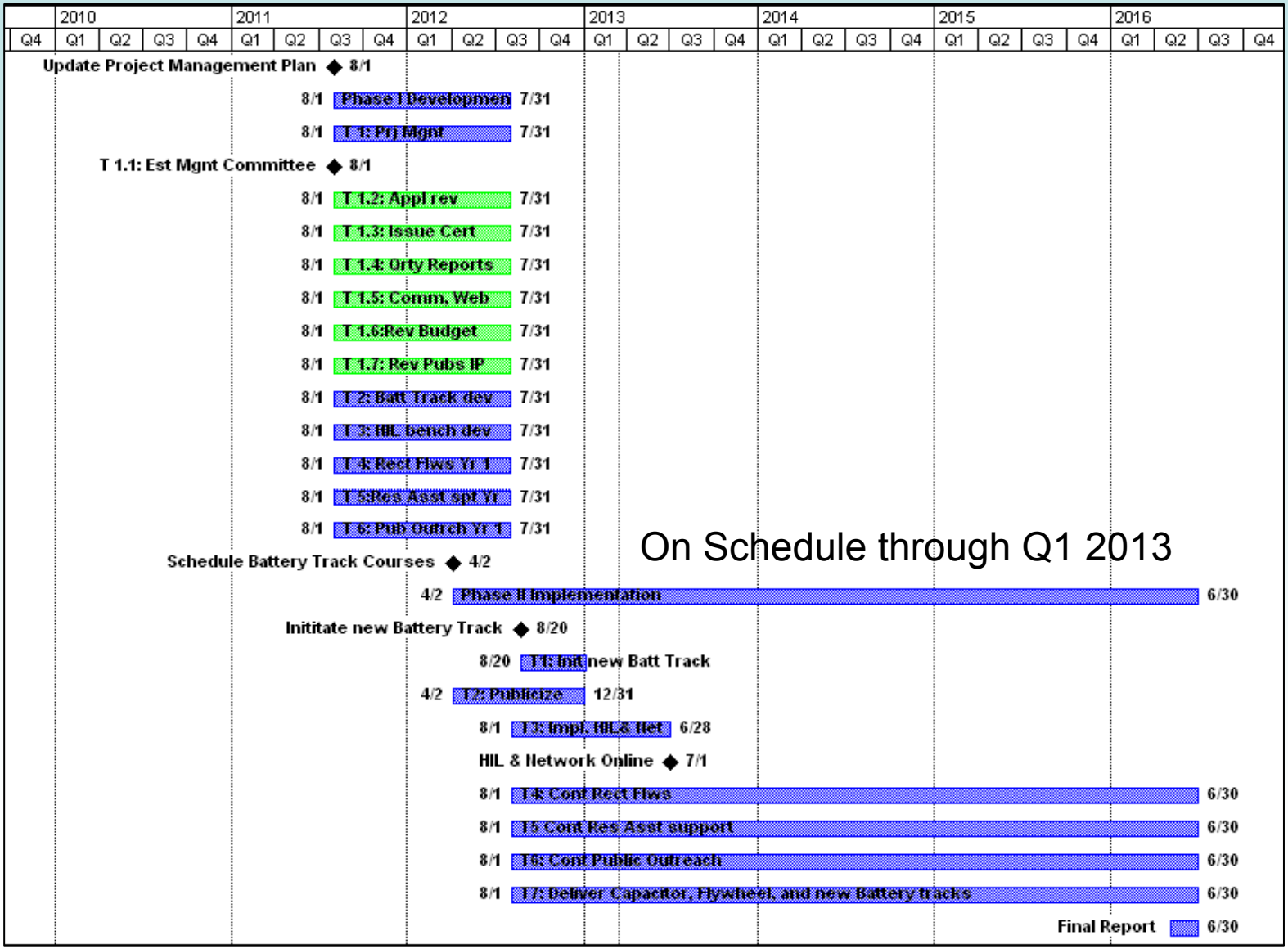
Project ID#
TI025

"This presentation does not contain any proprietary or confidential information"

Overview of PSU GATE Program

- Timeline
  - Start Oct 2011
  - End Oct 2016
- Budget
  - Awarded: $944,753
  - PSU Match: $374,672
  - Obligated: $287,412
  - Expended: $137,378
  - Expended match: $27,567
- Barriers
  - Energy storage cost and durability
  - Public Acceptance of electric drive (cost)
- Partners
  - US DOE and GM via EcoCAR 2
  - Clemson University

Schedule

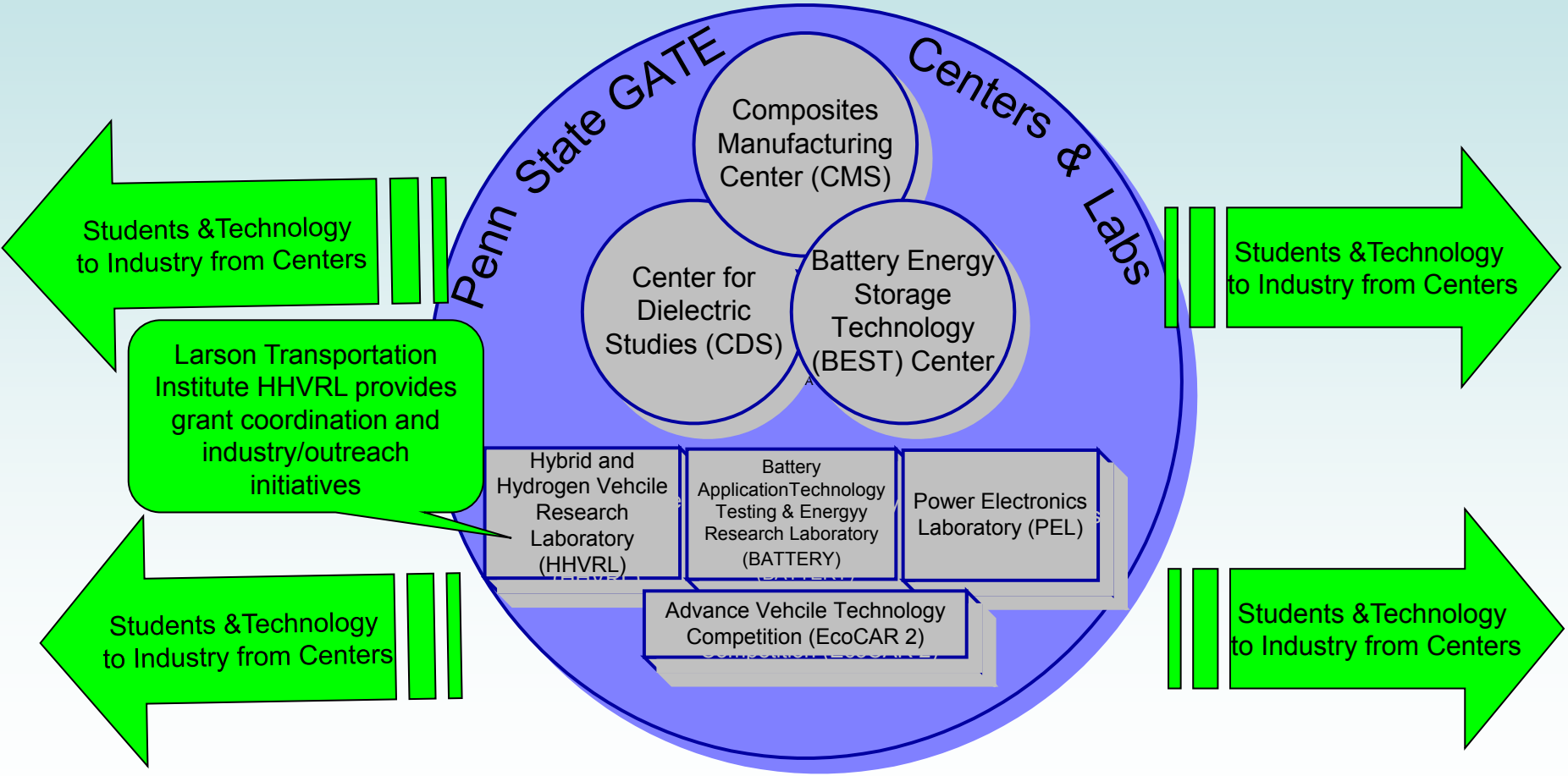


On Schedule through Q1 2013

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

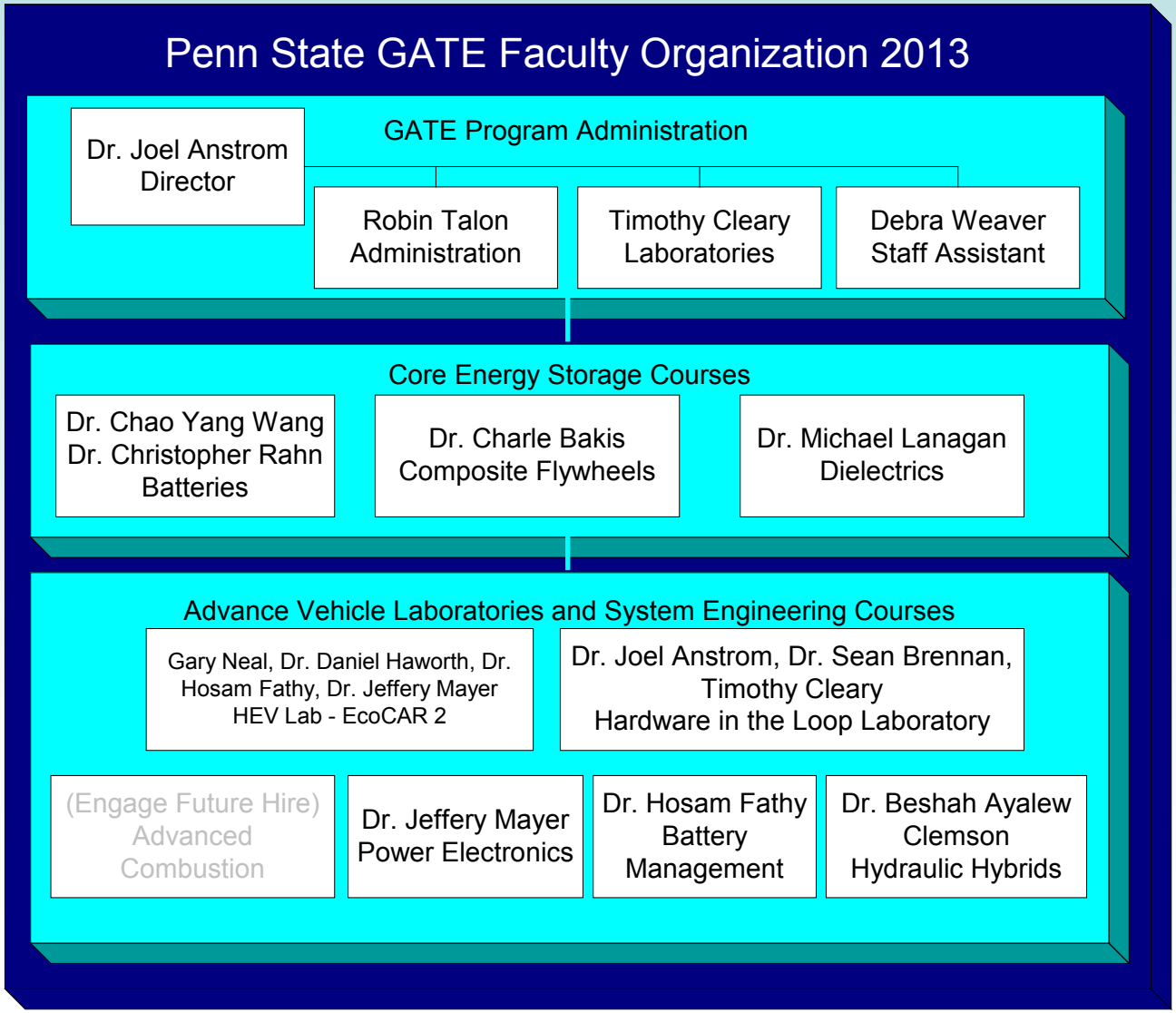


Penn State GATE Program Approach

- 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 GATE Faculty
  - Adv. Combustion – Andre Boehman (EMS, DCEL)
  - Power Electronics – Jeff Mayer and Heath Hofmann in 2009 (EE, PEL)
  - Controls – Sean Brennan (ME, Controls)
  - HEV Lab Instructor, Challenge X Advisor – Daniel Haworth (ME, Advanced Combustion)
- 2011 Created Four Separate Curriculum Tracks and Added GATE Faculty
  - Christopher Rahn – Battery Engineering and Controls
  - Hosam Fathy – Battery Management and Controls
  - Gary Neal – EcoCAR 2 Advisor
  - Timothy Cleary – Hardware in the Loop Support

Penn State GATE Program Approach

- 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 (EcoCAR 2)
- Provide dedicated “focus vehicle” platforms for GATE student research
- Hardware in the Loop Benches for each lab
- GATE graduates advance energy storage targets


Penn State GATE Faculty Organization 2013
GATE Program Administration
Dr. Joel Anstrom
Director
Robin Talon
Administration
Timothy Cleary
Laboratories
Debra Weaver
Staff Assistant
Core Energy Storage Courses
Dr. Chao Yang Wang
Dr. Christopher Rahn
Batteries
Dr. Charle Bakis
Composite Flywheels
Dr. Michael Lanagan
Dielectrics
Advance Vehicle Laboratories and System Engineering Courses
Gary Neal, Dr. Daniel Haworth, Dr. Hosam Fathy, Dr. Jeffery Mayer
HEV Lab - EcoCAR 2
Dr. Joel Anstrom, Dr. Sean Brennan, Timothy Cleary
Hardware in the Loop Laboratory
(Engage Future Hire)
Advanced
Combustion
Dr. Jeffery Mayer
Power Electronics
Dr. Hosam Fathy
Battery
Management
Dr. Beshah Ayalew
Clemson
Hydraulic Hybrids

Penn State GATE Curriculum for 2013

Group I Prerequisites - Nine Credits Required

- Select from Department Math Requirement (3)
- Select Numerical Methods Course (3)
- Select Advanced Track Course (3)

Group II GATE Track Coordinator and Required Courses - Three Credits

Battery Track	***Capacitor Track***	***Flywheel Track***	***System Track***
C. Rahn	***M. Lanagan***	***C. Bakis***	***J. Anstrom***
ME 597C (S13)* Battery Sys Eng	ME 597K (S13) Energy Storage	ME 597K (S13) Energy Storage	ME 597K (S13) Energy Storage

Group III Elective Courses - Six Credits

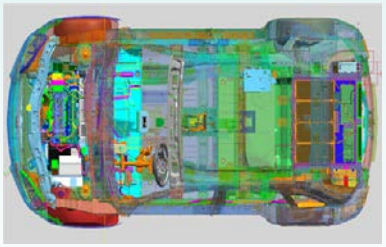
New Track

ME597D (S13) Materials for Energy Conversion & Storage	ME 442W (F12), 443W (S13) Adv. Veh. Design	ME 442W (F12), 443W (S13) Adv. Veh. Design	ME 442W (F12), 443W (S13) Adv. Veh. Design
Or	Or	Or	And
ME597B (F13) Optimal Control of Energy Systems	ME 597F (F14) HIL for Auto Development	ME 597F (F14) HIL for Auto Development	ME 597F (F14) HIL for Auto Development
Or	And	And	
ME59XX Battery Mfg (Future)	ESci 597A/MatSc 597D MicroWave Proc. of Materials	EMech 471 (F13) Engr. Composite Materials	

* Current or next semester course offering

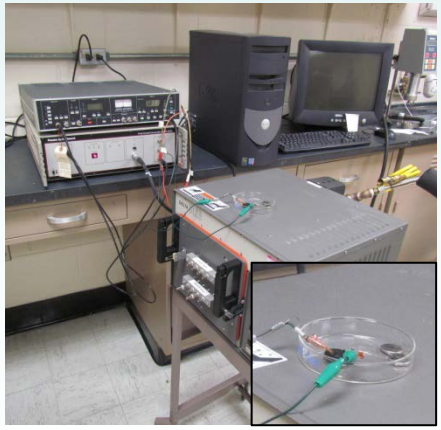
GATE Core Courses

- ME 597K/Esc 597C High Power In-Vehicle Energy Storage
  - Fundamental science of energy storage
    - Batteries: NiMH, Lithium Chemistries, battery management principles
    - Capacitors: double layer
    - Flywheels: composite rotor design and motors
  - Introduction to Energy Storage Models
  - Vehicle road loads, demos, and laboratories
  - ***Online pilot S13*** taught by five GATE faculty
- ME 442W/443W HEV Laboratory
  - Develop **DOE AVTC** Competition Vehicles
    - 1999-2004 FutureTruck – Lithium Tech cells
    - 2005-2008 Challenge X – Lithium Tech cells
    - 2008-2011 EcoCAR – A123 commercial pack
    - 2012-2013 ECOcar II – A123 commercial 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



Hardware in the Loop Benches for GATE Labs

- Developed automotive Hardware-in-the-Loop lab/course for GATE
  - 2-mode PHEV developed as HIL test bench
  - Mathworks™ donated licenses and hardware
  - ANL donated PSAT/Autonomie licenses
  - Energy storage HIL
    - Battery model & lab
    - Capacitor model & lab
  - System HIL labs
    - Engine model & lab
    - Electric motor & lab
    - Control strategy optimization
    - On track fuel economy



- Extend HIL capability to other GATE Centers/Labs
  - Piloting HIL button cell voltemetery in Materials Research Lab
  - Demonstrate HIL benefits at small scale
  - Extend HIL to other labs where beneficial
  - Leverage as GATE course laboratory exercises

Current GATE Fellows

- Jacob Ross
  - PhD Eng Science advisor Charles Bakis
  - Flywheel Rotor Design Optimization with Evolutionary Algorithms
- Julie Sawlsville
  - Masters Mechanical Engineering advisor C.Y. Wang
  - Battery and fuel cell research
- Max Ripepi
  - Masters Engineering Mechanics advisor Charles Bakis
  - Self levitating flywheel design

Accomplishments 1999-2013

- Current and previous GATE Programs (1999-2013) accomplishments:
  - 4 GATE fellows funded under current GATE program
  - 18 funded as GATE Fellows with previous DOE funding
  - ~50-70 funded as GATE Students with other funding
  - 5 PhD students graduated
  - ~500 student-semesters of HEV Lab
  - Other GATE research and students funded by:
    - DOE, NSF, DARPA, ARPA-E, DOT, DOS, NASA, PA-DEP, PA-DCED
    - GM, Ford, Volvo, Cummins, GE, Norfolk Southern, Air Products
  - Hundreds of K-12 students enriched by NSF outreach focused on advanced transportation and 21st Century Auto Challenge
  - PSU GATE Graduates placed in FCV/HEV development and testing at Ford, GM, Chrysler, Nissan, NREL, INL, Oakridge NL, Mack Volvo, Aberdeen Proving Grounds

Select 2013 GATE Publications

Prasad, G., and Rahn, C., “Development of a First Principles Equivalent Circuit Model for a Lithium Ion Battery,” Dynamic Systems and Control Conference, Paper ThCT8.3, Ft. Lauderdale, FL, October 17-19, 2012.

Y. Shi, C. Ferone, and C. Rahn, “Identification and Remediation of Sulfation in Lead-Acid Batteries Using Cell Voltage and Pressure Sensing,” Journal of Power Sources, Vol. 221, pp. 177 -185, January 2013.

G. Zhang, C. Shaffer, C.-Y. Wang, and C. Rahn, “In-Situ Measurement of Current Distribution in a Li-ion Cell,” Journal of The Electrochemical Society, Vol. 160, No. 4, pp. A610-A615, 2013.

Sylvain Marinel, Doo Hyun Choi, Romain Heuguet, Dinesh Agrawal, and Michael Lanagan. "Broadband Dielectric Characterization of TiO2 Ceramics Sintered Through Microwave and Conventional Processes." Ceramics International, 8 Pages (2012).

Sylvain Marinel, Doo Hyun Choi, Romain Heuguet, Dinesh Agrawal, and Michael Lanagan. "Broadband Dielectric Characterization of TiO2 Ceramics Sintered Through Microwave and Conventional Processes." Ceramics International, 8 Pages (2012).

T. Murata, P. Dash, E.Furman, C. G. Pantano, and M. T. Lanagan, "Electrode-Limited Dielectric Breakdown of Alkali Free Glass," J. Am. Ceram. Soc., 95(6):1915-1919, 2012.

L. Fredin, Z. Li, M.Ratner, M. Lanagan, and T. Marks, "Energy Storage: Enhanced Energy Storage and Suppressed Dielectric Loss in Oxide Core Shell Polyolefin Nanocomposites by Moderating Internal Surface Area and Increasing Shell Thickness" Advanced Materials 24(44) 5945-5945 2012.

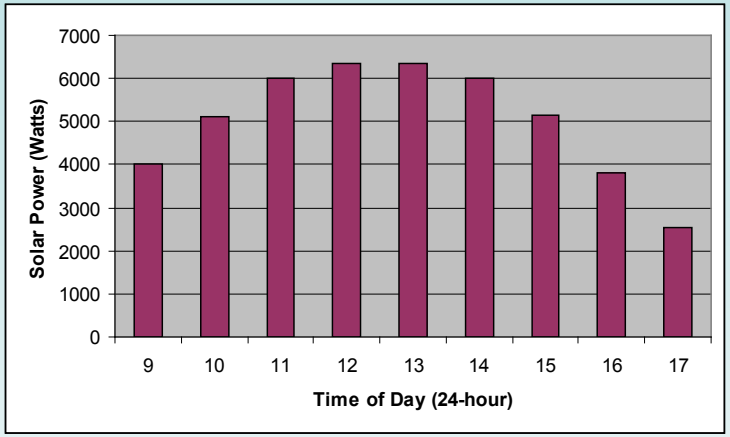
L. Fredin, Z. Li, M.Ratner, M. Lanagan, and T. Marks, "Substantial Recoverable Energy Storage in Percolative Metallic Aluminum-Polypropylene Nanocomposites." Advanced Materials 2012 (Accepted).

Outreach: 21st Century Automotive Challenge 2009-13

GATE Students and Alumni Help Organize and Host Annual Alt Fuel Vehicle Competition

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

Current Government and Industry Relationships

- Volvo and GE research and educational partnerships
- ARPA-E Modular BMS project
- ANL online course development for battery development
- Mathworks license arrangement with Penn State
- ANL Autonomie license arrangement for GATE HIL class
- Pi Innovo providing five M211F OpenECU controllers and OpenECU Developer Platform Sim32 software at significant discount
- GM annual gift to GATE - $5K
- Eastern Electric Vehicle Club collaboration for 21st Century Automotive Challenge Event

PSU GATE Academic Collaborations

- Penn State DOE AVTC EcoCAR 2 Team
- Pennsylvania College of Technology Advanced Automotive Technology Program
- Penn State Center for Sustainability and 2007 DOE Solar Decathlon home
- Penn State Applied Research Lab
- Clemson University GATE Program
  - GATE Seminar at Greenville SC February 2012
  - ASME IDETC AVT 5

Future Work

- Continue offering GATE core and elective courses
- Continue HEV lab participating in DOE EcoCAR 2
- Continual improvement GATE curriculum and labs
- Expand industry involvement, sponsorship, and projects
  - Continue recruitment of GATE partners
  - Annual vehicle competitions outreach to public, new students
- Expand online courses towards offering distance GATE certificate
- Continue focus vehicle use for GATE student thesis
  - EV1 based fuel cell vehicle
  - Two-mode PHEV $LiFePO_4$ pack
  - PHEV 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

Contact Information

Joel R. Anstrom
Director of Penn State GATE Center
201 Transportation Research Building
University Park, PA 16802

(814) 863-8904
jra2@psu.edu