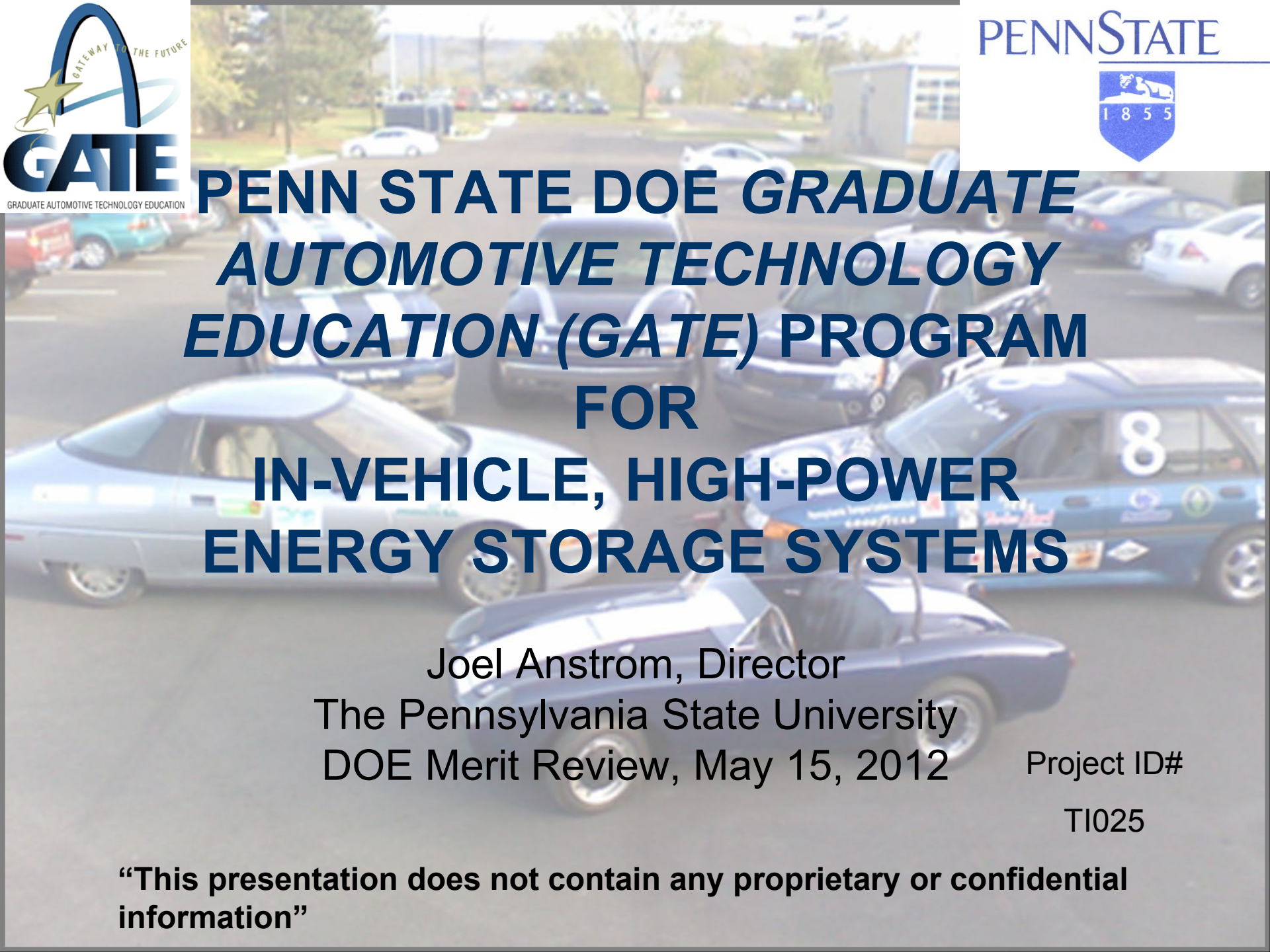


PENN STATE DOE *GRADUATE AUTOMOTIVE TECHNOLOGY EDUCATION (GATE)* PROGRAM FOR IN-VEHICLE, HIGH-POWER ENERGY STORAGE SYSTEMS

Joel Anstrom, Director
The Pennsylvania State University
DOE Merit Review, May 15, 2012

Project ID#
TI025

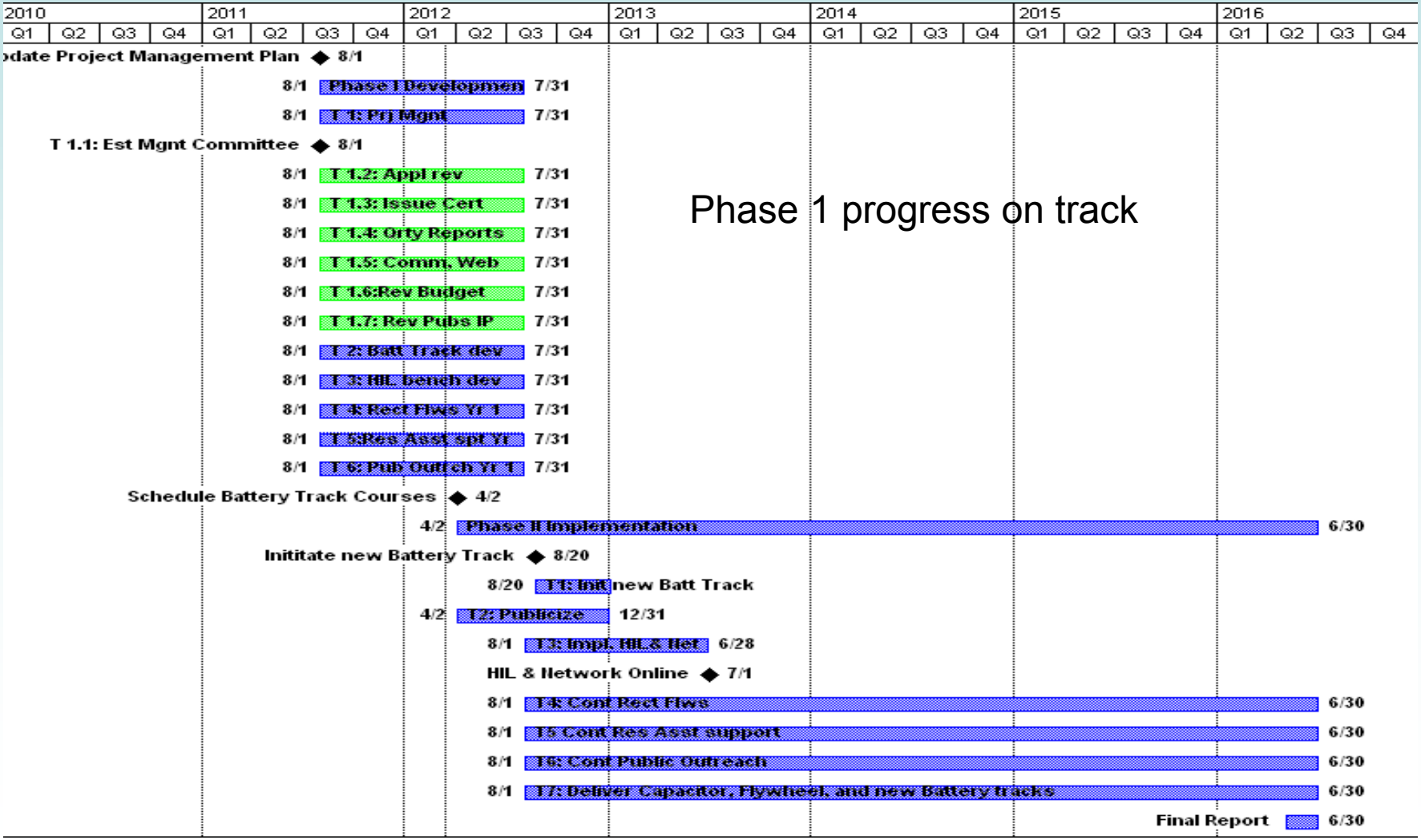
"This presentation does not contain any proprietary or confidential information"

Overview of PSU GATE Program

- Timeline
  - Start Oct 2011
  - End Oct 2016
- Budget
  - Awarded: $944,753
  - PSU Match: $374,672
  - Obligated: $72,420
  - Expended $30,000

- Barriers
  - Energy storage cost and durability
  - Public Acceptance of electric drive (cost)
- Partners
  - The Mathworks
  - US DOE and GM via EcoCAR II
  - Pennsylvania College of Technology
  - Clemson University

Milestones

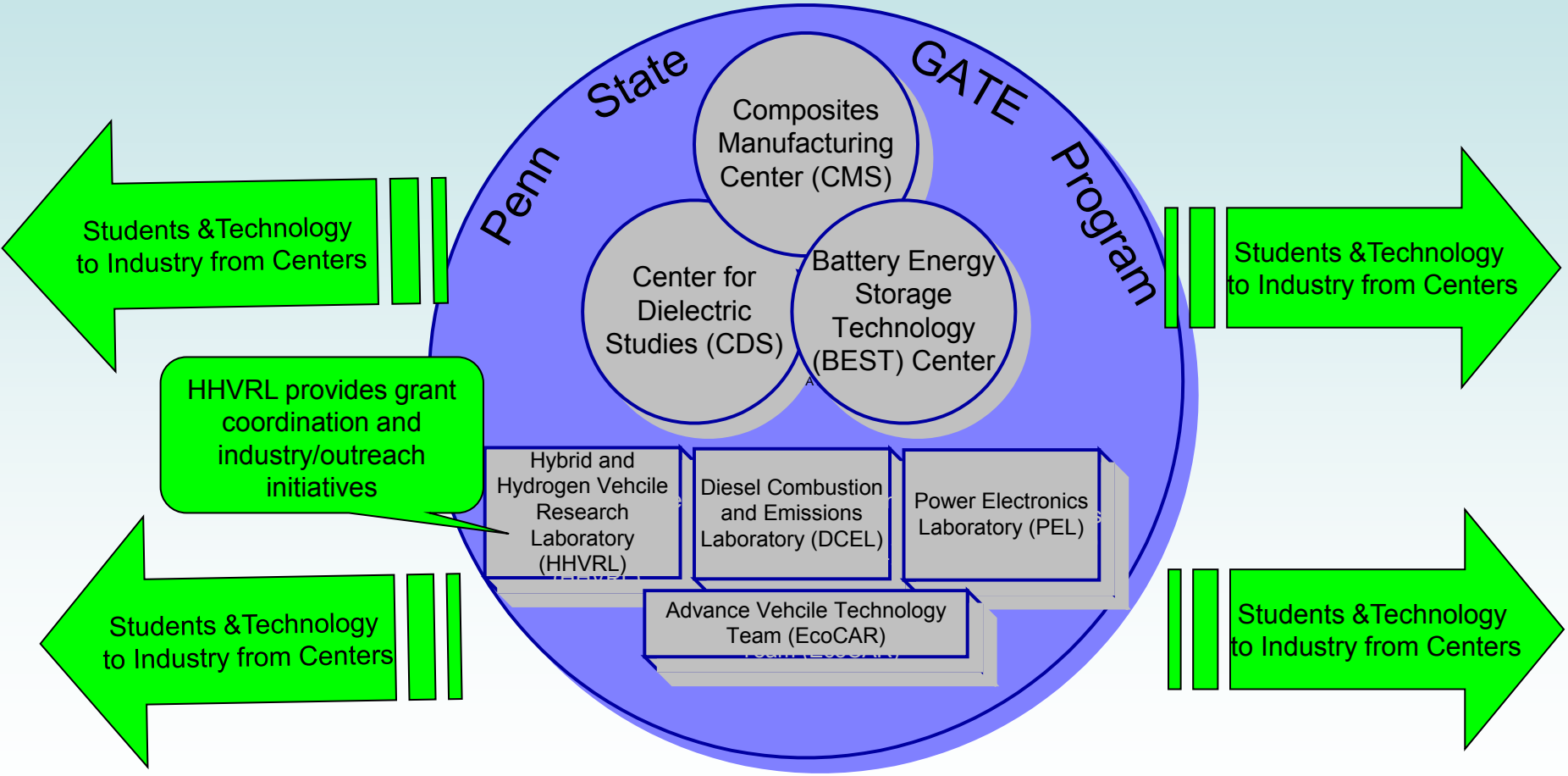


Phase 1 progress on track

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



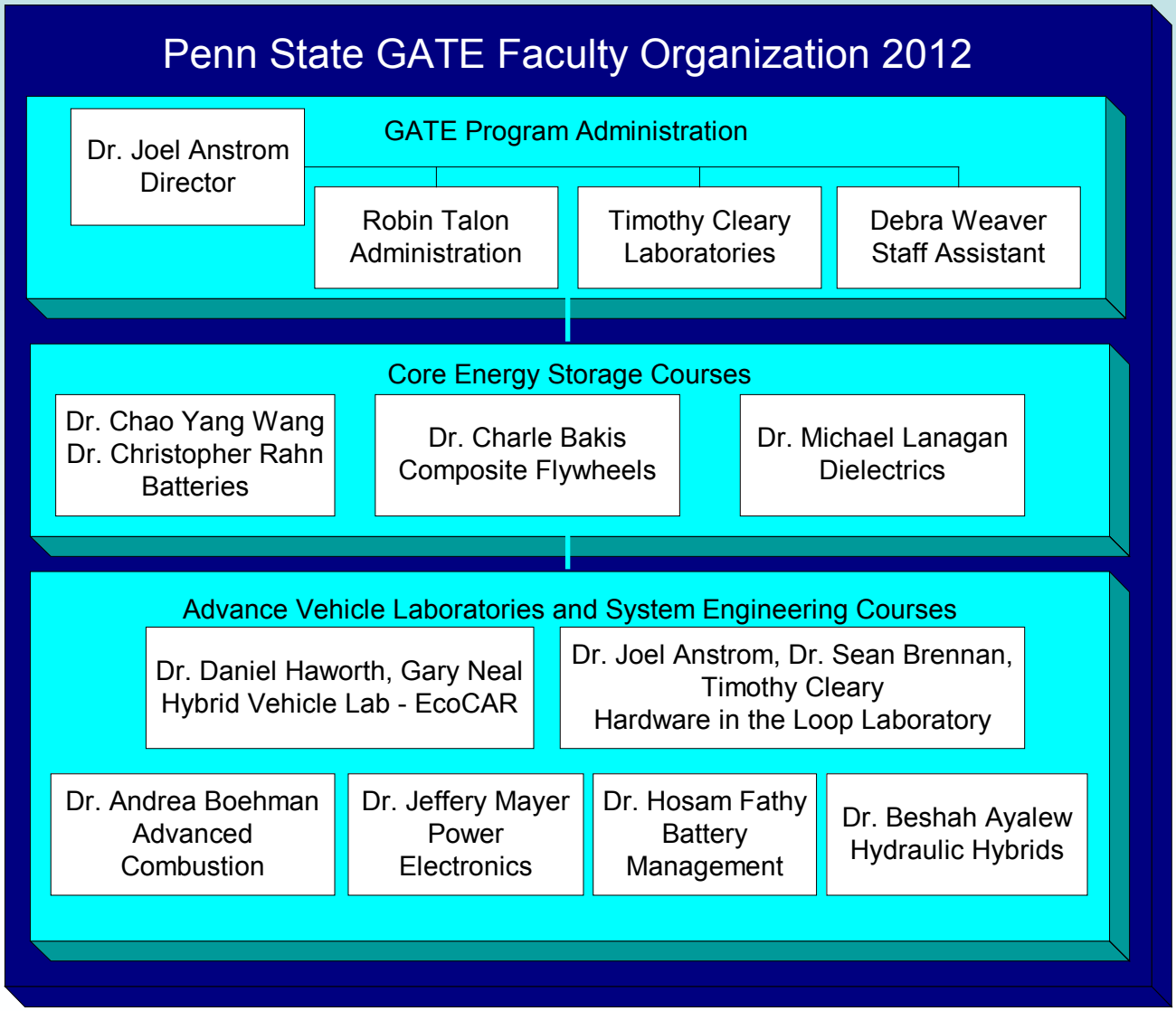
Penn State GATE Program Approach

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

PSU GATE Faculty Organized



PSU GATE Curriculum Organized

Penn State GATE Curriculum for 2012

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

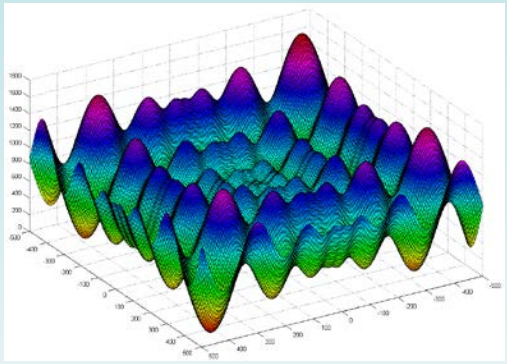
Battery Track *C. Rahn*	*Capacitor Track* *M. Lanagan*	*Flywheel Track* *C. Bakis*	*System Track* *J. Anstrom*
ME 597C Battery Sys Eng	ME 597K Energy Storage	ME 597K Energy Storage	ME 597K Energy Storage

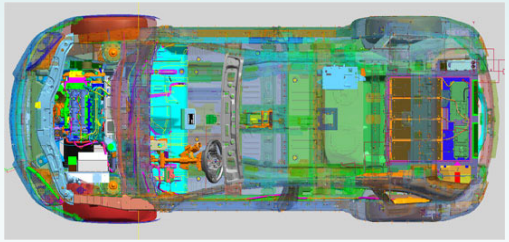
Group III Elective Courses - Six Credits

ME59XX Battery Materials D. Wang	ME 442W&443W Adv. Veh. Design I&II	ME 442W&443W Adv. Veh. Design I&II	ME 442W&443W Adv. Veh. Design I&II
Or	Or	Or	And
ME59XX Battery Mgmt Fathy	ME 597F HIL for Auto Development	ME 597F HIL for Auto Development	ME 597F HIL for Auto Development
Or	And	And	
ME59XX Battery Mfg C. Wang	ESci 597A/MatSc 597D MicroWave Proc. of Materials	EMech 471 Engr. Composite Materials	

GATE Core Courses

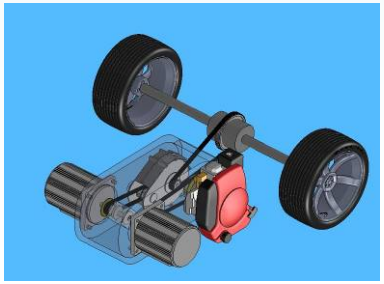
- ME 597K High Power In-Vehicle Energy Storage
  - Fundamental science of energy storage
    - Batteries: NiMH, Lithium Chemistries
    - Capacitors: double layer
    - Flywheels: composite rotor design and motors
  - Introduction to Energy Storage Models
  - Vehicle/Hardware Demos and Lab Tours
  - Team taught by five GATE Faculty
- ME 497A and B HEV Laboratory
  - Develop **DOE AVTC** Competition Vehicles
    - 1999-2004 FutureTruck – Lithium Tech cells
    - 2005-2008 Challenge X – Lithium Tech cells
    - 2008-2011 EcoCAR – 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

- Hardware-in-the-Loop techniques and systems developed previously for ME 597F elective
- 2-mode PHEV developed for class HIL elective
- Mathworks and ANL donated licenses and hardware ~$100K
- Will plan and implement unique HIL benchs for individual GATE Labs
- 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



Current GATE Fellows

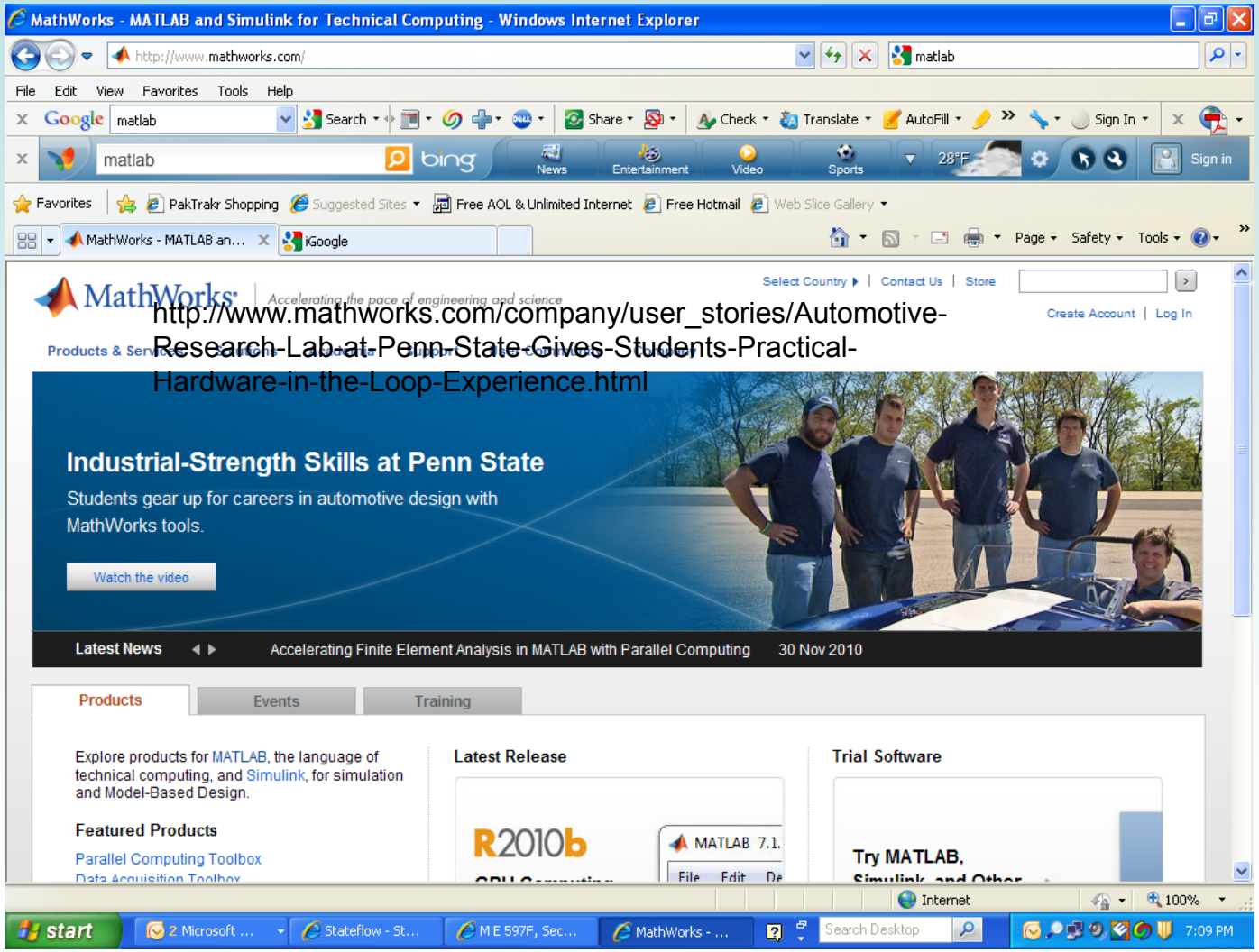
- PhD Candidate Gregory Lilik - advanced Diesel combustion demonstrates high cetane number fuel can reduce all major gaseous emissions (Sandia Nat'l Lab)
- PhD Candidate Jacob Ross - Flywheel Rotor Design Optimization with Evolutionary Algorithms
- MSME Student Julie Sawlsville – beginning battery and fuel cell research
- PhD Candidate Seth Berbano - interfacial electrochemistry of glass ceramic solid electrolytes in batteries and super-capacitors

PSU GATE

Progress and Deployment

- Previous GATE Programs (1999-2010) accomplishments:
  - 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

Penn State GATE – The Mathworks First User Video



http://www.mathworks.com/company/user_stories/Automotive-Research-Lab-at-Penn-State-Gives-Students-Practical-Hardware-in-the-Loop-Experience.html

Industry Outreach Networking Events

- GATE industry networking coordinated by Hybrid and Hydrogen Vehicle Research Lab http://www.vss.psu.edu/hhvrl/
- HHVRL/GATE Workshops April 2008 and 2009

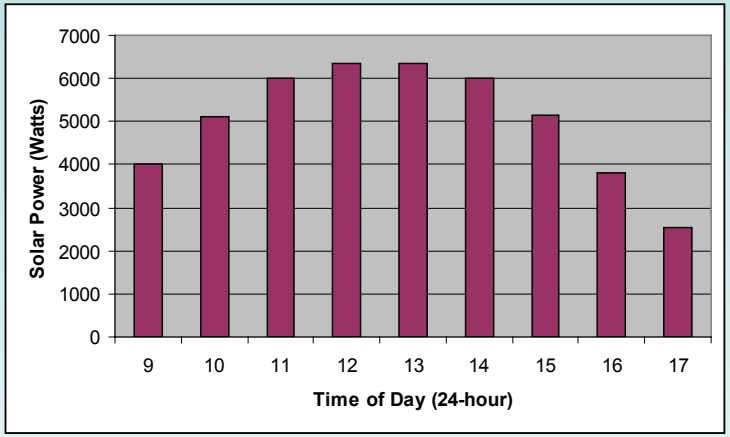
- Forming a GATE supporting Industry Consortium proving a challenge due to diversity of industry and academic interests
- A GATE Consortium may be redundant versus industry relationships with individual Centers which are more focused

21st Century Automotive Challenge

GATE Students and Alumni Helped Organize and Host Annual Alternative Fuel Event Since 2009

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

Ongoing Industry/Research Relationships

- GM annual gift to GATE - $5K
- 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
- Mid-Atlantic University Transportation Center – support for GATE students

PSU GATE Academic Collaborations

- Penn State **DOE AVTC EcoCAR II** 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 CU-ICAR

Future Work

- Continue offering GATE core and elective courses
- Continue HEV lab now participating in DOE EcoCAR II
- 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 $LiFePO_4$ 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

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